INFLUENCE OF PHOSPHORUS FERTILIZER ON POTATO (*Solanum tuberosum* L.) SEED PRODUCTION IN ACID SOILS IN KENYA

BY

EVANS MUTANGE AKOTO

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DECLARATION

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SAGR/SOS/M/002/17 **DATE**

DECLARATION BY SUPERVISORS

This thesis has been submitted with our approval as University supervisors

______________________________ ______________________________

PROF. CALEB O. OTHIENO **DATE**
DEPARTMENT OF SOIL SCIENCE,
SCHOOL OF AGRICULTURE
AND BIOTECHNOLOGY,
UNIVERSITY OF ELDORET, KENYA.

______________________________ ______________________________

PROF. JULIUS O. OCHUODHO **DATE**
DEPARTMENT OF CROPS, SEED
AND HORTICULTURAL SCIENCES
SCHOOL OF AGRICULTURE AND
BIOTECHNOLOGY,
UNIVERSITY OF ELDORET, KENYA.

DEDICATION

To my wife Judith; my parents Tokes and Benjamin; my children Mercy, Grace, Emmanuel and Victor for your invaluable support.

ABSTRACT

One of the major challenges facing potato (*Solanum tuberosum* L.) production in Kenya is the inadequate supply of high-quality seed. Of the approximated 70,000 tonnes of Kenya's potato seed annual requirement, only 1 % is available locally. Otherwise, farmers use low quality farm saved seed (KEPHIS, 2016). A major contributor to this state is low and declining soil fertility, particulary phosphorus among other challenges. Unfortunately, there is no documented phosphorus fertilizer rate recommendation for potato seed production in Kenya. This hinders economic utilization of phosphorus fertilizers in achieving optimal production of quality potato seed in Kenya where its deficiencies is dominant. Therefore, this study investigated the influence of different rates of phosphorus fertilizer on potato seed quantity and quality in three test sites: Lari, Ainabkoi and Saboti sub counties. Unica and Shangi varieties were tested. The experimental design was a split plot arrangement in RCBD with three replicates. Absolute control, 0, 30, 60, 90 and 120 kg ha^{-1} phosphorus were tested. Data collected included tuber weight, tuber quantity, tuber grade, number of eyes $tuber^{-1}$, tuber specific gravity, final germination percentage and phosphorus use efficiency (PUE). To monitor soil nutrient dynamics, soil pH, soil available phosphorus, total nitrogen and total carbon were determined at planting while soil available phosphorus and phosphorus content in the tubers were determined at harvesting. Data was analysed using analysis of variance (ANOVA) at 5 % confidence levels with GENSTAT software 14^{th} Edition. Means were separated by using error bars with 5 % value. Results indicated that rate of phosphorus application significantly influenced overall potato seed tuber yield in the test sites. At Saboti planting in absolute control and 0 kg ha^{-1} phosphorus for Shangi and Unica resulted in highest overall seed tuber yield of 33.7 and 33.3 t ha^{-1}, respectively. For Ainabkoi application of 60 and 30 kg ha^{-1} phosphorus produced highest overall potato seed tuber yields of 20.0 t ha^{-1} and 18.9 t ha^{-1} of Shangi and Unica, respectively. For Lari, application of 60 kg ha^{-1} and 90 kg ha^{-1}phosphorus produced highest overall potato seed tuber yield of 19.0 t ha^{-1} and 10.4 t ha^{-1} for Shangi and Unica, respectively. Unica had better final percentage germination than Shangi. In the test sites highest phosphorus use efficiencies at Saboti, Ainabkoi and Lari attained were 0 kg^{-1} kg^{-1}, 70 $kg^{-1}kg^{-1}$ and 76 kg^{-1} kg^{-1}, respectively. During the season, there was a build-up of soil available phosphorus (Bray 2 phosphorus): 57.71 ppm to 65.0 ppm (Saboti); 43 ppm to 52.3 ppm (Ainabkoi) and 20.4 ppm to 29.2 ppm (Lari). Hence, there is need for farmers to test their soils at the beginning of every potato growing season.

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LIST OF ABBREVIATIONS

ADC: Agricultural Development Cooperation.

ANOVA: Analysis of variance

ASDS: Agricultural Sector Development Strategy

ASDSP: Agricultural Sector Development Support Programmee

ASH: Africa soil health

ATP: Adenosine tri phosphate

CAN: Calcium ammonium nitrate

CIP: International Potato Centre.

CV: Coefficient of variation

DAP: Diamonium phosphate

DPIRD: Department of Primary Industries and Regional Development.

E.A: East Africa.

FAO: Food Agricultural Organization.

FUBC: Fertilizer use by crops.

GENSTAT: General Statistics

IBA: International Bio vision Africa Trust

ICP-AES: Inductively coupled plasma atomic emission spectroscopy

ILRI: International Livestock Research Institute

IPNI: International Plant Nutrition Institute**.**

ISTA: International Seed Testing Association.

KALRO: Kenya Agricultural and Livestock Research Organization.

KARI: Kenya Agricultural Research Institute

KEPHIS: Kenya Plant Health Inspectorate Service.

NAAIAP: National Accelerated Agricultural Inputs Access Programme

NAFIS: National Agricultural Farmers Information service

NPCK: National Potato Council of Kenya.

NPS: National potato strategy.

OM: Organic matter

PI: Principal investigator.

PPI: Potash and phosphate institute

PR: Phosphate rock

PUE: Phosphorus use efficiency

SHEP-PLUS: Smallholder Horticulture Empowerment & Promotion Project for Local and Up-Scaling

SG: Specific gravity.

SSA: Sub Saharan Africa.

TPS: True potato seed.

TSP: Triple supper phosphate

UNESCO: United Nations Educational Scientific and Cultural Organization

WRB: World resource base.

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CHAPTER ONE

INTRODUCTION

1.1 Background

Potato (*Solanum tuberosum* L.) is the second most important food crop after maize in Kenya and also the world's most important tuber crop grown in 158 countries (FAO, 2020; Wang, 2008). One billion out of eight billion people in the world eat potatoes (CIP, 2020). Potato originated from Andes, in South America (FAO, 2008), was taken to Ireland and later introduced into Kenya by the white settlers in 1880s (Spooner *et al* ., 2005). In Kenya, it is commonly called "Irish potato" because it was the main crop grown in Ireland in 1800s when the country was hard hit by the great Irish famine that was the worst agricultural, social and cultural disasters of the time that claimed 12.5% of the country's population of eight million people (FAO, 2008). It was grown for the first time in Kiambu, Nyeri and Muranga counties (NPCK, 2019). Currently, about 800,000 farmers (Out of which 500, 000 are small scale) grow potatoes mainly in five counties (Elgeyo Marakwet, Nyandarua, Meru, Nakuru and Uasin gishu) on about 217, 315 ha (FAO, 2020; Shawiza, 2017).

Potato is a food and cash crop with multipurpose domestic and industrial uses. Domestic uses include consumption as mashed potato as well as livestock feed while industrial uses include production of crisps, starch, soap, ethanol, "chevda", frozen potato chips and dried potato cubes (KEPHIS, 2016). It is a good source of carbohydrate; protein; vitamin B1, B3, B6 and C; fibre; iron; zinc and potassium. It is also naturally low in fat, cholesterol and sodium with antioxidants properties, making it healthy for human consumption (Duroy *et al*., 2009). Thus it greatly contributes to alleviating poverty and food insecurity (Abongo & Kabira, 2013).

Potato grows best in altitudes of 1500 to 3000 m above sea level (KEPHIS, 2016). However, with proper management and proper use of technology, the crop can grow well in lower altitude areas (Lutaladio *et al.,* 2009). Rainfall of about 750 mm and optimal temperatures of between 15 and 20 $^{\circ}$C are required during the growing period (KEPHIS, 2016 & MOA, 2011).

The crop requires well drained, high organic matter, fertile and loam textured soils with pH ranging from 4.5 to 8.5. However, potato seed does best at pH between 5.5 and 7.0 (MOA, 2011 & KEPHIS, 2016). The major nutritional requirements of the crop are potassium (K), nitrogen (N) and phosphorus (P). It is suggested to have the three nutrients in the ratio of 1:1:1 to avoid lowering tuber quality (Lutaladio *et al.,* 2009). In 2018, Kenya with a production of about 1.9 million tonnes was the 4th best African country in potato production after Egypt, Algeria and South Africa. Between 2007 and 2018, on average, Kenya's area under potato production and yield were 142,490 ha and 15.9 t ha^{-1}, respectively (FAO, 2020). Although, area under potato production increased by about 74, 825 ha between 2007 and 2018, potato yield declined by about 7.3 t ha^{-1} in the same period (FAO, 2020). This could be caused by many challenges in growing of potatoes which include high incidences of pests and diseases; weak research-extension linkage; poor market infrastructure; declining soil fertility; use of low quality and/or low supply of clean and certified seed (Muthoni, 2016; Karanja *et al.,* 2014).

The cost of potato seed accounts for between 35 and 50% of potato production costs (Lutaladio *et al.,* 2009). Currently, the demand for seed stands at about 70,000 metric tonnes against a supply of 1% of clean seed (KEPHIS, 2016). Thus, 98 % of the farmers use farm saved seed which are characterized by low quality (Janessens *et al.,* 2013). Hence, there is great need for rapid interventions to improve seed production and quality in Kenya. Unfortunately, this is hindered by erratic rainfall, pests, diseases and most importantly low and declining soil fertility (Karanja *et al.*, 2014).

The art of potato seed production in Kenya is guided by chapter 326 (Seed and plant varietis Act) of the laws of Kenya (NPCK, 2018). It is regulated by a state parastatal known as Kenya Plant Health Inspectorate Service (KEPHIS). Besides KEPHIS, other important players on the potato seed value chain include researchers, breeders, seed multipliers, “ware” potato producers, consumers, traders, transporters, processors and extensionists (NPCK, 2018).

The number of authorised potato seed producers in Kenya increased from 12 in 2013 to 27 in 2019 while the number of documented potato varieties increased from 13 to 60 in the same period (NPCK, 2013 & NPCK, 2019). Since 2005, small scale farmers interested in potato seed production have been encouraged to produce certified seed by affiliating to registed seed companies (KEPHIS, 2016). They are monitored with Ministry of Agriculture, KEPHIS, Kenya Agricultural Research Organization (KALRO) and the seed companies (NPCK, 2018).

The process of certified potato seed production begins with breeders who select true potato seeds. They plant the seeds which produce different cultivars. Apical cuttings or minitubers from prefered cutivars are multiplied using pots, hydroponics or aeroponic techniques. The first generation of the breeder’s seed is known as prebasic seed while the second generation is known as basic seed (NPCK, 2018). Certified seed is multiplied from the basic seed upto the third generation. Basic seed is not only bred in Kenya but also imported from other countries like Netherlands (NPCK, 2018). The procedures for availing certified seed involves registration of actors or dealers; performance trials; testing new varieties; release and gazettement of new varieties; seed multiplication; field inspection and seed testing (Hort, 2018). There exist informal techniques of improving potato seed production in Kenya which involve positive and negative selection (KEPHIS, 2016). To avoid build up of seed and soil born diseases particulary bacteria wilt, seed farmers are encouaraged to practice crop rotation (NPCK, 2019).

Fertilizers used by seed multipliers are mostly inorganic and mainly diamonium phosphate (DAP). It is recommended that the amount of fertilizer applied on potato seed be less than those apllied on "ware" potato because of their smaller size and shorter maturation period (KEPHIS, 2016). Deficiency of phosphorus has been reported in major potato producing areas in Kenya (Muthoni, 2016; Komen *et al.*, 2017). This could impact negatively on the potato seed quality and yields. The nutrient deficiency affect tuber skin setting; dry matter accumulation; time to maturity; storage quality of tubers; tuber size and tuber protein, nitrate and reducing sugar content (Tuhin *et al.*, 2007; Lutaladio *et al.*, 2009; Muthoni, 2016). However, none of the present fertilizer recommendations in Kenya focus on providing the right fertilizer rates for potato seed production. Therefore, this research focused on influence of application of phosphorus fertilizer on potato seed tuber yield and quality in Lari, Ainabkoi and Saboti sub counties.

1.2 Statement of the problem

Among the main challenges facing potato production in Kenya is inadequate supply of good quality seed. Currently, supply of clean seed stands at about 1% of the potato seed demand (KEPHIS, 2016). This has been caused mainly by low and declining soil fertility particularly phosphorus (Komen *et al.*, 2017; NAAIAP, 2014; Bukenda *et al.*, 2002). The available fertilizer recommendations focus on "ware" potato production. Potato seed require lesser amounts of fertilizer nutrients than "ware" potatoes since their recommended sizes and maturation period are smaller and lesser, respectively

(KEPHIS, 2016). However; there is no available phosphorus fertilizer rate recommendation for potato seed production in Kenya. This hinders economic utilization of phosphorus fertilizers in achieving optimal production of quality potato seed in Kenya where its deficiencies is dominant (NAAIAP, 2014).

1.3 Justification

As much as Kenya's potato production area has increased by 74, 825 ha over the last 12 years (2007 to 2018), to the contrary, its annual yield have continued to decline, with 7.3 t/ha, from the average annual yield of 15.9 t ha^{-1} over the same period (FAO, 2020). A contributor to the declining production is the low and declining soil fertility in Kenya (Muthoni, 2016).

Basing on potential yield of 25 t ha^{-1} achievable under rain fed agriculture (FAO, 2019), farmers in Kenya have been losing between 10-16 t ha^{-1} of potato. Further, basing on potential yield of 30 - 40 t ha^{-1}, experimental research has reported losses of 12 to 23 t ha^{-1} mainly due to low soil fertility (KEPHIS, 2016; Muthoni & Kabira 2011; FAO, 2008).

Potato contributes to wealth creation, food and nutritional security given its multi-purpose uses, short maturation period, and nutritional quality. It is also directly depended upon by over 3.3 million value chain actors (KEPHIS, 2016; Shawiza, 2017). Thus it's a critical target crop in achieving agricultural sector development strategy (2009 – 2020), agricultural sector transformation strategy (ASTS: 2020 - 2030), vision 2030, the current agenda four for Kenya and sustainable development goals (SDGs) of 2050 (KEPHIS, 2016). With emerging new diseases attacking maize crop, there is need for crop diversification. Maize, the main source of carbohydrate in Kenya, faces many challenges such as fall army worm, maize lethal necrosis disease (MLND) and head smut disease (NAFIS, 2018). These pests and diseases could cause up to 100% crop loss. Thus, to cushion farmers against such risks, there is need to embrace crop diversification. Given its short maturation period, high yields per unit area and carbohydrates content, potato is the best alternative to maize (MOA, 2011).

1.4 Objectives

1.4.1 Broad objective

To increase potato seed production in Kenya through enhanced phosphorus use efficiency.

1.4.2 Specific objectives

i. To assess the influence of phosphorus application rate on quantity and quality of potato seed.

ii. To determine phosphorus use efficiency in potato seed production.

1.5 Null hypothesis

i. Phosphorus rate has significant influence on quantity and quality of potato seed.

ii. Phosphorus rate has significant influence on phosphorus use efficiency in potato seed production.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of potato and potato seed situation in Kenya

Potato is the second most important crop in Kenya (KEPHIS, 2016). It is grown in more than 25 counties (Shawiza, 2017) by about 800,000 farmers (FAO, 2020). The current yield of potato is 8.6 t ha^{-1} (FAO, 2020) againist a potential of 40 t ha^{-1} (KEPHIS, 2016). Documented potato seed varieties in Kenya increased from13 in 2013 (NPCK, 2013) to 60 in 2019 (NPCK, 2019). There are only 27 documented potato seed producers in Kenya (Kaguora, 2018). These potato seed producers can only meet 1% of Kenya's pototo seed demand which is 70,000 tonnes per year. Potato seed will account for about 35 to 50 % of total production cost of potato (Sorphie, 2016). The first constraint in potato production is blight while the most important disease in potato production is bacteria wilt (Sophie, 2016). The documented phosphorus fertilizer recommendation available for potato production in Kenya (90 kg ha^{-1} phosphorus) (Kanguongo *et al.*, 2008) is general and is for "ware" potato and not seed potato. Seed potatoes require lesser fertilizer than ware potatoes (KEPHIS, 2016). Farmers use farm saved potato seed to grow their potato which is of low quality (KEPHIS, 2016). This results in low potato production yields (FAO, 2008). Laws governing potato seed production in Kenya are outlined in Chapter 326 (Seed and plant varietiesAct) of the laws of Kenya (NPCK, 2018). Potato seed production is regulated by a state parastatal known as Kenya Plant Health Inspectorate Service whose basic responsibility is to promote quality potato seed production in Kenya (KEPHIS, 2016).

2.2 Soils that support potato growth

Potato being a cool climate crop, it can be commercially produced on a wide range of soil types (INFONET, 2021), provided the climate is cool and there is adequate supply of soil moisture and nutrients during the growing period (KEPHIS, 2016). Potato requires well drained, light to deep and loose soils. The soils should also have high levels of organic matter. To maintain high levels of organic matter; it is recommended that organic matter be incorporated in the soil during the first ploughing (KEPHIS, 2016). Good drainage is necessary to allow proper aeration to promote root development and tuber growth with minimum disease infestation. Poorly drained wet soils delays emergence of the crop (INFONET, 2021).

As much as potato crop is more tolerant to low soil pH than most other crops, the crop can grow in soils with a wider range of pH (4.5 to 8.5) (MOA, 2011; KEPHIS, 2016; KARI, 2006; Haifa, 2014). Soil pH below 4.8 generally results in impaired growth (Haifa, 2014). However, incidence of common scabs of potatoes (*Strepotmyces scabies*) are low where soil pH is lower than 5.4; the problem becomes wide spread when soil pH is above 5.5. Although potatoes tolerate acid soil, there are benefits from raising the pH up to 6.0 - 6.5 since optimal soil pH for nutrient availability is between 6.0 and 7.0 (KEPHIS, 2016). Nitisols and planosols are among the soils that naturally support growth of potatoes in Kenya (KEPHIS, 2016 & MOA, 2011).

2.3 Nitisols and planosols

Nitosols are soils of the tropics. They occupy about 200 million hectares of the earth's surface (ISRIC, 2020). They are deep (more than 100 cm), well-drained, red soils with diffuse horizon boundaries and a subsurface horizon with more than 30 % clay and moderate to strong angular blocky structure elements that easily fall apart into characteristic shiny and polyhedric ('nutty') elements (FAO-UNESCO, 1974 & WRB, 2014). They occur in highlands and volcanic steep slopes (Gachene & Kimaru, 2003) like mount Elgon, Mount Kenya and Mount Kilimanjaro. Muindi *et al.*, 2017 noted that soils of central highlands were extremely acidic, had low extractactable phosphorus, high phosphorus sorption capacities and hence needed further research to determine optimal phosphorus requirements under field conditions. The author reported areas in central Kenya with extractable soil phosphorus levels of 15 mg kg^{-1} Bray 1 phosphorus.

Planosols are soils with a mostly light-coloured horizon that shows signs of periodic water stagnation and that abruptly overlies dense, slowly permeable subsoil with significantly more clay. They occupy about 130 million hectares on earth (FAO-UNESCO, 1974). They occur on very undulating to flat topography (Gachene & Kimaru, 2003).

2.4 Management of nitisols and planosols

Nitisols are among the most productive soils of the humid tropics. The deep and porous solum and the stable soil structure of these soils permit deep rooting and make these soils quite resistant to erosion. The good workability of the soils, their good internal drainage and fair water holding properties are complemented by chemical (fertility) properties that compare favourably with those of most other tropical soils (NAAIAP, 2014). The soils have relatively high contents of weathering minerals, and surface soils particularily under forest or tree crops may contain high organic matter. Commercial crops, such as cocoa, coffee, rubber, tea and pineapple and food crops like potato and maize grow on these soils. However, because of their aluminium and iron content, they have high phosphorus sorption that calls for application of phosphorus fertilizers (WRB, 2014 & FAO, 2006).

Planosols are soils of bottom lands developed from undifferentiated basement rocks (Jaetzold *et al* 2011). Natural planosol areas support sparse grass vegetation, often with scattered shrubs and trees that have shallow root systems and can cope with temporary waterlogging. Land use on these soils is normally less intensive than that on most other soils under the same climate conditions. Vast areas of the soils are used for extensive grazing (NAAIAP, 2014). Wood production on the soils is much lower compared with other soils under the same climate. In the temperate zone, these soils are mainly used for pasture or they are planted with arable crops such as wheat and sugar beet. Yields are modest even on drained and deeply loosened soils. Root development on natural, unmodified planosols is hindered severely by oxygen deficiency in the wet periods, the dense subsoil, and by toxic levels of aluminium (Al) in the root zone. The low hydraulic conductivity of the dense subsurface horizon makes narrow drain spacing necessary. Surface modification such as ridge and furrow can lessen crop yield losses from waterlogging (WRB, 2014 & FAO, 2006).

2.5 Nutrient management and potato growth

Optimum potato growth and profitable production depend on many management factors, one of which is ensuring a sufficient supply of nutrients (KEPHIS, 2016). When the supply of nutrients from the soil is not adequate to meet the demand for growth, fertilizer application becomes necessary (Mugo *et al.*, 2020). Therefore, a comprehensive nutrient management program is essential for maintaining a healthy potato crop, optimizing tuber yield and quality, and minimizing undesirable impacts on the environment. Potatoes have a sparse and shallow root system (Onder *et al.*, 2005). Consequently, potatoes are often unable to exploit nutrients and soil moisture fully within a soil profile and this result in their relatively high demand for many nutrients. Deep loose soils high in organic matter content would encourage good root formation and provide room for tuber expansion (KEPHIS, 2016). Since nutrients uptake is at its peak during tuber bulking stage, it is important to supply the required plant nutrients during this stage in right nitrogen-phosphorus-potassium ratio and in ample quantities (Haifa, 2014). The daily major nutrient requirements of potatoes during the critical bulking stage are 4.5 kg ha^{-1} nitrogen, 0.3 kg ha^{-1} phosphorus and 6.0 kg ha^{-1} potassium (Haifa, 2014). Potato tuber yield of 48 t ha^{-1} requires nitrogen of 79.4 kg ha^{-1}, phosphorus of 32.2 kg ha^{-1}, potassium of 151.0 kg ha^{-1} and Sulphur of 5 kg ha^{-1} (Mugo *et al.,* 2020). This is besides other plant essential nutrients (Lutaladio *et al.,* 2009). This requirement could be more since potato production is challenged with poor nutrient management strategies, poor cropping systems and accelerated soil erosion rates Mugo *et al.,* 2020 ; Muthoni, 2016). Tuber yield and quality are significantly affected by plant nutrition (KEPHIS, 2016). Phosphorus deficiency and/or excessive nitrogen may lead to lower tuber specific gravity. To keep specific gravity high, maintain adequate soil phosphorus concentrations. Phosphorus also influence net development (skin set) on tubers; its deficiency reduces netting when nitrogen levels are adequate or excessive (Tindall *et al.,* 1993). Nitrogen and phosphorus fertilizer application influence soil chemical properties. The soil pH will rise or fall depending on weather basic or acidic fertilizers, respectively are applied to the soil. Acidic or alkaline soils fix phosphorus due to reactions of orthophosphate, aluminium hydroxide and calcium ions that form insoluble compounds (Whitney *et al*., 1991).

2.6 Fertilizer use and potato growth

Fertilizer use in potatoes is low despite the crop being an important security food crop (FAO, 2013). There has been a general decline in potato production in Kenya (Gregory *et al.,* 2013) because of a number of constraints among them low soil fertility (FAO, 2013; Mugo *et al.,* 2020). In addition, fertilizers are usually applied below the recommended rate (90 kg nitrogen ha^{-1} + 90 kg phosphorus ha^{-1}) for potato production in Kenya (Mugu *et al.,* 2020; Kaguongo *et al.,* 2008; MOA, 2011; NAIAAP, 2014;

KARI, 2008). Continuous sole application of nitrogen and phosphorus fertilisers may have created a deficiency of potassium and perhaps other essential nutrients (Kamprath, 1984). Application of triple super phosphate (TSP) together with urea on crops has been recommended as it has been found to increase the efficiency of urea fertilizer. Banding urea with triple super phosphate could benefit phosphorus diffusion to plant roots in low calcium soils and increase fertilizer phosphorus availability (Ahmed *et al.,* 2006; Fan *et al.,* 1995). Triple super phosphate should not be blended with urea since the blend will cake, become sticky and therefore loss of nutrient value under storage. It has also been found that urea- triple super phosphate-mono ammonium phosphate (Urea-TSP-MAP) fertilizer combination could make efficient use of urea nitrogen by crops by reducing ammonia loss from urea hydrolysis (Fan *et al.,* 1995).

2.6.1 Nitrogen and potato growth

Nitrogen is often the most limiting of all essential plant nutrients for potato production. Application of nitrogen fertilizer is usually necessary to ensure optimum potato production because soil nitrogen is predominantly bound in organic matter and not readily available for uptake. Potatoes are highly responsive to application of nitrogen fertilizers (Muthoni, 2016). Both nitrogen rate and timing significantly affect potato yield and quality (Komen *et al.,* 2017). High nitrogen content in the potato is responsible for the dark colour in potato fries; low dry matter; high reducing sugar and high protein and nitrate content (Lutaladio *et al.,* 2009). Factors to consider when deciding on the rate of nitrogen to apply include: potato variety, yield potential or goal, growing season, soil organic matter content and previous crop (Hailu & Mosisa, 2019). If manure is used, then an estimate of nitrogen availability from the manure should be incorporated into the overall nitrogen applied (Zebarth *et al.,* 2007). In general, early maturing varieties, those grown for seed and early markets require less nitrogen than late maturing varieties. An adequate early season nitrogen supply is important to support vegetative growth but excessive soil nitrogen later in the season will enhance vegetative growth at the expense of tuber growth, suppress tuber initiation and maturity, reduce yields, decrease tuber density and result in poor skin set ultimately compromise the tuber quality and storage properties. On the other hand, inadequate soil nitrogen can accelerate early blight infestations (Muthoni, 2016; KEPHIS, 2016).

In general, split application of nitrogen are recommended for potatoes from both production and environmental stand point, as it enhances nitrogen-use efficiency by reducing leaching losses and availing nitrogen when it is needed. A portion of the nitrogen should be applied pre-plant or at planting and the remainder at emergence and hilling (Muthoni, 2016). Nitrogen uptake by the potato plant is highest during the tuber bulking stage. Applications of nitrogen after hilling should be based on petiole nitrate analysis (Haifa, 2014). Urea fertilizer is a source of nitrogen with 46% nitrogen. This fertilizer should not be blended with single super phosphate (SSP), triple super phosphate (TSP), calcium ammonium nitrate (CAN) and muriate of potash (KCl) (IPNI, 2018). However, the same fertilizer can be mixed with the same fertilizers and applied immediately to the crops. Urea is known to react with superphosphates to produce water that makes it difficult to store and apply the material. As much as urea can be mixed with most other fertilizers, fertilizer mixtures containing it should not be stored but applied immediately after mixing. Ammonium phosphates and super phosphates should not be blended with lime, slag, rock phosphate or calcium ammonium nitrate (CAN). Urea can however be mixed with ammonium sulphate before use and it is compatible with rock phosphate (PR) and diamonium phosphate (DAP) (IPNI, 2018).

2.6.2 Phosphorus and potato growth

Phosphorus being an important component of adenosine tri-phosphate (ATP) provides energy for plant processes such as ion uptake and transport (Muthoni, 2016). It plays an essential role in plant health and root development, which directly affects yield and quality (Muthoni, 2016). Phosphorus is also known to stimulate vigorous root system and healthy upper parts during early growth stages of a plant and hence influences uptake of other nutrients (Fageria *et al.,* 2001). Further, phosphorus enhances early potato tuber initiation and maturation. At tuber initiation, an adequate supply of phosphorus ensures formation of optimum number of tubers (Yara International, 2016). Phosphorus requirement in potatoes is frequently higher than of many field crops due to the high nutrient demand by potatoes and their relatively shallow root system (Mugo *et al.,* 2020). Potato plants require an adequate supply of phosphorus throughout the growing season to achieve optimum quality and yield (Yara International, 2016). Maximum potato yield occurs when sufficient phosphorus is available during early vegetative development and the entire period of tuber growth.

Potato plant phosphorus uptake increases rapidly during tuber initiation, levels off to a constant rate during tuber bulking, and ceases with plant maturation (Tindall *et al.,* 1993) when much of the nutrient demand of the tubers is met by trans-locating phosphorus from the upper part of the plant and to the roots then to the tubers (Potash & Phosphate Institute, 2000). Since phosphorus has very little mobility in soil, it is important to place it within the root zone to stimulate the early-season growth required for high yields (Muthoni, 2016). While potatoes are very responsive to fresh soil phosphate, the economic optimum rate is often very difficult to define. Rates will depend on soil type and soil test results (Yara International, 2016). Phosphorus deficiency results in reduced tuber yield, size and specific gravity (Yara International, 2016). The concentration of soluble phosphate in the soil solution is low and phosphorus is relatively immobile in the soil (Muthoni, 2016). Plant roots absorb phosphate ions only when they are dissolved in the soil water. Phosphorus deficiencies can occur even in soils with abundant available phosphorus if drought, low temperatures, or disease interfere with phosphorus diffusion to the root through the soil solution (Muthoni, 2016). Where sufficient soil phosphorus is not available for growth, foliar phosphate ensures rapid availability. Applied just before tuber initiation, foliar phosphate increases total tuber number.

Studies have been done on application of phosphorus to “ware” potatoes. These studies have shown that fertilizer recommendations for potatoes must be based on soil test results. From Ekelöf (2007), studies have shown that tuber quality is heavily correlated with phosphorus application. To minimize the impacts of phosphorus fixation, Ekelöf (2007) recommends banding of phosphorus fertilizer. Studies have shown that phosphorus fertilizer use efficiency can be increased by 45 % with the use of fertigation compared to broadcasting and with 25% compared to banding. It is important to have information on the critical level of phosphorus to minimize negative effects on potato tuber yield and quality. Optimum level of phosphorus fertilizer application for maximum growth varies considerably depending on several factors which include soil phosphorus status, soil physical and chemical properties, soil water content, seed variety, and application strategy. Therefore, sampling of both soil and plant tissue is needed to be able to fertilize phosphorus with satisfying accuracy. Olsen phosphorus is one of the most widely used and recommended method in determining the response of potatoes to phosphorus fertilization (Ekelof, 2007).

Grewal and Trehan, (1993) made a comprehensive collection of data from approximately 60 field experiments made in India over the six decades regarding phosphorus fertilization of potato. In these trials the optimum application rates varied from 17 to 77 kg phoshorus ha^{-1} and the yield response was in the range of 1 to 7.7 metric tonnes ha^{-1}. The response showed good correlation with soil phosphorus levels measured with the Olsen phosphorus method. Alvarez *et al.* (1999) tested 13 different phosphorus application rates varying from 0 to 207 kg phosphorus ha^{-1}. The experiment was carried out in an Andosol (7.8 mg Olsen P l^{-1}) in Mexico. The highest yield increase observed was 6 t ha^{-1} compared to the control with no phosphorus, and the optimum phoshorus application rate was 90 kg ha^{-1} phosphorus.

In the United States of America (USA), Oregon state university extension service conducted field experiments over a period of time starting in 1999 and lasted through 2004. In these experiments three application rates were tested; 0, 68 and 136 kg phosphorus ha^{-1}. Yield on average increased by 6.7 metric tons ha^{-1} when phosphorus was added, but the difference was not significant. The experiments were conducted on soils with high phosphorus levels (Phosphorus Olsen 30 mg l^{-1}).

Hahlin, (1992) investigated the optimum phosphorus fertilizer application rate for potatoes on loamy soils in the central parts of Sweden. Three application rates were tested 0, 45 and 90 kg phosphorus ha^{-1}. A yield increase from 29.05 to 30.00 t ha^{-1} was found when an application rate was increased from 45 to 90 kg phosphorus ha^{-1}. The author concluded that optimal application rate was more likely higher than 90 kg phosphorus ha^{-1}.

In a summary of 244 field trials, Allison *et al.*, 2001 concluded that responses of phosphorus fertilizer are most likely to occur on Index 0 and 1 soils (Olsen phosphorus). The chances of the same responses occurring on Index 3 soils are slim. With increasing application of phosphorus, the potato yield response reduces. In upper areas of rift valley of more than 2000 m asl, yield increase to phosphorus application was as follows:

0 - 30 kg phosphorus ha^{-1} : 2.1 t ha^{-1}; 30 - 60 kg ha^{-1}: 1.2 t ha^{-1} ; 60 - 90 kg phosphorus ha^{-1} : 0.8 t ha^{-1} and 90 - 120 kg phosphorus ha^{-1} was 0.5 t ha^{-1} (ASH, 2017). For the lower parts of Rift Valley (less than 2300 m a.s.l), the responses were 2.4, 1.6, 1.0 and 0.7 t ha^{-1}, respectively. On the upper parts of western Kenya (more than 1400 m asl), the increases were: 0-30 kg ha^{-1}: 2.1 t ha^{-1}; 30-60 kg ha^{-1} : 1.3 t ha^{-1} and 60-90 kg ha^{-1} : 0.8 t ha^{-1} (ASH, 2017).

Potatoes require 500 kg ha^{-1} of diamonium phosphate (DAP), applied at planting (FUBC, 2017). This translates to 90 kg ha^{-1} nitrogen and 101 kg ha^{-1} phosphorus. Diamonium phosphate is the main fertilizer used by potato farmers (Mugo *et al.,* 2020) despite other fertilizers like N: P: K 23:23:0 being recommended (NAAIAP, 2014 & FUBC, 2017). The weight of DAP used in 2011, 2012 and 2013 was 13.4, 12.4 and 11.1 million tonnes, respectively. These give an average of 103 kg ha^{-1} DAP which is about five times lower than the recommended rate (FUBC, 2017). Diamonium phosphate is however associated with reduced soil ph and hence high soil acidity (Mugo *et al.,* 2006). Triple superphosphate (TSP) was one of the first high analysis phosphorus fertilizers that became widely used in the 20th century (Crop Nurition, 2021). It is an excellent phosphorus source, but its use has declined as other phosphorus fertilizers have become more popular. It has several agronomic advantages that make it such a popular phosphorus source for many years. (Crop Nutrition, 2021). It has the highest phosphorus content of dry fertilizers that do not contain nitrogen. Over 90% of the total phosphorus in triple super phosphate is water soluble, so it becomes rapidly available for plant uptake. As soil moisture dissolves the granule, the concentrated soil solution becomes acidic. Triple super phosphate also contains 15 % calcium (Ca) (IPINI, 2018).

2.6.3 Potassium and potato growth

Potassium is one of the major nutrients required by potatoes. In comparison to all the nutrients required by the crop, it is needed in largest amounts. Potato has been noted to have high demand of potasium than any other vegetable crop (Cindy, 2010). Potasium influences the yield and quality of potato. It is needed in regulating water and ionic nutrient uptake, reducing sugar content and specific gravity of potato tubers. It also enhances root growth and tolerance to external stress like heat, drought and high light intensity. As much as potato can take potassium luxuriously (Haifa, 2014 & Kang *et al.,* 2014), Lutaladio *et al.,* 2009 noted that nitrogen: phosphorus: potassium ratio of 1:1:1 is ideal for potato production. Also Zeru *et al.,* 2016 noted potassium influence on potato yield and productivity in Eritrea. In studies done by NAAIAP (2014), potassium was found to be sufficient in Uasin-gishu, Kiambu and Saboti soils rendering its application to be inconsequential in influencing potato yield and growth. However, it is important for farmers to check and base potassium application on soil test results than assuming that its application is or not necessary (Zeru *et al.,* 2016). Sangula (2019) recommended 207 kg ha^{-1}, 125 kg ha^{-1} and 83 kg ha^{-1} on "ware" potato production and 83 kg ha^{-1} on potato seed production in Milimani area, Saboti Sub County, Trans Nzoia County.

2.6.4 Organic matter and potato growth

Soil preparation for the potato crop should be adequate with minimum soil disturbance. Naturally loose soils and loamy and sandy loam soils that are rich in organic matter with good drainage and aeration are the most suitable (FAO, 2008). It is recommended to avoid using fresh, incompletely decomposed manure because it will become active too late in the season and may reduce dry matter content, delay maturity and transmit diseases like *Rhizoctonia solani* (Lutaladio *et al.,* 2009). Potatoes are known to benefit from application of organic manure at the start of a new rotation - it provides a good nutrient balance and maintains the structure to the soil. Crop fertilization requirements need to be correctly estimated according to the expected yield, the potential of the variety and the intended use of the harvested crop (FAO, 2008). There is a general decline in soil organic matter and soil pH in most Kenyan soils, a trend that is common in degraded soils (Kamprath, 1984; NAIAAP, 2014). From ASH (2017), manure is commonly used on potatoes by small holders who practice crop-livestock farming but its use is limited by its low availability.

The amount of carbon retained and accumulated in soil depends on a number of factors like soil management, climate and soil type. Increased nitrogen deposition may enhance carbon sequestration in ecosystems that are nitrogen-limited. Poorly drained soils and those high in clay content may also enhance carbon retention because of decreased decomposition rates in the former and greater physiochemical protection in the latter. Carbon can be stabilized in mineral soil by physical protection in micro aggregates, chemical protection through organo-mineral complexes with silt and clay particles, and biochemical protection by the formation of recalcitrant organic compounds. It has been shown that denser organo-mineral particles are more enriched in nitrogen (lower carbon/nitrogen ratio) and higher in microbial breakdown products than in the bulk organic matter (Donald *et al.,* 2011). The desired soil carbon: nitrogen ratio is less or equal to 24:1. Lower carbon: nitrogen ratio leads to volatilization of nitrogen while a higher ratio leads to un-decomposed organic matter (USDA, 2011).

2.7 Potato production and yields

In Kenya, potatoes have a yield potential and actual yield of 40 t ha^{-1} and 8.6 t ha^{-1}, respectively and ranked 26 out of 39 African countries in terms of yield (KEPHIS, 2016 & FAO, 2020). Kenya was also the 4th and 2nd best African producing country with respect to potatoes' annual production (1.9 million tonnes) and area of production (217, 315 ha), respectively (FAO, 2020). There are several contributors to potato yields which include variety (genetic potential of the potatoes), seed quality (size, number of eyes, health, and taste of customers), environmental factors (like altitude, rainfall and soil nutrient status) and agronomical factors (FAO, 2020).

2.8 Potato seed quality

Choudhary and Viji (2016) stated that seed quality is the possession of seed with the required genetic and physical purity that is accompanied with physiological soundness and health status. Major seed quality characters include physical quality, genetic purity, physiological purity and seed health.

Potato seed quality can be categorised into two: biological/physiological and commercial/physical (Wang, 2008). Two factors that determine biological/physiological quality are level of disease infestation and physiological age of the seed tubers. Virus and virus like organisms often lead to degeneration of potato seed. Major virus affecting the potato seed include: potato Virus Y (PVY), potato Virus X (PVX), potato Virus M (PVM), potato Virus A (PVA), potato leaf roll virus (PLRV) and potato spindle tuber viroid (PSTV). Apart from the virus, fungal and bacteria pathogens in tubers lead to late blight, ring rot, black leg and other diseases that limit seed quality (NPCK, 2013). Hence, biological/physiological quality can be guaranteed from disease free seed, seed multiplication that begin from clean stocks and appropriate multiplication technologies applied to classes of seed being multiplied (Wang, 2008). The implication of physiological age is that young seeds have higher yields than old seeds. Physiological quality leads to good germination percentage and vigorous growth. Commercial quality is defined by uniformity, size and external appearance of potato seed. A reasonable potato seed size should be 30 to 80 g (Lutaladio *et al.,* 2009). MOA, 2011 indicates that potato seed sizes should range between 25 mm and 55 mm while KEPHIS (2016) gives a range of 28-60 mm for potato seed sizes. Large size potatoes increase cost and very small size potatoes stand a risk of rotting before emergence. Physical quality parameters include weight, volume, projected area, centre of gravity, width, length, thickness and appearance (Birhanu *et al*., 2019). Yield and physical quality is influenced by soil type, cultivar, weather conditions, water management, plant population, seed piece size, pests and diseases (Birhanu *et al*., 2019).

The factors that affect potato yield and quality include altitude, choice of variety, and physiological stage of seed, early planting and crop management. Potato seed should be grown at an altitude of 2100 to 3000 m above sea level. At lower altitudes there is prevalence of aphids and hence bacteria wilt that lowers the quality of potato seed. Varieties that resist or tolerate diseases are high yielding, have desirable keeping and processing qualities. Tubers that have 4 to 6 sprouts which are healthy, strong and of good colour development are recommended. When potato seed are planted early, they escape diseases like early and late blight and because they receive all season’s rainfall, they grow with vigour and produce high yields. Good crop management include weeding, ensuring sufficient moisture, protection against diseases and pests, hilling and rouging (KEPHIS, 2016).

Potato specific gravity is an expression of potato relative density. It correlates highly with the the tubers dry matter content or total solids in the tuber. It is the ratio of weight of a potato tuber to the weight of an equal volume of water. It is measured by dividing the weight of a potato tuber in air with the difference between the weight of the same tuber in air and water. Conversion tables based on the high correlation between specific gravity and dry matter are also available to give a corresponding dry matter percentage for a given specific gravity reading. A specific gravity reading of 1.080 would be equivalent to a dry matter of 21.2% (Agriculture Victoria, 2010).

To produce potatoes with high specific gravity, it is important to follow good agronomic practices, use high quality seed of the correct variety, plant the variety at the right spacing and time of year, apply nitrogen and potassium fertiliser to meet crop needs and apply adequate irrigation. Over fertilising and over irrigating can result in lower specific gravities in tubers. Avoiding planting on wet soils and taking special care on very sandy soils is also recommended (DPIRD, 2019).

Germination percentage is an indicator of seed quality; the higher the germination percentage, the better the seed quality. From Powell (2009), germination percentage is the (ratio of normal seedlings that can be established in the field to the total seeds planted) x 100%.

2.9 Techniques used in potato seed production

2.9.1 Overview

Certified potato seed production, begins with breeders establishing true potato seeds (TPS) which result from pollination of ovules, the “eggs” of plants and harvested from potato fruits. To differentiate them from potato seed which are genetically identical clones of the parent plant, they are referred to as “true potato seed” (TPS). True potato seeds are not genetically identical; they are ‘highly heterozygous autotetraploids’ that contain four copies of each chromosome with considerable genetic variation between chromosomes (Schneider, 2015).

From the KEPHIS (2016), the seed classification system of Kenya begins with healthy mother plants, followed by in-vitro plants and minitubers that are classified as breeder’s seed. From this material, pre-basic seed (with a maximum of one generation) is produced, followed by basic seed (with a maximum of two generations). What follows is production of certified seed 1, 2 and 3 with production of one, two and three maximum number of generations, respectively. Pre-basic and basic seed are produced by KALRO, ADC Molo and Kisima Farm. Certified seed is produced by seed multipliers and every season seed crops are downgraded one class due to degeneration of the tubers (KEPHIS, 2016).

There are several technologies recommended to produce quality potato seed. They include seed plot technology which can save land for seed production by 50%, aeroponics which is 10 times better than the conventional technologies, positive seed selection that can increase potato yields by more than 30% as compared to farmers practice. Other techniques include hydroponics and tissues culture. The latter two and aeroponics are however noted to be time consuming and tedious for farmers to implement (Ahesibwe *et al.*, 2015).

2.9.2 Seed plot system of potato production

Seed plot system is one of the methods used to plant potato seed. The principle in this system involves maximising tuber production per unit area of limited, disease-free land through high-density planting in a seed plot and also separation of seed and "ware" (larger tubers meant for consumption) potato production. The system uses 50% less land than the "ware" production to meet on-farm seed tuber requirements. In Kenya there is a very large commercial opportunity in the production of certified potato seed (KEPHIS, 2016). The demand for and commercial price of clean potato seed tubers is far higher than "ware" potatoes. In mid-2010 it was established that Kenya only produces about 1% of the potato seeds needed every year by potato farmers countrywide (KEPHIS, 2016). Clean seed is the best start for a good potato crop yield as most potato farmers know or have discovered. Farmers interested in production of commercial potato seed are expected to seek advice from KEPHIS and the local agricultural extension officers. KEPHIS provides inspection and certification while agricultural extension officers provide extension service (MOA, 2011 & KEPHIS, 2016).

The following factors should be considered in choosing plots for potato seed production: It should not have had any members of solanacea or black night shade family (Irish potatoes, capsicums, eggplants (brinjals) and tomatoes) grown in it for the last 5 years and preferably it should have had a dense mat of grass growing on it for at least one year during the last 5 years. Other probable sites for seed plots include virgin land and land that has been under fallow for 2-3 seasons. Further, it should not have been given agricultural lime for the last 5 years. Also the plot should be located in full sunshine in highland areas, and in half shade (for example shaded half the day) in hotter areas. The seed plot should not be situated in low-lying or water-logged areas where run-off water flows into it. There should be a good supply of well composted farm yard manure applied just before planting the certified potato seed tubers. If the amount of manure is not enough, it should be applied in the trenches dug for planting tubers. Finally, if *Lantana camara* bushes grow in your neighbourhood it is very beneficial to also mix in leaves of lantana in the potato planting rows to repel insects (IBA, 2019).

Tubers harvested from seed plots are divided into two lots: one lot is used to establish a new seed plot (for not more than three seasons) as described above and the other lot is used for production of “ware” potato in main fields (IBA, 2019).

To protect the seed plot, the seed plot area is fenced to restrict movement that can cause contamination. Maize is planted around the seed plot as a border crop to minimize aphid infestation. At least four rows of maize are planted two to three weeks before potato seed are planted. Further, it is important to clean /and disinfect all tools, feet and shoes before entering the seed plot area (KEPHIS, 2016).

2.9.3 Positive and negative seed selection method of producing potato seed

Positive selection is an old technology that was used primarily in formal potato seed multiplication to select mother plants from the best plot of potatoes as the starting point of the multiplication system (De Bokx & Van de Want, 1987). In this system, the best potato plants in a field are marked before crop senescence that obscures disease symptoms. The marked plants serve as mother plants for potato seed used for the next season's potato crop. Positive selection has been used in central Africa as the starting point for a seed multiplication system (Haverkort, 1986). Positive selection is now widely regarded as an obsolete technology in formal potato seed production systems. Currently, potato seed in formal seed systems are multiplied from tested, disease-free, tissue culture material or from other nuclear stock which has been proven to be disease free. The use of positive selection as an on-farm method to maintain potato seed quality is also mentioned by Struik & Wiersema (1999), but is not commonly used by "ware" potato producers, nor is its use promoted.

In Kenya, potato seed quality is often a major yield constraint in potato production as smallholder farmers use farm-saved seed without proper management of seed-borne pests and diseases. Farm-saved seed is therefore often highly degenerated. In an on farm research carried to assess whether farmer-managed positive seed selection could improve yield, positive selection gave an average yield increase in farmer-managed trials of 34%, corresponding to a Ksh 36,322 increase in profit per hectare at an additional production cost of only Ksh 774/ ha. Positive selection is recommended as an important alternative and complementary technology to regular seed replacement, especially in the context of imperfect rural economies characterized by high risks of production and insecure markets (Gildermancher *et al.*, 2011). It does not require cash investments and is thus accessible for all potato producers. It can also be applied where access to high-quality seed is not guaranteed. The technology is also suitable for landraces and unrecognized cultivars that cannot be multiplied formally. Finally, the technology fits seamlessly within the seed systems of sub-Saharan Africa, which are dominated by self-supply and neighbour supply of potato seed (Gildermancher, 2012). From KEPHIS, 2016 negative seed selection involves scouting and removing unhealthy plants from an establishment of potatoes from certified seed. Whatever remains is harvested as potato seed and graded accordingly.

2.9.4 Tissue culture techniques

Tissue culture potato seed production involves taking tissues from meristem or apical areas on potato plant, culturing them in a nutrient media to develop plantlets that are used to produce micro and min-tubers for potato seed production. Most tissues from the meristem areas of potatoes are viral and disease free or are minimally infected. The plantlets produced can be planted in green houses or directly in the field. They may be grown hydroponically or aeroponically or in pots (Minhas, 2016 & KEPHIS, 2016).

2.9.5 Hydroponics techniques

Hydroponics is an alternative method for obtaining high yields of potato seed and, as such, may play a key role in satisfying the demands of a growing market. Although the installation of a hydroponic unit represents a high capital expenditure, the initial costs can be spread over numerous production cycles (Ricardo *et al.*, 2009). An alternative strategy to facilitate the commercialisation of such a unit and to maximise profits would be for producers to organise themselves into cooperatives. Hydroponics may also offer an attractive solution to the problems that will be caused by increasing controls over the use of water in agriculture and concerns over the excessive exploitation of soils by rotation of short term crops such as potatoes. The recirculation of water in a hydroponic system is economical in terms of preventing waste and in avoiding the need for the application of insecticides. However, some improvements to the systems currently in use need to be made, including: (i) the development of alternative nutrient solutions containing, for example, more appropriate concentrations of potassium and boron, which are elements involved in the translocation of photo- assimilates from source to the sink tissues; and (ii) more efficient management of the plant material with special emphasis on alternative methods of supporting the aerial parts of plants grown hydroponically. In recent years, hydroponics has proven to be a very successful strategy for the production of pre-basic potato seed. Hydroponic techniques are much more efficient than the more traditional methods of cultivation of potato seed (i.e. in fields, planting beds or containers) and productivity can be three times greater (15 vs. 5 tubers per plant, respectively). Hydroponic methods not only facilitate the adequate supply of nutrients to the plants but also permit multiple harvesting of mini-tubers, a procedure that can be performed at specified intervals throughout the production cycle. The number of mini-tubers obtained via systematic harvesting is high in comparison with a single harvest strategy and the product obtained will be of uniform size. Since hydroponic cultivation avoids attack by pests and the dissemination of pathogens, the resulting tubers are normally disease-free (Ricardo *et al.*, 2009).

2.9.6 Aeroponic techniques

The aeroponic production of potato mini-tubers started at the beginning of the 21st century due to an increased demand for more efficient, high-quality seed production methods. In the aeroponic cultivation system, the root is free in the air of the dark chamber (the aeroponic module). The plant is attached to the aeroponic module cover on the passage of the tree into the root. The plant receives water and nutrients through an aerosol of the nutrient solution. The number and harvest intervals are one of the key factors in optimizing the production of mini-tubers. The aeroponic technology is potentially more efficient for specific potato varieties (Zoran *et al.,* 2018).

2.10 Diseases and pests that attack potato

Health potato crop can produce between 25 and 35 t ha^{-1} of fresh potato tubers in Kenya, this is hardly realised by most famers mainly due to poor control of pests and diseases (KEPHIS, 2016). Viruses and poor control of late blight has been noted to cause losses of between 80 and 90 % (KEPHIS, 2016). It is important to ensure that the crop is protected against fungal foliar diseases throughout the growing period. Fungal diseases on potatoes include late blight, early blight, black scurf/stem canker and fusaruim dry rot. Bacterial diseases include bacterial wilt, black leg or soft rot, potato common scab and bacterial ring rot. Virus diseases include potato leaf roll virus (PLRV), potato virus Y (PVY), potato virus X (PVX), potato virus A (PVA). Insect pests that attack potatoes in Kenya include potato aphids, cutworms, potato tuber moth and nematodes. Of all crop pests worldwide, potato cyst nematodes are among the most difficult pests to control. They can survive in an area for over 30 years (NPCK, 2013).

The economic damage including yield losses and management cost from late blight in developing contries is eastmated at 3 billion US dolars annually (Baker *et al.,* 2014 & CIP, 2017). The disease is the first constrant in potato production in Kenya (Sophie, 2018). The symptoms of late blight begin as white to grey spots on the lower tips on edges of young leaves and spread quickly to cover the infected leaves if conditions remain favourable. In severe cases the disease damages stems and tubers. The affected tubers display brown-coloured spots on their skins and flesh (Sophie, 2018). If late blight is not controlled, the plant will die within three days. Symptoms of early blight include dry brown spots usually bound by the leaves’ ribs. The spots enlarge and join together to form big concentric /circular rings. This disease first becomes apparent during the tuber bulking stage and develops leading to harvest. Early blight as opposed to late blight rarely causes complete crop failure (KEPHIS, 2016). Its symptoms are normally on the old leaves (NPCK, 2013).

Bacteria wilt is the most important bacterial disease affecting potatoes in Kenya. It affects about 70 % of the potato farmers and can lead to 50 to 100 % of yield loss (Sophie, 2018). It expresses best under conditions of warm temperatures and high soil moisture. Plants begin to wilt, starting from the tips of the leaves or where the stems branch out and spread to all parts of the plant even when soil moisture is sufficient. Leaves become yellow at their bases and the whole plant wilts and dies. When stems are cut, a brown ring is visible. Mildly infected tubers may not show any outward visible symptoms, but when cut brown or black rings will be visible (Sophie, 2018). If left for a while, these rings will exude a thick white fluid. A further symptom is white fluid coming out of the eyes. This can be signified by soil sticking to tuber eyes when crops are harvested. Serious infection causes tubers to rot starting with the vascular rings.

Black leg or soft rot is a wide spread seed borne disease caused by a bacterium *Erwinia spp* which affects stems and tubers through break down of plant cell walls. It is prevalent in warm and humid areas. The bacteria invade the mother seed tuber but the disease development is dependent on the time the mother tuber rots. In Kenya, common scab is common in areas with high soil pH. The disease reduces the quality of potato because it affects its visual appearance. Bacterial ring rot begins in the potato seed tuber. The leaves of the potato turn yellow and lower leaves start mottling. The leaf margins roll upwards and curl inwards. Eventually the tissues die from necrotic areas. When the tuber is cut necrotic areas are seen along the vascular tissues. While in bacteria wilt the bacteria oozes from the vascular tissues, in ring rot the cheesy exudes oozes from the vascular ring. In advanced stages, the necrotic areas breakdown to form grey pockets of decayed tissues around the vascular ring. About 40 viruses are known to affect the potato crop. Viruses are classified according to the mode of transmission which can be contact or by vectors. Contact viruses include Potato Virus X and Potato Virus S. Those spread by vectors include Potato Virus A, Potato Virus Y, Potato Leaf Roll Virus and Potato Mop Tap Virus (PMTV). Viruses in general lead to smaller potato tubers being produced (KEPHIS, 2016).

Blight can be prevented using protectant (contact) fungicides under conditions of dry weather or slow crop growth. Systemic (curative) fungicides can also be used. They should be applied when the crop is growing rapidly or when the crop is under conditions of high relative humidity (prolonged periods of fog or rain). In severe cases, application of the fungicide should be repeated within four to seven days. Under normal conditions the application should be repeated within seven to ten days till maturity of the crop (NPCK, 2013; KEPHIS, 2019).

Pests can be managed by use of contact insecticides as soon as the pest emerges. This should be alternated with systemic insecticides. Other methods of managing pests include use of healthy, certified seed, deployment of predators like lady bird, lace wigs and fall midge, crop rotation with non-host (non – solanaceous) plants, planting at recommended depth of 20 – 25 cm deep, proper hilling or "earthing up" of tubers to prevent them from being infested through adults laying eggs in the tubers, maintenance of soil moisture at field capacity during harvesting, maintaining farm and store hygiene, application of plants rich in oils like *Eucalyptus* or *Lantana camara* leaves which will repel the pest, rogueing volunteer plants, harvesting as soon as "dehaulming" is done, using sex pheromones, use of pyrethroid insecticide to destroy the pest, proper scouting to check for foliage or stem damage. Other methods are planting resistant varieties, bio fumigation and crop rotation of up to 10 years (9 to 10 years rotation is needed to reduce the population of potato cyst nematodes) (NPCK, 2013).

Methods to manage viruses include: use of certified or clean seed for planting, rogueing diseased plants, use of monitoring traps for aphids, use of registered insecticides to kill vectors (mainly aphids), use of resistant cultivars, application of mineral oils to prevent virus transmission aphids, not cutting potato seed, ensuring field and store hygiene, restricted movement from infected to uninfected fields and early harvesting of seed crop (KEPHIS, 2016).

2.11 Shangi and Unica potato varieties

Shangi and Unica are among the 60 varieties of potatoes grown in Kenya (NPCK, 2019). National potato council of Kenya has documented 27 producers as potato seed producers in Kenya (Kaguora, 2018).

2.11.1 Shangi potato variety

This is a highly prolific and versatile variety that was released in Kenya in 2015 (Sophie, 2018). It grows to a height of about 1 m. Its leaves are broad and light green without anthocyanin pigmentation of the mid rib. It has an upright growth and abundant flowers. The tubers of this variety are oval, uniform in grading with cream skin, white flesh and medium to deep eyes with pink pigmentation. The dormancy of the tuber is very short (3 to 4 weeks). The potato takes ≤ 3 months to mature. Its yield potential is low (30 - 40 t ha^{-1}). It is moderately susceptible to late blight. It can be mashed, boiled, roasted or cooked as chips. It grows well at an altitude of 1500 to 2800 m a.s.l (FAO, 2008; NPCK, 2019).

2.11.2 Unica potato variety

This variety was released in Kenya in 2016 (Sophie, 2018). It is medium tall with strong semi erect stems and dark green medium sized leaves. It flowers profusely, the flowers are pink and the eyes are shallow. It is moderately resistant to late blight (LB), highly resistant to potato virus X (PVX) and resistant to potato leaf roll virus (PLRV). Its tuber dormancy is long (2.5 to 3.5 months). The tuber is long with red skin, shallow eyes and cream flesh. It has a yield potential of greater than 45 t ha^{-1} and matures within 2.5 to 3.5 months. It can produce between 533,333 to 800,000 tubers ha^{-1} unlike older varieties that produce between 160,000 to 213, 332 tubers ha^{-1} (Waikwa, 2018). The variety does well at altitudes of 1400 to 3500 m a.s.l. It is used for chips and crisps. It is rich in vitamin C, iron and zinc (FAO, 2008; NPCK, 2019).

2.12 Phosphorus use efficiency

Agronomic fertilizer use efficiency is the ratio of yield increase above control to the weight of fertilizer applied (Dobermann, 2007). This efficiency addresses the need to enhance crop yield at reduced cost. It is influenced by crop, soil and climatic factors (Fixen *et al.,* 2014). Inefficiency may be as a result of plant roots being unable to grow and function to their fullest extend in utilizing the soil available nutrients. The current crop yields in the tropics are far below their potential yields necessitating research on nutrient use efficiency in the same areas (Baligar & Bernett, 1986).

There are a number of ways of measuring phosphorus use efficiency in agriculture according to Eklorf (2014). These include recovery of fertilizer or yield per unit of phosphorus supplied.

The recovery method can be estimated with several different methods (Eklorf, 2014). In the direct method, the amount of fertilizer phosphorus acquired by the crop (PA), measured by radioisotope analysis, is divided by the total amount of phosphorus supplied (PS). Recovery (direct method) = PA/PS. This method is used to evaluate whether phosphorus reserves are increasing, decreasing or remaining constant over time. Values lower than 100% calculated with the balance method indicate that more phosphorus is being applied than is removed by the crop, and thus soil phosphorus reserves are building up. In the difference method, the yield or phosphorus acquisition from a non-phosphorus fertilized plot is compared with that from a phosphorus-fertilized plot. This method can be used in two different ways. In the first one, yield in the non-phosphorus fertilized plot (Y0) is subtracted from yield in the phosphorus fertilized plot (Y1) and the result is divided by the total amount of phosphorus supplied (PS); that is $(Y1 - Y0)/PS$. In the alternative, phosphorus acquisition in the non phosphorus-fertilized plot (A0) is subtracted from phosphorus acquisition in the phosphorus-fertilized plot (A1) and the result is divided by the total amount of phosphorus supplied given by $(A1 - A0)/PS$. This is often referred to as the apparent efficiency of phosphorus. Phosphorus use efficiency can also be defined as dry weight yield (DWY) per unit of phosphorus supplied (PS). When uptake of phosphorus by the crop is used in the calculation; the efficiency is referred to as internal or physiological. Where the yield of crop is used in the calculation, the efficiency is known as external or agronomic use efficiency (Ekelorf, 2014).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Determination of potato seed quantity and quality

3.1.1 Determination of potato seed quantity

Description of study site

This study was carried out at three locations (Saboti, Ainabkoi and Lari) as indicated in Figure 1 and as described below:

Saboti is located in Trans-nzoia County about 20 km from Kitale town. The soils of this area are humic nitisols. Its coordinates are (0.94 °N, 34.84 °E) while its elevation is 1923 m above sea level. The agro ecological zone of the area is upper midland (Maize and coffee) zone. The area receives 1000 to 1200 mm of rainfall annually and has temperature range of 10 to 27 °C. Ainabkoi is located about 66 km from Eldoret town in Ainabkoi sub County, Uasin-gishu County on latitude 0.18° N and longitude 35.53° E, at an altitude of above 2300 m above sea level. The agro ecological zone of the area is upper highland zone 2 (UH2) which is a pyrethrum and wheat zone. The area receives annual rainfall range of about 1200 to 1400 mm. Annual temperature range is between 13.3 to 15.7 °C while the main soil type is humic nitisols developed on tertiary basic igneous rocks. Lari is located about 70 km from the city of Nairobi in Lari sub County, Kiambu County. Its coodinates are (1.11 °S, 36.64 °E). It has an elevation of 2550 m above sea level, annual rainfall of 1400 mm, temperature of 12 - 21 °C and an agro ecological zone of upper highland zone1 (pyrethrum and dairy zone). Its soils are planosols (NAIAAP, 2014; Jaetzold & Schmidt, 2009; Jaetzold *et al.*, 2011).

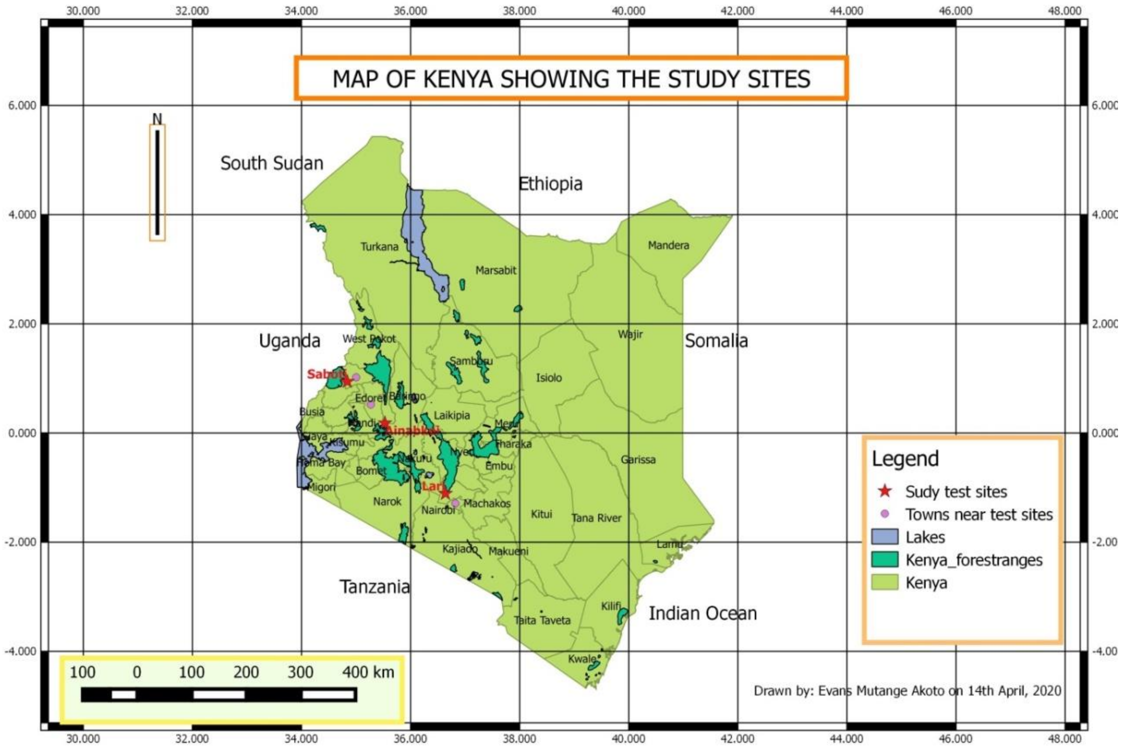

Figure 1: Map of Kenya showing location of the study sites. Source: First hand data by GPS machine; ILRI (2015) and Open Africa (2020)

Potato varieties

The test varieties were Unica and Shangi; Unica was selected based on its high yielding potential (> 45 t ha^{-1}) and suitability for chips, crisps and domestic uses (NPCK, 2019). It is rich in vitamin C, iron and zinc. Shangi was selected based on its popularity with farmers and its local availability (Muthoni *et al.*, 2013). Unica is an alternative to Shangi which has shorter storage time (NPCK, 2019).

Experimental treatments and coding

In each site, nitrogen was applied at planting as a basal fertilizer at the rate of 90 kg nitrogen ha^{-1} as urea. Phosphorus was also applied at the same time at the rate of 0 (control), 30, 60, 90, 120 kg phosphorus ha^{-1} as triple super phosphate. There was provision for Absolute control (0 nitrogen; 0 phosphorus). The nitrogen rate of 90 kg ha^{-1} and phosphorus rate of 90 kg ha^{-1} were based on recommendation by Kaguongo *et* *al*., 2008; MOA, 2011, KARI, 2008 & NPCK, 2013. These recommendations are backed by Lutaladio, 2009 who recommends nitrogen: phosphorus ratio of 1:1 for potato production. They are recommended rates for "ware" potato production. The rates for potato seed production are yet to be documented. Potassium was not tested because it was found to be adequate in the test sites (NAAIAP, 2014). Also, preliminary soil tests done at National Agricultural Laboratories (NARL) Kabete at planting on the soils of the test sites (Appendix 48) using Mehlich 3 method indicated that potassium was high or adequate in the test sites. In Saboti (2.0 %) and Ainabkoi (1.0 %) it was high while in Lari (0.7 %) it was adequate. The treatments were coded as follows (Table 1).

Experimental design and layout

The experimental design was a split plot in RCBD. Two varieties (main plot treatments) were tested under six phosphorus levels (sub plot treatments). Absolute controls were provided for in the sub plot treatments. The numbers of replications (blocks) were three. Thus, each site had 2 varieties by 6 phosphorus levels by 3 replicates summing to 36 experimental units (Tables 1).

Table 1: Phosphorus (P) fertilizer treatments/coding and experimental lay out

(a) Phosphorus (P) fertilizer treatments and coding				(b) Experimental layout					
Treatment No.	**Description**		**Code**	**Block 1**		**Block 2**		**Block 3**	
				Main plots		**Main plots**		**Main plots**	
	Rates of phosphorus ha^{-1}	**Rates per plant :** $\boldsymbol{TSP} = 0.093xP grams$ per tuber(P in kg/ha) $\boldsymbol{Urea} = 0.041N\ grams\ per\ tuber(N\ in\ kg\ /ha)$		**Unica**	**Shangi**	**Shangi**	**Unica**	**Unica**	**Shangi**
1	0N,0P (AC or Absolutecontrol)	0 g Urea, 0 g TSP tuber^{-1}	AC	P0	P2	AC	P3	P4	P1
2	0 kg P ha^{-1} (P0 or Positive control)	0 g TSP tuber^{-1}	P0	P4	AC	P0	P2	P3	P4
3	0 kg P ha^{-1} (P1)	2.8 g TSP tuber^{-1}	P1	P1	P3	P4	AC	P2	P0
4	60 kg P ha^{-1} (P2)	5.6 g TSP tuber^{-1}	P2	P3	P4	P2	P1	P0	AC
5	90 kg P ha^{-1} (P3)	8.4. g TSP tuber^{-1}	P3	AC	P0	P1	P4	P1	P2
6	120 kg P ha^{-1} (P4)	11.2 g TSP tuber^{-1}	P4	P2	P1	P3	P0	AC	P3

(c) Amount of triple super phosphate and urea used

Name of Fertilizer	**Rate tuber^{-1}(g)**	**Amount (g)**	**Remarks**
TSP	2.8	2.8 x 40 x 6x3 = 2016 g = 2.02 kg	Total TSP needed = 20.16 kg Total Urea needed = 13 kg
TSP	5.6	5.6 x 40 x 6x 3 = 4032 g = 4.03 kg	
TSP	8.4	8.4 x 40 x 6 x 3 = 6048 g = 6.05 kg	
TSP	11.2	11.2 x 40x6x3 =8064 g = 8.06 kg	
Urea	3.6	= 3.6 x 40 x 30 x3 g=12960g= **13 kg**	Urea applied to all plots as basal except in the absolute controls

The formula for converting P ha^{-1} to TSP per tuber is given by $TSP = P\left(\frac{142}{62}\right)x\left(\frac{100}{46}\right)x\left(\frac{25x75}{10000x100x100}\right)x1000g = 0.093P grams\ per\ tuber$--Equation 1

The formula for converting nitrogen per hectare to urea per tuber is given by:

$Urea = N\left(\frac{100}{46}\right)x\left(\frac{75x25}{10000x100x100}\right)x1000g = 0.041N grams\ per\ tuber$)-Equation 2

Where units of N and P are in kg ha^{-1} and those of urea and TSP are in grams plant^{-1}.

Area of potatoes needed

Each block had 12 experimental Units. The size of each plot was 4 m x 3m. Providing for 1m path around each plot, the length and width of 3 blocks was 31 m and 25 m respectively. The size of the three blocks was therefore 31x25 = 775 m^2. For three sites, the area was = 3 x 775= 2325 m^2 (0.23 ha).

Weight of potatoes used

Since a potato seed is about 30-40 g (FAO, 2008), the mass of potatoes (using the potato size of 40g) used = 0.04x4x3x36x3/ (0.25x0.75) = 276 kg = 6 (50 kg bags) of potato seed for the three sites**.** The rate used in this calculation is about 2.13 t ha^{-1}.

Soil sampling and seed bed preparation

Land was ploughed before the onset of rains and sub divided into 36 experimental units. The size of each unit was 4 m by 3 m surrounded by 1 m wide path. The total area needed for the study was therefore 0.23 ha. Soil samples were obtained before planting and after harvesting. Two composite soil samples (0-15 cm and 15-30 cm) were taken in grid style before planting. Further, soil samples (0-15 cm) were taken at harvesting in grid style in each experimental unit. The samples were collected in clearly labelled "khaki" bags and stored in the greenhouse for 14 days for air drying before they were analysed. The samples obtained at planting were analysed for pH, available phosphorus, total nitrogen, total organic carbon, exchangeable acidity (Lari only), potassium (K), calcium (Ca), magnesium (Mg), copper (Cu), iron (Fe), zinc (Zn) and sodium (Na) according to Mehlich 3 procedures (Harova & Spejra, 2014). Further, soil samples taken at planting and harvesting were also analysed for available phosphorus using Bray 2 procedures as outlined by Okalebo *et al.*, 2002.

Planting

The seed used for planting was good quality seed obtained from two seed multipliers; ADC Molo and Mrs Lydia Chepkoril Marindichi of Ainabkoi. The size of the seed used was large grade (45 to 60 mm diameter). Potato seed was planted at a spacing of 75 cm between rows and 25 cm within rows. Planting was done at the onset of long rains in three sites where fertilizers were mixed well with the soil to avoid scorching the seed. Well sprouted seed tubers were then placed in the furrow and covered with soil immediately. Fertilizer rates were applied according to the treatment plan (Plate 1 and Table 1).

A

B

Plate 1: Planting potatoes at A-Ainabkoi, B-Lari

Ridging, weeding, diseases and pests management

Ridging or "earthing up" was done at 30 to 45 days after planting. Weeding was done concurrently with ridging. To maintain quality tubers, undesirable plants like those infected by seed borne diseases and off types or volunteers were roughed out. Tools and protective gear used in seed crop were only used at the seed crop in a particular plot and not in other plots. Fungicides and pesticides were applied according to need to control diseases and pests.

“Dehaulming”, harvesting and post-harvest handling

The potato seed crops were monitored for tuber sizes to avoid them becoming too big for seed. When the tops started to turn yellow (physiological maturity) and 60 to 70 % of the tubers were in the seed size grade (28 mm to 60 mm), the above ground biomass was cut (“dehaulmed”) and left for two weeks for tuber skin to harden before harvesting.

Harvesting was done in the morning and late in the afternoon when temperatures were warm and soils were moist but not wet to minimise scorching of tubers caused by the bright sunlight (Plate 2). The harvest of the two end rows and the last two plants per row were separated from the rest of the plants before storage since they were not used in data analysis. Potato seeds were stored at ambient temperatures in a storage shed (MOA, 2011)

Sorting and grading of potato seed

Since there were few damaged and diseased potatoes, sorting was minimally done. Grading was done using three callibated boxes with circular holes cut at their bases (Plate 2). The circular holes at the bases were of diameters 28 mm, 45 mm and 60 mm. The boxes were used to grade potato tubers in four categories starting with charts (diameter < 28 mm), small grade (diameter from 28 mm to 45 mm), large garde (diameter from 46 mm to 60 mm) and ending up with “ware” potato tubers (diameter > 60 mm) (Table 2). Charts’ potato tubers passed through all the grading boxes, small grade potato tubers passed through 45 mm and 60 mm diameter grading boxes, large grade potato tubers passed through 60 mm diameter grading box only and the remaining (“ware” potato tubers) could not pass through any of the grading boxes. The number and the weight of the sample potato tubers per plot were measured using an electronic balance and recorded in a field note book.

Further, sample potato seed from test sites (two per plot) were chopped into small pieces and air dried in the greenhouse for the determination of plant tuber phosphorus.

Table 2: Grading of the potato seed

Diameter size of tuber	Grade	Remarks
< 28 mm	Chatts	Very small potatoes not fit for seed as they rot
28 – 45 mm	1	Small size grade
46 – 60 mm	2	Large size grade
> 60mm	"Ware" potato	Recommended for human consumption

A B C

Plate 2: Harvesting of potato seed. A-Ainabkoi, B- Saboti, C- Lari

Crop data on quantity

Crop data on quantity determined was yield per hectare (t ha^{-1}) and number of tubers per hectare (tubers ha^{-1}). Potato quantities under the following classes; < 28 mm, 28 - 45 mm, 46 - 60 mm and > 60 mm were determined using equation 1 & 2. The classes were based on KEPHIS (2016) guidelines.

Yield per hectare (t ha^{-1}): The yield per hectate (G_1) was determined using the formula in equation 3 below

$G_1 = \frac{10000}{0.25x\ 0.75x\ 1000}$ x Y_1--Equation 3

Where:

G_1= Yield in tonnes per hectare

Y_1= Average yield of sampled plants = Weight (kg) of sampled plants/Number of plants sampled (18 plants excluding quard row plants and 2 plants at the end of every raw).

Number of potato seed tubers:

The number of seed per each of the following categories was counted: < 28mm, 28-35 mm, 36 - 45 mm, 46 - 60 mm and > 60 mm as described in section 3.1.2 (KEPHIS, 2016). Number of potato seed tubers per hectare (G_2) was determined using the formula in equation 4 below

$G_2 = \frac{10000}{Sample\ area}$ x Y_2 ……………………………………………………….Equation 4

Y_2 = Number of potato seed per sample area (18/53333 x 10000 = 3.375 m^2).

3.1.2: Determination of potato seed quality

Seed used

Harvested seed was used to access the influence of phosphorus fertilizer on quality of potato seed.

Drying and curing of seed

The harvested potatoes were dried quickly to remove excess water from the surface and improve their tuber keeping quality. The tubers were dried in a storage shed to avoid tuber greening. They were also sheltered from rain and water runoff.

Data on seed quality

The following data on seed quality was collected:

Final germination percentage

This was done by counting the number of bushes planted and survived up to harvesting; dividing the same with the total number of tubers planted and multiplying the result with 100. A bush is a collection of all plants growing from a planted potato tuber. This percentage was a measure of how many potato tubers were planted, germinated and survived to produce tubers at harvest time. Final germination percentage was determined using the formula (Equation 5):

$$\% G = \frac{\text{Number of planted and survived bushes}}{Total\ number\ of\ tubers\ planted} \times 100\% \quad \text{……………………………..Equation 5}$$

Where % G = Final germination percentage

Number of eyes: Number of eyes per seed tuber was also counted as a measure of seed quality. The number of eyes for five sample large size potatoes were counted and divided by five to get the average number of eyes per potato. The desirable number of eyes per tuber is 4 to 6 eyes (KEPHIS, 2016).

Weight: Weight per each category of the tuber sizes described above was measured in air (Wa) and when immersed in water (Ww) according to Agriculture Victoria (2010).

Seed specific gravity: Seed specific gravity of each category was calculated according to equation 6

Specific gravity (g g^{-1}) = $\frac{Wa}{Wa-Ww}$ …………………………………………..Equation 6

(Source: Edgar, 1951; Agriculture Victoria, 2010; Turburt & Smith, 1959; Norgia *et al.,* 2008)

3.1.3 Laboratory analysis

Laboratory analysis for soil samples before planting was done at National Agricultural Research Laboratories (NARL) using the Mehlich 3 protocol (Harova & Spejira 2014). Mehlich 3 protocol estimated plant available micro- and macro-nutrients on soils. During the extraction, phosphorus is solubilized by several different mechanisms: (1) Nitric and acetic acid increases the solubility of iron (Fe) and aluminium (Al) - phosphates and extracts a portion of calcium phosphates if present. (2) Acetic acid buffers the solution below pH 2.9 to prevent calcium fluoride from precipitating. (3) Fluorine (Fl) will complex aluminium ions (Al^{2+}) that potentially bind with phosphorus. (4) Ammonium ions (NH_4^+) exchanges with potassium, calcium and magnesium and ethylenediaminetetraacetic acid (EDTA) chelates iron, manganese, zinc, and copper. Phosphorus and cations can be determined by inductively coupled plasma atomic emission spectroscopy (ICP-AES) instrumentation simultaneously. Phosphorus content in solution can also be determined spectrophotometrically at an acidity of 0.20 M H_2SO_4 (Rodriguez *et al.,* 1994) by reacting with ammonium molybdate using ascorbic acid as a reactant in the presence of antimony (Murphy & Riley, 1962; Harova & Spejira (2014).

Soil analysis at both planting and harvesting for available phosphorus was done using Bray 2 method as outlined in Okalebo *et al.* (2002). Soil samples were dried in the greenhouse for two weeks then sieved through a 2 mm sieve. 2.5 g of each sample was placed in a plastic bottle to which Bray 2 extracting solution was added and contents shaken for 5 minutes. Whatman 5 folded papers were used to get a clear filtrate. The

Bray 2 extracting solution was a solution of 0.03 M ammonium fluoride and 0.1 M hydrochloric acid. Standard solutions were made from monobasic potassium hydrogen sulphate solution. Blue colour development was done by using 0.8 M boric acid and ascorbic acid. The intensity of the blue colour which correlates with the concentration of phosphorus in the sample solution was a measure of concentration of phosphorus. To determine intensity of the blue colour, standard phosphorus solutions, soil sample solutions and blanks were placed in a calorimeter and light absorbance determined at 880 nm wavelengths. A calibration graph of standard solutions was drawn. The same graph was used to determine concentration of phosphorus in the sample solutions and the blanks. Available phosphorus solution was determined using equation 7:

$$\mathrm{P\ (ppm)} = \frac{(a-b) \times v \times f \times 1000}{1000 \times w}$$ ……………….Equation 7 (Source: Okalebo *et al.,* 2002)

Where a = concentration of P mg l^{-1} in extract solution, b = concentration of P mg l^{-1} in the blank sample, v = extract volume, w = weight of the air dried sample and f = additional dilution factor (optional).

Total phosphorus in potato tubers was determined by sampling two best potatoes from each experimental plot, slicing and drying them in the greenhouse for three weeks. Thereafter, the samples were crashed using pestle and mortar then sieved through 0.25 mm mesh. Thereafter 0.3 g of each sample was weighed and placed in a boiling tube, to which 2.5 ml of digestion mixture (hydrogen peroxide + concentrated sulphuric acid + selenium powder + salicylic acid) was added. The contents were digested at 110 °C then at 330 °C until a clear solution was obtained. To the clear solution, standard phosphorus solutions and blanks, ascorbic acid was added to prepare the blue colour for calorimetric determination of total phosphorus at 880 nm wavelength. Using absorbance against standard phosphorus concentration curve, the concentration of total phosphorus in the tubers was determined. Tuber plant phosphorus was determined using equation 8:

$$P\ (\%) = \frac{c \times v \times f \times 1000}{w}$$ ………………Equation 8 (Source: Okalebo *et al.,* 2002)

Where c = the corrected concentration of P in the sample; v = volume of the digest; f = dilution factor; w = weight of the sample.

3.2 Determination of potato phosphorus use efficiency

The potato phosphorus use efficiency determined was agronomic (external), (equation 9).

$$PUE = \frac{Average\ sample\ \ tuber\ weight\ in\ treatment(kg) - Average\ tuber\ weight\ in\ the\ control)}{Phosphorus\ \ applied(kg)}$$ ...Equation 9

(Source: Fageria *et al.,* 1997 & Ekelof, 2014)

3.3 Data analysis

All data was subjected to analysis of variance (ANOVA) using GENSTAT software at 5% confidence level. GENSTAT and excel softwares were used to determine Pearson correlation coefficiency between yield and each of the following variables of harvested seed tubers: number, specific gravity, final percentage germination, number of eyes tuber^{-1}, soil available phosphorus, plant (tuber) phopshorus and phoshorus use efficiency.

3.3.1 Experimental design and model

The experimental design was a split plot arrangement in Randomised Complete Block (RCBD). The main plot treatments were potato varieties while the sub plot treatments were phosphorus rates. All treatments were replicated three times.

The linear statistical model for the split-plot design is (Equation 10):

$Y_{ijk} = \mu + V_i + B_j + \varepsilon_{1(ij)} + P_{(k)} + VP_{ik} + \varepsilon_{2ijk}$……………………………...Equation 10

Where: Y_{ijk} = Total effect

μ = Mean effect.

V_i = The i^{th} effect of variety (V) (Main plot)

B_j = The j^{th} effect of blocks

$\varepsilon_1(ij)$ = Main plot error.

$P_{(k)}$ = The k^{th} effect of P (Sub plot)

VP_{ik} = Effect due to interaction between variety (V) and P

$\varepsilon_2(ijk)$ =Split plot Error.

i= 1……..m j= 1…………b k= 1………t $\varepsilon_{1(ij)} = N(0, \alpha_M)$ $\varepsilon_{2ijk} = N(0, \alpha_I)$

3.3.2 The skeletal analysis of variance table

Each of the three sites was divided into three blocks (replicates), each block was divided into two main or whole plots and each whole plots was divided into six sub plots. Each whole plot was planted with two potato seed test varieties (Shangi and Unica) at random. Each variety was planted in six sub plots. Each sub plot was treated with its own phosphorus rate at random. Nitrogen was applied as a basal nutrient at the rate of 90 kg ha^{-1} while the plot with 0 kg ha^{-1} phosphorus was the normal control plot. There was provision for Absolute control (AC) plots (Table 3).

Table 3: Skeletal analysis of variance (ANOVA) table

SOV	**df**	**SS**	**MS**	**Fcal**	**p-value**
Blocks or replications (B)	b-1 = 2	B_{SS}	B_{MS}	$B_{SS}/E_{MS(a)}$	By GENSTAT
Main plots : Varieties (V)	v-1 = 1	V_{SS}	V_{MS}	$V_{SS}/E_{MS(a)}$	By GENSTAT
Main plot Error (V x B) or Error (a)	(b-1) (v-1) = 2	$E_{SS(a)}$	$E_{MS(a)}$		
Sub-plots: P rates	p-1 = 5	P_{SS}	P_{MS}	$P_{SS}/E_{MS(b)}$	By GENSTAT
V x P-rates	(v-1) (p-1) = 5	VP_{SS}	VP_{MS}	$VP_{SS}/E_{MS(b)}$	By GENSTAT
Sub plot error V(P x B) or Error (b)	v(p-1)(b-1)= 20	$E_{SS(b)}$	$E_{MS(b)}$		
Total	bvp-1=35	T_{SS}	T_{MS}		

F cal > F table => Significance or p value < 0.05 => significance because it shows that the chances that the null hypothesis (no significant difference between the source of variation) is less than 0.05 implying that there is a significant difference between the sources of variation. To determine which means were significantly different from others, error bars were used.

CHAPTER FOUR

RESULTS

4.1 Soil characteristics of test sites prior to treatment applications

The chemical characterization of the top 0-15 cm soils from the three test sites at planting showed that they were acidic. Lari with a pH level of 4.6 was strongly acidic while Saboti and Ainabkoi with pH levels of 5.8 and 5.6, respectively were moderately acidic. The available soil phosphorus levels were low at Lari, adequate at Ainabkoi and high at Saboti. In all the three test sites, potassium level was adequate. Saboti and Ainabkoi had low soil zinc level while Lari had adequate soil zinc levels. In all the test sites total nitrogen was adequate except in 15-30 cm depth of Ainabkoi where it was low. As much as total organic carbon was adequate in Saboti and Lari, it was moderate in Ainabkoi (Table 4, Appendix XLVIII).

Table 4: Chemical properties of the surface soils (0-15 cm and 15 - 30 cm) before planting

Soil property	**Critical value**	**Saboti**		**Ainabkoi**		**Lari**	
Depth of soil sample (cm)	N/A	0-15	15-30	0-15	15-30	0-15	15-30
Soil pH (1: 2.5 Soil: Water)	≥ 5.5	5.83	5.67	5.62	5.59	**4.6**	**4.83**
Exchangeable acidity (me %)						0.4	0.4
Total nitrogen (%)	≥ 0.2	0.34	0.30	0.24	**0.18**	0.25	0.24
Total Organic carbon (%)	≥ 2.7	3.55	3.13	**2.54**	**2.01**	**2.7**	**2.51**
Phosphorus (ppm)	≥ 30	45	45	40	35	**25**	**30**
Potassium (me %)	≥ 0.24	1.00	0.41	2.03	2.03	0.71	0.69
Calcium (me %)	≥ 2.0	26.0	26.8	14.2	10.2	**1.4**	**1.2**
Magnesium (me %)	≥ 1.0	4.06	5.10	4.04	3.56	**0.79**	**0.82**
Manganese (me %)	≥ 1.0	**0.96**	**0.62**	**0.64**	**0.67**	**0.48**	**0.36**
Copper (ppm)	≥ 1.0	9.83	9.71	2.50	2.15	2.4	2.1
Iron (ppm)	≥ 10	16.1	17.2	16.2	17.8	220	224
Zinc (ppm)	≥ 5	**2.46**	**1.40**	**4.31**	**3.84**	8.58	5.29
Sodium (me %)	N/A	0.50	0.54	0.50	0.48	0.62	0.86
Soil colour	N/A	Dark brown	Dark reddish brown	Dark brown	Reddish brown	Grey	Greyish brown
Soil type	N/A	Nitisol		Nitisol		Planosol	

Source of the critical values: NAIAAP (2014). Bolded figures indicte low soil property status

me= milliequivalent. The values given are averages.

The soils of Saboti and Ainabkoi were deep and dark brown in colour. However, the soils at Ainabkoi were deep and less dark in colour when compared to those of Saboti. Further, the ground in both sites had a slope of between 10 to 15 %. The vegetation on these soils included maize, potatoes, beans, scattered shrubs and trees. Lari soils were greyish brown in colour and were on a gentle plateau. The soil profile showed that, there was abrupt colour change from greyish brown to reddish brown. Water logging was evident as drainage channels were established in every farm, the water table was high (about 3 m) and there was an underlying hard pan. Indications of phosphorus deficiency were noted as the colour of young maize crops planted in the area was purple.The stickness of the soil increased with soil depth.

4.2 Influence of phosphorus rate on soil available phosphorus and potato plant tuber phosphorus

4.2.1 Influence of phopshorus rate application on soil available phosphorus at harvesting

In Saboti varieties did not significantly influence soil available phosphorus ($p = 0.137$). The mean soil available phosphorus at harvesting in the Shangi’s and Unica’s main plots were 60.0 ppm and 70.0 ppm Bray 2 phosphorus, respectively. Interaction between phosphorus rate and variety significantly ($p = 0.046$) influenced soil available phosphorus. The highest soil available phosphorus at harvesting in Shangi’s (61.7 ppm Bray 2 phosphorus) and Unica’s (103.3 ppm Bray 2 phosphorus) plots were realised at phosphorus application rate of 30 and 120 phosphorus ha^{-1}, respectively. In general, phosphorus rate significantly ($p = 0.007$) influenced the soil available phosphorus at harvesting resulting in highest soil available phosphorus (82.4 ppm Bray 2 phosphorus) being attained at phosphorus rate of 120 phosphorus ha^{-1} (Table 5 & Appendix I).

In Ainabkoi varieties did not significantly (p = 0.187) influence soil available phosphorus at harvesting. The mean soil available phosphorus at harvesting in Shangi's and Unica's main plots were 65.0 ppm and 44.6 ppm Bray 2 phosphorus, respectively. Interaction between phosphorus and variety did not significantly (p= 0.103) influence the soil available phosphorus. The highest soil available phosphorus at harvesting in the Shangi's (91.8 ppm Bray 2 phosphorus) and Unica's (92.2 ppm Bray 2 phosphorus) plots were realised at phosphorus application rate of 60 and 90 phosphorus ha^{-1}, respectively. In general, phosphorus rate significantly (p =0.02) influenced the soil available phosphorus at harvesting resulting in highest soil available phosphorus (76.0 ppm Bray 2 phosphorus) being attained at phosphorus rate of 60 phosphorus ha^{-1} (Table 5, Appendix II and Appendix LV).

In Lari, varieties did not significantly (p = 0.558) influence soil available phosphorus at harvesting. The mean soil available phosphorus in Shangi's and Unica's main plots was 31.0 ppm and 27.5 ppm Bray 2 phosphorus, respectively. Interaction between phosphorus and variety significantly (p = 0.002) influenced soil available phosphorus. The highest soil available phosphorus at harvesting in Shangi's (46.7 ppm Bray 2 phosphorus) and Unica (54.2 ppm Bray 2 phosphorus) plots were realised at phosphorus application rate of 60 and 0 phosphorus ha^{-1}, respectively. In general, phosphorus rate significantly (p = 0.031) influenced the soil available phosphorus at harvesting resulting in highest soil available phosphorus (36.2 ppm Bray 2 phosphorus) being attained without phosphorus application (0 P) (Table 5, Appendix III and Appendix LV).

Table 5: Influence of phopshorus rate on soil available phosphorus at harvesting

Phosphorus rate (kg ha^{-1})	**Mean variety available phosphorus (ppm) at harvesting**								
	Saboti			**Ainabkoi**			**Lari**		
	Shangi	**Unica**	**Mean**	**Shangi**	**Unica**	**Mean**	**Shangi**	**Unica**	**Mean**
AC	52.8	56.6	**54.7**	30.3	26.4	**28.3**	25.0	19.8	**22.4**
0	52.4	54.5	**53.5**	29.4	54.8	**42.1**	18.2	54.2	**36.2**
30	61.7	72.4	**67.0**	30.0	24.5	**27.3**	24.9	19.8	**22.3**
60	66.2	57.1	**61.6**	91.8	60.2	**76.0**	46.7	20.6	**33.6**
90	65.7	76.1	**70.9**	40.5	92.8	**66.7**	21.5	21.0	**21.3**
120	61.5	103.3	**82.4**	45.4	101.1	**73.2**	49.4	29.5	**39.5**
Mean	**60.0**	**70.0**	**65.0**	**44.6**	**60.0**	**52.3**	**31.0**	**27.5**	**29.2**
	LSD$_{p=0.05}$ Variety =17.8 Phosphorus rate =15.2 Variety * Phosphorus rate =21.3			**LSD $_{p=0.05}$** Variety = 33.5 Phosphorus rate =35.3 Variety * Phosphorus rate =48.1			**LSD $_{p=0.05}$** Variety =21.5 Phosphorus rate =13.6 Variety * Phosphorus rate =20.7		
CV %	19.4 %			56.1 %			27.0 %		

At Saboti, correlation between phosphorus rate and soil available phosphorus at harvesting in Shangi's experimental units (plots) was positive (r = +0.7). Correlation between phosphorus rate and soil available phosphorus in Unica's plots was also positive (r = +0.8). In general, correlation between phosphorus rate and soil available phosphorus at harvesting was positive (+0.9). At Ainabkoi, correlation between phosphorus rate and soil available phosphorus at harvesting in Shangi's experimental units (plots) was positive (r = +0.4). Correlation between phosphorus rate and soil available phosphorus in Unica's plots was also positive (r = +0.9). In general, correlation between phosphorus rate and soil available phosphorus at harvesting was positive (+0.8). At Lari, correlation between phosphorus rate and soil available Phosphorus at harvesting in Shangi's experimental units (plots) was positive (r = +0.6). Correlation between phosphorus rate and soil available phosphorus in Unica's plots was negative (r = -0.3). In general, correlation between phosphorus rate and soil available phosphorus at harvesting was positive (r = +0.3). The soil available phosphorus at planting at Saboti, Ainabkoi and Lari were 57.7, 43.0 and 20.4 ppm Bray 2 phosphorus, respectively (Table 5 & Appendix LXII).

4.2.2 Influence of phosphorus rate on potato plant (tuber) phosphorus

In Saboti varieties did not significantly (p = 0.502) influence potato plant tuber phosphorus at harvesting. The mean potato plant tuber phosphorus in the Shangi's and Unica's main plots were 0.88 % and 0.87 %, respectively. Interaction between phosphorus rate and variety significantly (p = 0.005) influenced potato plant tuber phosphorus. The highest soil available phosphorus at harvesting in Shangi's (0.93 %) and Unica's (1.08 %) plots were realised at phosphorus application rate of 0 and 90 phosphorus ha^{-1}. In general, phosphorus rate significantly (p = 0.004) influenced plant tuber phosphorus at harvesting resulting in highest potato plant tuber phosphorus

(1.02%) being realised at phosphorus rate of 120 phosphorus ha^{-1} (Table 6, Appendix VI and Appendix LVI).

In Ainabkoi, varieties did not significantly (p = 0.561) influence potato plant tuber phosphorus at harvesting. The potato plant tuber phosphorus in Shangi's and Unica's main plots was 0.59 % and 0.57 %, respectively. Interaction between phosphorus rate and variety significantly (p= 0.010) influenced potato plant tuber phosphorus. The highest potato plant tuber phosphorus at harvesting in Shangi's (0.67 %) and Unica's (0.62 %) plots were both realised without phosphorus application (0 P). In general, phosphorus rate also significantly (p = 0.004) influenced potato plant tuber phosphorus at harvesting resulting in highest potato plant tuber phosphorus (0.65 %) being realised without phosphorus application (0 P) (Table 6, Appendix V and Appendix LVI).

In Lari, varieties did not significantly (p = 0.909) influence potato plant tuber phosphorus at harvesting. The plant tuber phosphorus at harvesting in the Shangi's and Unica's main plots were 0.50 % and 0.49 %, respectively. Interaction between phosphorus and variety did not significantly (p= 0.087) influence plant tuber phosphorus. Highest plant tuber phosphorus at harvesting in Shangi's (0.48 %) and Unica's (0.53 %) plots were both realised without phosphorus application (0 P). In general, phosphorus rate also significantly (p = 0.007) influenced potato plant tuber phosphorus at harvesting resulting in highest potato plant tuber phosphorus (0.57 %) being realised at phosphorus rate of 60 kg phosphorus ha^{-1} (Table 6, Appendix VI and Appendix LVI).

Table 6: Influence of phosphorus rate on potato plant (tuber) phosphorus

Phosphorus rate (kg ha^{-1})	**Mean potato plant tuber phosphorus (%) at harvesting**								
	Saboti			**Ainabkoi**			**Lari**		
	Shangi	**Unica**	Mean	Shangi	Unica	Mean	Shangi	Unica	Mean
AC	0.81	0.81	**0.81**	0.47	0.54	**0.50**	0.56	0.45	**0.5**
0	0.93	0.77	**0.85**	0.67	0.62	**0.65**	0.48	0.53	**0.51**
30	0.80	0.91	**0.86**	0.50	0.58	**0.54**	0.61	0.47	**0.54**
60	**0.91**	0.88	**0.90**	0.77	0.55	**0.66**	0.54	0.61	**0.57**
90	0.96	1.08	**1.02**	0.48	0.56	**0.52**	0.42	0.47	**0.44**
120	0.89	**0.77**	**0.83**	0.66	0.55	**0.61**	0.36	0.42	**0.39**
Mean	**0.88**	**0.88**	**0.89**	**0.59**	**0.57**	**0.58**	**0.50**	**0.49**	**0.49**
	LSD$_{p=0.05}$ Variety =0.08 Phosphorus rate =0.08 Variety * Phosphorus rate =0.11			**LSD $_{p=0.05}$** Variety = 0.15 Phosphorus rate =0.09 Variety * Phosphorus rate =0.14			**LSD $_{p=0.05}$** Variety =0.17 Phosphorus rate =0.09 Variety * Phosphorus rate =0.15		
CV %	7.3 %			12.7 %			15.6 %		

At Saboti, correlation between phosphorus rate and plant tuber phosphorus at harvesting in Shangi's and Unica's experimental units (plots) were + 0.4 and + 0.3, respectively. In general, correlation between phosphorus rate and potato plant tuber phosphorus at harvesting was positive (r = +0.4). At Ainabkoi, correlation between phosphorus rate and potato plant tuber phosphorus at harvesting in Shangi's and Unica's experimental units (plots) were + 0.2 and - 0.4, respectively. Generally, correlation between phosphorus rate and potato plant tuber phosphorus at harvesting was positive (r = + 0.1). At Lari, correlation between phosphorus rate and potato plant tuber phosphorus at harvesting in Shangi's and Unica's experimental units (plots) were - 0.7 and - 0.2, respectively. In general, correlation between phosphorus rate and potato plant tuber phosphorus at harvesting was negative (r = - 0.7) (Table 6 & Appendix LXIII).

4.3 Influence of phosphorus on potato seed quantity

4.3.1 Influence of phosphorus on overall potato seed quantity

Influence of phosphorus on overall yield of potato seed at Saboti

The results indicate that there is significant difference (p = 0.045) between the overall seed yield of Shangi and Unica. Phosphorus rate significantly and negatively (p < 0.001; r = - 0.6) influenced the overall potato seed yield. Interaction between phosphorus rate and variety also significantly (p < 0.001) and inversely influenced Shangi's (r = -0.2) and Unica's (r = -0.6) overall potato seed yield. This resulted in the highest yield (33.7 t ha^{-1}) for Shangi being produced with Absolute control treatments while that of Unica (33.3 t ha^{-1}) being produced without phosphorus fertilizer (0 P) (Table 7, Appendix VII and Appendix LVII).

Table 7: Influence of phosphorus on yield (t ha^{-1}) of overall potato seed at Saboti

Phosphorus rate (kg ha^{-1})	Mean variety yield in t ha^{-1}		Mean phosphorus rate yield in t ha^{-1}
	Shangi	**Unica**	
AC	33.7	12.4	**23.1**
0	18.3	33.3	**25.8**
30	11.9	10.9	**11.4**
60	26.4	9.3	**17.9**
90	24.6	12.9	**18.8**
120	18.7	7.5	**13.1**
Mean	**22.3**	**14.4**	**18.3**
	LSD$_{P=0.05}$	**CV (%)**	
Variety	=7.40	21.3	
Phosphorus rate	=4.70		
Variety * Phosphorus rate	=7.15		

Further, results show that interaction between phosphorus and variety significantly influenced the “ware” yield of the test varieties. Also, there was a positive correlation between phosphorus rate and “ware” tuber yields of Shangi (r = +0.6) and Unica (r = +0.7) (Appendix XXXVII & Appendix LXIV).

Influence of phosphorus on overall yield (t ha^{-1}) of potato seed at Ainabkoi

The results indicate that variety (p = 0.402) and phosphorus (p = 0.119) had no significant influence on the yield of potato seed in Ainabkoi. However, interaction between phosphorus and variety significantly (p= 0.026) influenced the yield of potato seed. The highest yield of Shangi (20.0 t ha^{-1}) was attained with 60 kg ha^{-1} phosphorus while Unica’s highest yield (18.9 t ha^{-1}) was achieved with phosphorus rate of 30 kg ha^{-1} (Table 8, Appendix VIII and Appendix LVII).

Table 8: Means of yield (t ha^{-1}) of overall potato seed at Ainabkoi

Phosphorus rate (kg ha^{-1})	Mean variety yield in t ha^{-1}		Mean phosphorus rate yield in t ha^{-1}
	Shangi	**Unica**	
AC	12.9	12.7	**12.8**
0	16.3	15.6	**16.0**
30	13.2	18.9	**16.1**
60	20.0	8.9	**14.5**
90	18.1	19.7	**18.9**
120	18.3	17.2	**17.7**
Mean	**16.5**	**15.5**	**16.0**
	$LSD_{P=0.05}$	**CV (%)**	
Variety	=4.1	23.5%	
Phosphorus rate	=4.5		
Variety * Phosphorus rate	=6.1		

Further, results indicate that correlation between phosphorus rate and mean tuber yield was positive (r = +0.7). Also, correlation between phosphorus rate and tuber yield of Shangi (r= + 0.7) and Unica (r = + 0.3) was positive (Appendix LXIV).

Influence of phosphorus on overall yield (t ha^{-1}) of potato seed at Lari

The results show that there was significant difference (p = 0.010) between the mean potato seed yields of Shangi (15.1 t ha^{-1}) and Unica (7.6 t ha^{-1}). Phosphorus rate significantly ($p < 0.001$) influenced overall potato seed yield. Interaction between phosphorus rate and variety significantly (p = 0.004) influenced overall potato seed yield. The highest yield of Shangi and Unica were 19.0 t ha^{-1} and 10.4 t ha^{-1}, respectively.These yields were realised at phosphorus rates of 60 kg ha^{-1} and 90 kg ha^{-1}, respectively (Table 9 , Appendix IX and Appendix LVII).

Table 9: Means of the yield (t ha^{-1}) of overall potato seed at Lari

Phosphorus rate (kg ha^{-1})	Mean variety yield in t ha^{-1}		Mean phosphorus rate yield in t ha^{-1}
	Shangi	**Unica**	
AC	5.0	7.0	**6.0**
0	10.9	6.0	**8.4**
30	15.2	7.0	**11.1**
60	19.0	8.5	**13.8**
90	20.1	10.4	**15.3**
120	20.6	6.5	**13.5**
Mean	**15.1**	**7.6**	**11.4**
	$LSD_{P=0.05}$	**CV (%)**	
Variety	= 3.2	27.0	
Phosphorus rate	= 3.7		
Variety * Phosphorus rate	= 5.0		

Results also show that correlation between phosphorus rate and mean potato seed yield was positive (r = +0.9). Also, correlation between phosphorus rate and mean yield of Shangi (r = +0.9) and Unica (r = +0.4) was positive (Appendix LXIV).

Influence of phosphorus on overall tuber number (tubers ha^{-1}) of potato seed at Saboti

The results indicate that phosphorus rate, variety and interaction between phosphorus rate and variety had significant ($p < 0.05$) influence on number of potato seed tubers produced from Saboti test site. The highest numbers of tubers (469627 tubers ha^{-1}) for Shangi variety were produced at phosphorus rate of 60 kg ha^{-1} while that of Unica variety (414812 tubers ha^{-1}) were produced in the Absolute control treatments (Table 10 , Appendix X and Appendix LXXIV).

Table 10: Means of the number of overall potato seed tubers (tubers ha^{-1}) at Saboti

Treatments	**Mean variety tuber number ha^{-1}**		**Mean phosphorus rate tuber number ha^{-1}**
Phosphorus rate (kg ha^{-1})	**Shangi**	**Unica**	
AC	395553	414812	**405183**
0	391109	401476	**396294**
30	362467	220739	**291603**
60	469627	174814	**322220**
90	325924	202962	**264443**
120	502219	211851	**357035**
Mean	**407816**	**271109**	**339463**
	LSD$_{P=0.05}$	**CV (%)**	
Variety	=94904	21.7	
Phosphorus rate	=88858		
Variety * Phosphorus rate	=123075		

Correlation between phosphorus rate and its mean tuber number was negative (r = -0.5). Also, correlation between phosphorus rate and mean tuber number of Shangi was positive (r = +0.4) while correlation between the same rate and mean tuber number of Unica was negative (r = -0.8). However, there was a positive correlation between phosphorus rate and “ware” tuber numbers of Shangi (r = +0.5) and Unica (r = +0.4) (Appendix LXXI).

Influence of phosphorus on overall tuber number (tubers ha^{-1}) of potato seed at Ainabkoi

The results show that phosphorus rate significantly and positively influenced (p = 0.002; r = +0.4) number of potato seed tubers produced in Ainabkoi. Interaction between variety and phosphorus rate had significant and positive influence (p = 0.048) on number of potato seed tubers produced at the same site. The highest tuber numbers of Shangi (402960 tubers ha^{-1}) and Unica (285430 tubers ha^{-1}) varieties were produced in the Absolute controls. There was also significant difference (p = 0.009) between tuber number from the test varieties. The mean production of Shangi was 407, 816 while that of Unica was 271, 109 tubers ha^{-1} (Table 11, Appendix XI, Appendix LXXI and LXXIV)).

Table 11: Means of overall number of potato seed tubers (tubers ha^{-1}) at Ainabkoi

Treatments	**Mean variety tuber number ha^{-1}**		**Mean phosphorus rate tuber number ha^{-1}**
Phosphorus rate kg ha^{-1}	**Shangi**	**Unica**	
AC	402960	285430	**344195**
0	416646	290369	**353507**
30	391701	197777	**294739**
60	441281	235293	**338287**
90	410642	277035	**343838**
120	452696	300862	**376779**
Mean	**419321**	**264461**	**341891**

	$LSD_{P=0.05}$	**CV (%)**
Variety	= 63765	8%
Phosphorus rate	=32853	
Variety * Phosphorus rate	=54688	

Correlation between phosphorus rate and Shangi's tuber numbers was strongly positive (r = +0.7) while correlation between phosphorus rate and Unica's tuber numbers was weekly positive (r = +0.2) (Appendix LXXI).

Influence of phosphorus on overall tuber number ha^{-1} of potato seed at Lari

The results indicate that number of potato seed tubers produced from test varieties were significantly different (p = 0.005). The mean production from Shangi and Unica were 348,349 and 140,900 tubers ha^{-1}, respectively. Phosphorus rate significantly and positively ($p < 0.001$; $r = + 0.8$) influenced number of tubers produced. The interaction between variety and phosphorus rate had significant ($p < 0.001$) and positive influence on number of Shangi ($r = +0.8$) and Unica ($r = +0.5$) potato seed tubers produced. The highest number of Shangi tubers (454812 tubers ha^{-1}) was produced at phosphorus rate of 60 kg ha^{-1} while that of Unica (162962 tubers ha^{-1}) was produced at phosphorus rate of 30 kg ha^{-1} (Table 12, Appendix XII, Appendix LXXI and Appendix LXXIV).

Table 12: Means of overall number of potato seed tubers (tubers ha^{-1}) at Lari

Treatments	**Mean variety tuber number ha^{-1}**		**Mean phosphorus rate tuber number ha^{-1}**
Phosphorus-rate kg ha^{-1}	**Shangi**	**Unica**	
AC	158518	132810	**145664**
0	298996	119999	**209498**
30	348146	162962	**255554**
60	454812	137777	**296294**
90	399998	134814	**267406**
120	429627	157036	**293332**
Mean	**348349**	**140900**	**244624**
	$LSD_{P=0.05}$	**CV (%)**	
Variety	=63943	18%	
Phosphorus rate	=52961		
Variety * Phosphorus rate	=74970		

4.3.2 Influence of phosphorus on small grade tuber quantity of potato seed

Influence of phosphorus on small grade yield (t ha^{-1}) of potato seed at Saboti

The results show that interaction between phosphorus and variety had significant ($p = 0.024$) influence on small grade potato seed yield of Shangi and Unica. Phosphorus also significantly ($p = 0.006$) influenced the yield of both test varieties. However, varieties did not influence the yield. The mean yield of Shangi and Unica were 4.8 t ha^{-1} and 5.0

t ha^{-1}, respectively. The highest yields for both Shangi (11.0 t ha^{-1}) and Unica (9.5 t ha^{-1}) were realised at phosphorus application rate of 60 kg ha^{-1} and without phosphorus application (0 P), respectively. (Table 13, Appendix XIII and Appendix LVIII).

Table 13: Means of small grade yield (t ha^{-1}) of potato seed at Saboti

Phosphorus rate (kg ha^{-1})	Mean variety yield (t ha^{-1})		Mean phosphorus rate yield (t ha^{-1})
	Shangi	**Unica**	
AC	4.2	2.7	**3.5**
0	2.3	9.5	**5.9**
30	3.8	2.5	**3.2**
60	11.0	6.9	**9.0**
90	3.0	3.9	**3.5**
120	4.3	4.2	**4.2**
Mean	**4.8**	**5.0**	**4.9**
	$LSD_{P=0.05}$	**CV (%)**	
Variety	= 5.0	52.8%	
Phosphorus rate	= 3.1		
Variety * Phosphorus rate	= 4.8		

Results further indicate that correlation between phosphorus rate and small grade seed yield of Shangi and that of Unica were + 0.2 and - 0.2, respectively (Appendix LXV).

Influence of phosphorus on small grade yield (t ha^{-1}) of potato seed at Ainabkoi

Results show that varieties had significant ($p = 0.018$) influence on small grade yield. The mean small grade yield of Shangi was 7.1 t ha^{-1} while that of Unica was 4.0 t ha^{-1}. Phosphorus rate and interaction between it and variety had high significant ($p < 0.001$) influence on the yield of potato seed. The highest yield of Shangi (10.1 t ha^{-1}) and Unica (4.6 t ha^{-1}) were achieved at phosphorus application rate of 120 kg ha^{-1} and in Absolute controls (0 N, 0 P), respectively (Table 14, Appendix XIV and Appendix LVIII).

Table 14: Means of small grade yield (t ha^{-1}) of potato seed at Ainabkoi

Phosphorus rate (kg ha^{-1})	Mean variety yield (t ha^{-1})		Mean phosphorus rate yield in (t ha^{-1})
	Shangi	**Unica**	
AC	7.9	4.6	**6.3**
0	6.2	2.4	**4.3**
30	3.4	4.7	**4.1**
60	7.6	3.9	**5.8**
90	7.3	3.9	**5.6**
120	10.1	4.3	**7.2**
Mean	**7.1**	**4.0**	**5.5**

	$LSD_{P=0.05}$	**CV (%)**
Variety	=1.8	17.9
Phosphorus rate	=1.2	
Variety * Phosphorus rate	=1.8	

Correlation between phosphorus rate and small grade yield of Shangi and that of Unica were + 0.6 and +0.3, respectively (Appendix LXV).

Influence of phosphorus on small grade yield (kg ha^{-1}) of potato seed at Lari

Variety, phosphorus rate and their interaction had very high significant ($p < 0.001$) influence on small grade yield of potato seed at Lari. The mean small grade yield of Shangi and Unica varieties were 7.0 t ha^{-1} and 2.5 t ha^{-1}, respectively. The highest yield of both Shangi (10.4 t ha^{-1}) and Unica (3.2 t ha^{-1}) were realised at phosphorus rate of 120 kg ha^{-1} (Table 15, Appendix XV and Appendix LVIII).

Table 15: Means of small grade yield (kg ha^{-1}) of potato seed at Lari

Phosphorus rate (kg ha^{-1})	Mean variety yield (t ha^{-1})		Mean phosphorus rate yield (t ha^{-1})
	Shangi	Unica	
AC	3.0	1.9	**2.5**
0	5.6	2.5	**4.0**
30	7.7	2.7	**5.2**
60	9.2	2.7	**6.0**
90	5.9	2.0	**3.9**
120	10.4	3.2	**6.8**
Mean	**7.0**	**2.5**	**4.7**
	$LSD_{P=0.05}$	**CV (%)**	
Variety	=0.3	22.0%	
Phosphorus rate	=1.3		
Variety * Phosphorus rate	=1.6		

Correlation between phosphorus rate and yield of Shangi and the same rate with yield of Unica were +0.7 and +0.5, respectively (Appendix LXV).

Influence of phosphorus on small grade seed tuber number ha^{-1} at Saboti

Results indicate that variety, phosphorus rate and interaction between phosphorus rate and variety had significant influence ($p < 0.05$) on the number of small grade potato tubers at Saboti test site. The mean number of Shangi (189340 tubers ha^{-1}) was greater than that of Unica (123209 tubers ha^{-1}). The highest number of Shangi (290369 tubers ha^{-1}) and Unica (182221 tubers ha^{-1}) were realised at phosphorus rate of 60 kg ha^{-1} and 0 kg ha^{-1}, respectively (Table 16, Appendix XVI and Appendix LXXV).

Table 16: Means of number of small grade potato tubers (tubers ha^{-1}) at Saboti

Phosphorus rate (kg ha^{-1})	Mean variety tuber number ha^{-1}		Mean phosphorus rate (tuber number ha^{-1})
	Shangi	**Unica**	
AC	189628	137777	**163703**
0	197350	182221	**189875**
30	120740	103703	**112222**
60	290369	81481	**185925**
90	142221	119999	**131110**
120	195554	114073	**154814**
Mean	**189340**	**123209**	**156275**
	$LSD_{p = 0.05}$	**CV (%)**	
Variety	=51765	24.7	
Phosphorus rate	=46553		
Variety * Phosphorus rate	=64903		

Further, results show that correlation between phosphorus rate and Shangi and the same rate with Unica were 0.0 and -0.5, respectively (Appendix LXXII).

Influence of phosphorus on small grade tuber number (tubers ha^{-1}) of potato seed at Ainabkoi

Results indicte that varieties had significant influence (p =0.022) on number of potato seed tubers. The mean number of Shangi was 230472 tubers ha^{-1} while that of Unica was 107897 tubers ha^{-1}. Phosphorus rate (p= 0.103) had no significant influence on the number of tubers peoduced. Interaction between phosphorus rate and variety (p= 0.277) variety had no significant influence on the number of tubers produced. Thus highest yields of both Shangi (272042 tubers ha^{-1}) and Unica (142221 tubers ha^{-1}) were attained in the absolute controls (Table 17, Appendix XVII and Appendix LXXV).

Table 17: Means of small grade potato tuber number (tubers ha^{-1}) at Ainabkoi

Phosphorus rate (kg ha^{-1})	Mean variety tuber number ha^{-1}		Mean tuber number ha^{-1}
	Shangi	**Unica**	
AC	272042	142221	**207137**
0	182221	81742	**131982**
30	193579	134999	**164289**
60	244739	121568	**183154**
90	247281	72592	**159937**
120	242961	94259	**168610**
Mean	**230472**	**107897**	**169185**
	$LSD_{p = 0.05}$	**CV (%)**	
Variety	=79697	25.7	
Phosphorus rate	=50480		
Variety * Phosphorus rate	=76864		

Correlation between phosphorus rate and Shangi and Unica were + 0.3 and -0.5, respectively (Appendix LXXII).

Influence of phosphorus on small grade potato tuber number (tubers ha^{-1}) of potato seed tubers at Lari

The results show that varieties significantly influenced number of small grade potato seed tubers. Further, phosphorus rate had significant influence on the number of small grade seed potatoes. Interaction between phosphorus rate and variety had significant influence on the number of small grade potato seed tubers. The mean tuber number of Shangi was 224995 tubers ha^{-1} while that of Unica was 77448 tubers ha^{-1}. The highest tuber number of Shangi (309, 628 tubers ha^{-1}) was achieved with phosphorus rate of 60 kg ha^{-1} while that of Unica (108, 147 tubers ha^{-1}) was realised with phosphorus rate of 30 kg ha^{-1} (Table 18, Appendix XVIII and Appendix LXXV).

Table 18: Means of small grade potato tuber number (tubers ha^{-1}) at Lari

Phosphorus rate (kg ha^{-1})	Mean variety tuber number ha^{-1}		Mean phosphorus rate tuber number ha^{-1}
	Shangi	**Unica**	
AC	124444	51852	**88148**
0	206970	59259	**133115**
30	217864	108147	**163006**
60	309628	72592	**191110**
90	185184	90864	**138024**
120	305880	81975	**193928**
Mean	**224995**	**77448**	**151222**

	$LSD_{p = 0.05}$	**CV (%)**
Variety	=48996	20.1
Phosphorus rate	=36658	
Variety * Phosphorus rate	=53098	

Results also show that correlation between phosphorus rate and Shangi and Unica were +0.6 and +0.5, respectively (Appendix LXXII).

4.3.3: Influence of phosphorus on large grade tuber quantity of potato seed

Influence of phosphorus on large grade yield (t ha^{-1}) of potato seed at Saboti

From the results, varieties had no significant ($p = 0.106$) influence on large grade yield of potato seed. Mean large grade yield of Shangi and Unica were 12.8 t ha^{-1} and 11.3 t ha^{-1}, respectively. Phosphorus rate had significant influence ($p < 0.001$) on the yield of potato seed. Interaction between phosphorus rate and variety had high significant ($p < 0.001$) influence on the yield of potato seed. The highest yield of Shangi (19.8 t ha^{-1}) was realised in Absolute control treatments while that of Unica (25.3 t ha^{-1}) was realised at without phosphorus fertilizer application (Table 19, Appendix XIX and Appendix LIX).

Table 19: Means of large grade potato yield (t ha^{-1}) at Saboti

Phosphorus rate (kg ha^{-1})	Mean variety yield in t ha^{-1}		Mean phosphorus rate yield in t ha^{-1}
	Shangi	**Unica**	
AC	19.8	9.7	**14.7**
0	17.8	25.3	**21.6**
30	7.4	7.5	**7.5**
60	8.7	13.5	**11.1**
90	8.3	6.3	**7.3**
120	14.9	5.4	**10.1**
Variety mean	**12.8**	**11.3**	**12.0**
	$LSD_{p = 0.05}$	**CV (%)**	
Variety	= 2.4	22.0%	
Phosphorus rate	= 3.2		
Variety * Phosphorus rate	= 4.3		

Results also indicate that correlation between phosphorus rate and yield of Shangi and the same rate with yield of Unica were -0.4 and -0.6, respectively (Appendix LXVI).

Influence of phosphorus on large tuber seed grade yield (t ha^{-1}) at Ainabkoi

Results showed that varieties had significant influence on yield of potato seed. Mean yield of Shangi was 8.1 t ha^{-1} while that of Unica was 13.4 t ha^{-1}. Interaction between phosphorus rate and variety had no significant influence on yield of potato seed. However, phosphorus rate had significant influence on mean yield of both test varieties. The highest yields of Shangi (10.1 t ha^{-1}) and Unica (13.1 t ha^{-1}) were realised at phosphorus rate of 30 and 0 kg ha^{-1}, respectively (Table 20, Appendix XX and Appendix LIX).

Table 20: Means of large grade potato yield (t ha^{-1}) at Ainabkoi

Phosphorus-rate (kg ha^{-1})	Mean variety yield (t ha^{-1})		Mean phosphorus rate yield (t ha^{-1})
	Shangi	**Unica**	
AC	3.2	8.9	**6.0**
0	6.5	13.1	**9.8**
30	10.1	14.2	**12.2**
60	10.4	14.7	**12.5**
90	10.9	14.2	**12.5**
120	7.2	15.4	**11.3**
Variety mean	**8.1**	**13.4**	**10.7**
	LSD$_{p = 0.05}$	**CV (%)**	
Variety	= 2.5	14.7	
Phosphorus rate	= 1.9		
Variety * Phosphorus rate	= 2.7		

Correlation between phosphorus rate and yield of Shangi and the same rate with yield of Unica were +0.5 and +0.7, respectively (Appendix LXVI).

Influence of phosphorus on large grade yield (t ha^{-1}) of potato seed at Lari

From results, variety had significant ($p=0.009$) influence on yield of large grade potato seed. Mean yield of Shangi and Unica varieties were 8.7 t ha^{-1} and 4.9 t ha^{-1}, respectively. Phosphorus rate and interaction between phosphorus rate and variety had very high significant ($p < 0.001$) influence on yield of the potato seed. Highest yield of both Shangi (16.4 t ha^{-1}) and Unica (6.8 t ha^{-1}) potato seed were realised at phosphorus rate of 60 kg ha^{-1} phosphorus (Table 21 , Appendix XXI and Appendix LIX).

Table 21: Means of large grade potato seed yield (t ha^{-1}) at Lari

Phosphorus rate (kg ha^{-1})	Mean variety yield (t ha^{-1})		Mean phosphorus rate yield (t ha^{-1})
	Shangi	**Unica**	
AC	2.0	4.7	**3.4**
0	5.3	3.5	**4.4**
30	7.5	5.1	**6.3**
60	16.4	6.8	**11.6**
90	11.1	4.5	**7.8**
120	10.2	4.9	**7.5**
Variety mean	**8.7**	**4.9**	**6.8**
	$LSD_{p = 0.05}$	**CV (%)**	
Variety	=1.6	22.0%	
Phosphorus rate	=1.9		
Variety * Phosphorus rate	=2.5		

Further, results indicate that correlation between phosphorus rate and yield Shangi and the same rate with yield of Unica were + 0.7 and + 0.3, respectively (Appendix LXVI).

Influence of phosphorus on large grade seed tuber number (tubers ha^{-1}) at Saboti

Results indicate that variety had significant influence on number of large grade tubers produced. Mean yield of Shangi was 22941 tubers ha^{-1} while that of Unica was 142468 tubers ha^{-1}. Phosphorus rate and interaction between it variety had very high significant influence on number of tubers produced. The highest tuber number of both Shangi (293924 tubers ha^{-1}) and Unica (254813 tubers ha^{-1}) were realised in Absolute control treatments (Table 22, Appendix XXII and Appendix LXXVI).

Table 22: Means of large grade potato seed tuber number (tubers ha^{-1}) at Saboti

Phosphorus rate (kg ha^{-1})	Mean variety tuber number ha^{-1}		Mean phosphorus rate tuber number ha^{-1}
	Shangi	**Unica**	
AC	293924	254813	**274369**
0	267653	219258	**243455**
30	194073	106666	**150369**
60	193332	93333	**143332**
90	119999	82962	**101481**
120	286665	219258	**274369**
Variety mean	**225941**	**142468**	**184205**
	LSD$_{p = 0.05}$	**CV (%)**	
Variety	= 36658	9.7	
Phosphorus rate	= 48996		
Variety * Phosphorus rate	= 53098		

Correlation between phosphorus rate and Shangi's and Unica's number of tubers was -0.3 and -0.3, respectively (Appendix LXXIII).

Influence of phosphorus on large grade seed tuber number (tubers ha^{-1}) at Ainabkoi

From results, varieties significantly ($p = 0.048$) influenced tuber number with the mean number of Shangi and Unica being 162963 tubers ha^{-1} and 153150 tubers ha^{-1} , respectively. Further, phosphorus rate and interaction between phosphorus rate and variety highly significantly ($p< 0.001$) influenced tuber number. Highest number from Shangi (238305 tubers ha^{-1}) was realised with 0 phosphorus application (0 P) while that of Unica (223615 tubers ha^{-1}) was realised with phosphorus rate of 60 kg ha^{-1} (Table 23, Appendix XXIII and Appendix LXXVI).

Table 23: Means of large grade potato seed tuber number (tubers ha^{-1}) at Ainabkoi

Phosphorus rate (kg ha^{-1})	Mean variety tuber number ha^{-1}		Mean phosphorus rate tuber number ha^{-1}
	Shangi	Unica	
AC	52390	139723	**96057**
0	238305	75381	**156843**
30	149332	111296	**130314**
60	232591	223615	**228103**
90	163360	183703	**173531**
120	141798	185184	**163491**
Mean	**162963**	**153150**	**158057**
	$LSD_{p = 0.05}$	**CV (%)**	
Variety	= 9582	14.7	
Phosphorus rate	= 27952		
Variety * Phosphorus rate	= 36315		

Correlation between phosphorus rate and tuber number of Shangi and the same rate and tuber number of Unica were +0.1 and +0.7, respectively (Appendix LXXIII).

Influence of phosphorus on large grade seed tuber number (tubers ha^{-1}) at Lari

Results show that varieties significantly ($p = 0.033$) influenced tuber number. Mean tuber number of Shangi and Unica was 130453 tubers ha^{-1} and 67242 tubers ha^{-1}, respectively. Further, phosphorus rate and interaction between phosphorus rate and variety significantly ($p < 0.001$) influenced tuber number. The highest numbers from both Shangi (241916 tubers ha^{-1}) and Unica (91851 tubers ha^{-1}) were realised with phosphorus rate of 60 kg ha^{-1} (Table 24, Appendix XXIV and Appendix LXXVI).

Table 24: Means of large grade potato seed tubers (tubers ha^{-1}) at Lari

Phosphorus rate (kg ha^{-1})	Mean variety tuber number ha^{-1}		Mean phosphorus rate tuber number ha^{-1}
	Shangi	**Unica**	
AC	34074	80000	**57037**
0	92026	40000	**66013**
30	118343	68143	**93246**
60	241916	91851	**166883**
90	147339	71111	**109225**
120	149019	52345	**100682**
Mean	**130453**	**67242**	**98848**
	LSD$_{p = 0.05}$	**CV (%)**	
Variety	= 50659	21.5%	
Phosphorus rate	= 22568		
Variety * Phosphorus rate	= 43024		

The results also show that the correlation between phosphorus rate and Shangi's number of tubers and the same rate with Unica's number of tubers were +0.6 and 0.0, respectively (Appendix LXXIII).

4.4: Influence of phosphorus on potato seed quality

4.4.1: Influence of phosphorus on potato seed tuber specific gravity (g g^{-1}) at Saboti

Results indicate that there was no significant difference ($p = 0.074$) between the specific gravity of Shangi (1.05444) and Unica (1.06111). Phosphorus rate significantly and negatively ($p < 0.001$ and $r = -0.6$) influenced seed specific gravity. Interaction between phosphorus and variety significantly ($p < 0.001$) influenced seed specific gravity. Highest specific gravity for Shangi (1.0600) was realised with phosphorus rate of 0 kg

ha^{-1} while that of Unica (1.0850) was achieved with phosphorus rate of 30 kg ha^{-1} (Table 25 & Appendix XXV).

Table 25: Means of the specific gravity (g g^{-1}) of tuber potato seed at Saboti

Treatments	**Mean variety tuber specific gravity**		**Mean phosphorus rate tuber specific gravity**
Phosphorus rate (kg ha^{-1})	**Shangi**	**Unica**	
AC	1.05667	1.05500	**1.05583**
0	1.06000	1.0650	**1.06500**
30	1.05000	1.08500	**1.06750**
60	1.05000	1.05500	**1.05250**
90	1.05000	1.06000	**1.05550**
120	1.06000	1.04667	**1.05333**
Mean	**1.05444**	**1.06111**	**1.05778**
	$LSD_{p = 0.05}$	**CV (%)**	
Variety	= 0.00828	0.4	
Phosphorus rate	= 0.00568		
Variety * Phosphorus rate	= 0.00842		

From the results, there was also negative correlation between phosphorus rate and specific gravity of Shangi (r = -0.1) and Unica (r = -0.5) (Appendix LXVII).

4.4.2 Influence of phosphorus on potato seed specific gravity (g g^{-1}) at Ainabkoi

Results indicate that there was significant difference (p= 0.014) between specific gravity of Shangi (1.0542) and Unica (1.0447). Phosphorus rate had significant and positive ($p < 0.001$; r = +0.6) influence on seed specific gravity. Interaction between phosphorus rate and variety significantly ($p < 0.001$) influenced seed specific gravity. Highest specific gravity of Shangi (1.0750) and Unica (1.0600) were achieved with phosphorus rate of 120 kg ha^{-1} (Table 26 & Appendix XXVI).

Table 26: Means of the specific gravity (g g^{-1}) of potato seed at Ainabkoi

Treatments	Mean variety tuber Specific Gravity		Mean phosphorus rate tuber specific gravity
Phosphorus rate (kg ha^{-1})	Shangi	Unica	
AC	1.0733	1.0367	**1.0550**
0	1.0400	1.0333	**1.0367**
30	1.0400	1.0550	**1.0475**
60	1.0400	1.0400	**1.0400**
90	1.0567	1.0433	**1.0500**
120	1.0750	1.0600	**1.0675**
Mean	**1.0542**	**1.0447**	**1.0494**
	$LSD_{p = 0.05}$	**CV (%)**	
Variety	= 0.00478	0.6	
Phosphorus rate	= 0.00810		
Variety * Phosphorus rate	= 0.01067		

There was also positive correlation between phosphorus rate and specific gravity of Shangi (r = +0.4) and Unica (r = +0.7) (Appendix LXVII).

4.4.3 Influence of phosphorus on potato seed specific gravity (g g^{-1}) at Lari

Results indicate that there was significant difference (p = 0.010) between the specific gravity of Shangi (1.0862) and Unica (1.0737). Phosphorus rate had no significant influence (p = 0.184) on seed specific gravity. Interaction between phosphorus and variety significantly (p = 0.007) influenced seed specific gravity in Lari. Highest specific gravity of Shangi (1.1018) was realised with phosphorus rate of 120 kg ha^{-1} while that of Unica (1.0880) was realised with phosphorus rate of 60 kg ha^{-1} (Table 27 & Appendix XXVII).

Table 27: Means of the specific gravity (g g^{-1}) of potato seed at Lari

Treatments	**Mean variety tuber specific gravity**		**Mean phosphorus rate tuber specific gravity**
Phosphorus rate (kg ha^{-1})	**Shangi**	**Unica**	
AC	1.0700	1.0850	**1.0775**
0	1.0880	1.0525	**1.0702**
30	1.0950	1.0700	**1.0825**
60	1.0810	1.0880	**1.0845**
90	1.0815	1.0727	**1.0771**
120	1.1018	1.0740	**1.0879**
Variety mean	**1.0862**	**1.0737**	**1.0800**
	$LSD_{p = 0.05}$	**CV (%)**	
Variety	= 0.00545	1.1	
Phosphorus rate	= 0.01433		
Variety * Phosphorus rate	= 0.01865		

There was positive (r = +0.7) correlation between phosphorus rate and its mean specific gravity. There was also positive correlation between phosphorus rate and specific gravity of Shangi (r = +0.5) and Unica (r = +0.2) (Appendix LXVII).

Influence of phosphorus on potato seed no eyes per tuber at Saboti

The results indicate that there was no significant (p = 0.199) difference between the number of eyes per tuber of the test varieties. Further there was no significant (p = 0.117) influence of phosphorus rate on number of eyes per tuber of test potato seed. Interaction between phosphorus and variety significantly (p = 0.045) influenced number of eyes per tuber of potato seed. Potato seed whose number of eyes per tuber (Shangi-7 and Unica-5) was closer to a range of 4- 6 were found in the Absolute control treatments (Table 28 & Appendix XXVIII).

Table 28: Means of the number of eyes tuber^{-1} of potato seed at Saboti

Treatments	Mean variety number of eyes tuber^{-1}		Mean phosphorus rate number of eyes tuber^{-1}
Phosphorus rate (kg ha^{-1})	**Shangi**	**Unica**	
AC	7	5	**6**
0	7	7	**7**
30	7	7	**7**
60	8	7	**7**
90	7	7	**7**
120	7	6	**7**
Mean	**7**	**7**	7
	LSD$_{p = 0.05}$	**CV (%)**	
Variety	= 1	11.2%	
Phosphorus rate	= 1		
Variety * Phosphorus rate	= 1		

Number of eyes in this table have been rounded off to the nearest eye

Correlation between phosphorus rate and mean number of eyes per tuber was positive (r = +0.20). There was also a positive correlation between phosphorus rate and potato number of eyes per tuber of Shangi (r = +0.20) and Unica (r = +0.20) (Appendix LXVIII).

Influence of phosphorus on potato seed no eyes tuber^{-1} at Ainabkoi

From results, interaction between phosphorus rate and variety significantly influenced (p= 0.005) number of eyes per tuber of potato seed. There was significant differences between varieties (p = 0.034) with Shang's and Unica's number of eyes tuber^{-1} being 11 and 9, respectively. Phosphorus rate did not interact significantly with variety (p = 0.191). The potato seed with number of eyes per tuber (Shangi-10 and Unica-7) closer to the 4 - 6 range were found in the Absolute control treatments (Table 29 and Appendix XXIX).

Table 29: Means of the number of eyes tuber^{-1} of potato seed at Ainabkoi (Number of eyes ronded off to the nearest eye)

Treatments	Mean variety number of eyes tuber^{-1}		Mean phosphorus rate number of eyes tuber^{-1}
Phosphorus rate (kg ha^{-1})	**Shangi**	**Unica**	
AC	10	7	**9**
0	12	9	**10**
30	11	9	**10**
60	11	10	**10**
90	10	8	**9**
120	10	9	**9**
Mean	**11**	**9**	**10**
	$LSD_{p = 0.05}$	**CV (%)**	
Variety	= 2	7.4%	
Phosphorus rate	= 1		
Variety * Phosphorus rate	= 2		

From correlation analysis, there was a negative correlation (r = -0.5) between phosphorus rate and mean number of eyes per tuber. There was also negative correlation between phosphorus rate and number of eyes per tuber of Shangi (r = - 0.6) but a positive one between phosphorus rate and number of eyes per tuber of Unica (r = + 0.3) (Appendix LXVIII).

Influence of phosphorus rate on potato seed no eyes per tuber at Lari

Phosphorus rate and interaction between phosphorus rate and variety did not have significant ($p > 0.050$) influence on number of eyes per tuber. Further, varieties did not differ significantly ($p = 0.057$). Treatments that produced potatoes with number of eyes tuber^{-1} close to the recommended range of 4-6 eyes per tuber were Absolute control and 0 phosphorus for Shangi and Unica, respectively (Table 30 & Appendix XXX).

Table 30: Means of the number of eyes per tuber of potato seed at Lari ((Number of eyes ronded off to the nearest eye)

Treatments	**Mean variety number of eyes tuber^{-1}**		**Mean phosphorus rate number of eyes tuber^{-1}**
Phosphorus rate (kg ha^{-1})	**Shangi**	**Unica**	
AC	8	8	**8**
0	9	7	**8**
30	8	7	**8**
60	9	7	**8**
90	9	7	**8**
120	9	7	**8**
Mean	**9**	**7**	**8**
	$LSD_{p = 0.05}$	**CV (%)**	
Variety	= 2	8.8%	
Phosphorus rate	= 1		
Variety * Phosphorus rate	= 2		

Correlation between phosphorus rate and Shangi's number of eyes tuber^{-1} (r = +0.6) was positive.The correlation between phosphorus rate and Unica's number of eyes tuber^{-1} (r = - 0.5) was negative (Appendix LXVIII).

Influence of phosphorus on final germination percentage (%) at Saboti

Phosphorus rate and interaction between it and variety did not significantly (p = 0.134 and p = 0.332, respectively) influence final germination percentage. There was also no significant difference (p = 0.390) in final germination percentage of varieties (Table 31 & Appendix XXXI).

Table 31: Means of percentage (%) germination at Saboti

Treatments	Mean variety final germination percentage (%)		Mean phosphorus rate final germination percentage (%)
Phosphorus rate (kg ha^{-1})	**Shangi**	**Unica**	
AC	75.3	96.0	**85.7**
0	81.5	100	**90.8**
30	100	100	**100**
60	88.9	100	**94.5**
90	100	100	**100**
120	88.9	100	**94.5**
Mean (%)	**89.1**	**99.3**	**94.2**
	$LSD_{p = 0.05}$	**CV (%)**	
Variety	= 40.5	10.3	
Phosphorus rate	= 11.7		
Variety * Phosphorus rate	= 30.7		

From correlation analysis, phosphorus rate correlated positively (r = +0.5) with final percentage germination. There was also positive correlation between phosphorus rate and final germination percentage of Shangi (r = +0.5) and Unica (r = +0.5) test potatoes (Appendix LXIX).

Influence of phosphorus rate on final percentage (%) germination at Ainabkoi

Results indicate that there was no influence (p > 0.05) of phosphorus rate, variety and their interaction on final percentage germination of potato seed at Ainabkoi (Table 32 & Appendix XXXII).

Table 32: Means of final germination percentage (%) at Ainabkoi test site

Treatments	**Mean variety final percentage (%) germination**		**Mean phosphorus rate final percentage (%) germination**
Phosphorus rate (kg ha^{-1})	**Shangi**	**Unica**	
AC	100	83.3	**91.7**
0	79.6	98.1	**88.9**
30	88.9	92.6	**90.7**
60	94.4	96.3	**95.4**
90	85.5	100	**92.6**
120	92.6	96.3	**94.4**
Mean	**90.1**	**94.4**	**92.3**
	$LSD_{p = 0.05}$	**CV (%)**	
Variety	= 6.0	14.0	
Phosphorus rate	= 15.6		
Variety * Phosphorus rate	= 20.3		

However, there was a strong positive correlation (r= +0.7) between phosphorus rate and its mean percentage germination. There was also some correlation between phosphorus rate and final percentage germination of Shangi (r = +0.1) and Unica (r = + 0.5) test potatoes (Appendix LXIX).

Influence of phosphorus on final germination percentage (%) at Lari

Results indicates that there was no influence ($p > 0.05$) of phosphorus rate, variety and their interaction on final percentage germination of potato seed (Table 33 & Appendix XXXIII).

Table 33: Means of final germination percentage (%) at Lari

Treatments	Mean variety final percentage (%) germination		Mean phosphorus rate final germination percentage (%)
Phosphorus rate (kg ha^{-1})	**Shangi**	**Unica**	
AC	100	100	**100**
0	97.2	100	**98.2**
30	97.2	100	**98.6**
60	98.1	100	**99.1**
90	87.0	100	**93.5**
120	94.4	100	**97.2**
Mean	95.7	100	**97.8**
	$LSD_{p = 0.05}$	**CV (%)**	
Variety	= 10.6	6.6%	
Phosphorus rate	= 7.8		
Variety * Phosphorus rate	= 11.4		

Further, there was a negative (r = -0.6) correlation between phosphorus rate and its mean final percentage germination. Correlation between phosphorus rate and final germination percentage of Shangi was negative (r = -0.7) (Appendix LXIX).

4.5 Influence of phosphorus on its use efficiency

4.5.1 Influence of phosphorus on its use efficiency (kg kg^{-1}) at Saboti

Results show that phosphorus rate influenced ($p < 0.001$) its use efficiency. Also, varieties influenced ($p = 0.001$) phosphorus use efficiency of potato seed. The mean phosphorus use efficiency for Shangi was 0 kg kg^{-1} while for Unica was -396 kg kg^{-1}. Interaction between phosphorus and variety influenced ($p < 0.001$) phosphorus use effciency resulting in maximization of Shangi's (136 kg kg^{-1}) and Unica's (-226 kg kg^{-1}) phosphorus use efficiency at 60 and 90 kg ha^{-1} phosphorus, respectively (Table 34 , Appendix XXXIV and Appendix LX).

Table 34: Means of phosphorus use efficiency (kg kg^{-1}) at Saboti

Treatments	**Mean variety phosphorus use efficiency in kg kg^{-1}**		**Mean phosphorus rate phosphorus use efficiency in kg kg $^{-1}$**
Phosphorus rate kg ha^{-1}	**Shangi**	**Unica**	
30	-211	-745	**-478**
60	136	-398	**-131**
90	71	-226	**-77**
120	3	-214	**-106**
Mean	**0**	**-396**	**-198**
	LSD$_{p = 0.05}$	**CV (%)**	
Variety	= 65.1	39.5 %	
Phosphorus rate	= 98.4		
Variety * Phosphorus rate	= 123.5		

The results further indicate a very strong postive correlation ($r = +0.8$) between phosphorus rate and its mean phosphorus use efficiency. Also, correlation between phosphorus rate and phosphorus use efficiency of Shangi ($r = +0.9$) and Unica ($r = +0.8$) was postive (Appendix LXX).

4.5.2 Influence of phosphorus on its use efficiency (kg kg^{-1}) at Ainabkoi

Results show that phoshorus rate influenced ($p < 0.001$) its use efficiency. Also, interaction between phosphorus rate and variety significantly ($p < 0.001$) influenced phosphorus use efficiency of the test varieties resulting in maximization of both Shangi's (31 kg kg^{-1}) and Unica's (109 kg kg^{-1}) at 30 kg ha^{-1} phosphorus. Further, there was no significant difference ($p = 0.556$) between phosphorus use efficiency of Shangi and Unica (Table 35, Appendix XXXV and Appendix LX).

Table 35: Means of the phosphorus use efficiency (kg kg^{-1}) at Ainabkoi

Treatments	**Mean variety phosphorus use efficiency in kg kg^{-1}**		**Mean phosphorus rate phosphorus use efficiency in kg kg $^{-1}$**
Phosphorus-rate kg ha^{-1}	**Shangi**	**Unica**	
30	30.6	109.3	**70**
60	19.1	-111.4	**-46.2**
90	33.6	45.3	**39.5**
120	32.3	13.0	**22.6**
Mean	**28.9**	**14.1**	**21.5**
LSD$_{p = 0.05}$			
Variety	= 91.91		
Phosphorus rate	= 44.49		
Variety * Phosphorus rate	= 74.99		

Results also show a weak positive correlation (r = -0.1) between phosphorus rate and its mean phosphorus use efficiency. Correlation between phosphorus rate (30 to 120 kg ha^{-1} phosphorus) and the phosphorus use efficiency of Shangi (r = +0.4) and Unica (r = - 0.2) was also weakly negative (Appendix LXX).

4.5.3 Influence of phosphorus on its use efficiency (kg kg^{-1}) at Lari

Results show that phosphorus rate did not significantly (p = 0.125) influence its use efficiency. Further, results indicate a perfect negative correlation (r = -1.0) between phosphorus rate and the mean phosphorus use efficiency. Varieties also differed significantly (p = 0.017) on their phosphorus use efficiency. The mean phosphorus use efficieny of Shangi was 116 kg kg^{-1} while that of Unica was 6 kg kg^{-1}. There was no significant (p = 0.568) interaction between phosphorus rate and variety. Highest Shangi's (145 kg kg^{-1}) and Unica's (19 kg kg^{-1}) phosphorus use efficiency was realised at 30 and 60 kg ha^{-1} phosphorus, respectively (Table 36 , Appendix XXXVI and Appendix LX).

Table 36: Means of the phosphorus use efficiency (kg kg^{-1}) at Lari

Treatments	**Mean variety phosphorus use efficiency (kg kg^{-1})**		**Mean phosphorus rate phosphorus use efficiency (kg kg^{-1})**
Phosphorus rate (kg ha^{-1})	**Shangi**	**Unica**	
30	144.8	7.4	**76.1**
60	135.7	19.4	**77.6**
90	103.1	4.6	**53.9**
120	81.0	-7.6	**36.7**
Mean	**116.1**	**6.0**	**61.1**
	$LSD_{p = 0.05}$		
Variety	= 63.26		
Phosphorus rate	= 39.31		
Variety * Phosphorus rate	= 58.12		

Correlations between phosphorus rate and phosphorus use efficiency of Shangi (r = -1.0) and Unica (r = -0.7) were negative (Appendix LXX).

4.6 Comparisons of parameters at the test sites

4.6.1 Comparison of qualitative parameters at the test sites

Parameters compared include soil colour, soil depth, vegetative cover, soil type, rainfall, altitude and temperature. The colour of the soils of the test sites changed down the soil profile. Saboti soils were dark brown within the range of 0-15 cm. At the depth of 15 to 30 cm, the colour changed to light brown. The colour of soils at Ainabkoi was similar to that of Saboti, except that it was lighter. The colour of soils at the Lari was greyish brown in the range of 0 to15 cm. From 15 to 30 cm, the colour changed to reddish brown. High water table (< 3m) and a hard pan were evident in Lari unlike Saboti and Ainabkoi. In all the test sites, the soils also become increasingly sticky down the profile indicating clay illuviation. The vegetative cover of Lari was dominated with horticultural crops like potato, cabbage and kales. Those of Saboti and Ainabkoi were dominated with potato, maize, beans, tomato and indigenous trees. The terrain of Lari was gentle while that of Saboti and Ainabkoi was sloppy. The test site with the highest altitude, highest annual rainfall and lowest temperature was Lari. While the test site with the lowest altitude, lowest annual rainfall and highest temperature was Saboti. The altitude, annual rainfall and temperature of Ainabkoi were average. The frequency of control of blight and pests reduced with increasing altitude: it was highest in Saboti, average in Ainabkoi and lowest in Lari. Lari however experienced more periods of very low temperatures and frost than the other two sites necessitating precautionary measures to control late blight. From the physical observations, Saboti and Ainabkoi have nitisols while Lari has a planosol (Table 37).

Table 37: Observable and secondary data of the test farms

Parameter	**Test Farm**		
	Saboti	**Ainabkoi**	**Lari**
Altitude (m a.s.l)	1,923	2,300	2,550
Rainfall (mm)	1264	1300	1400
Agro ecological zone	UM4	LH2	LH1
Soil colour (0-15 cm)	Dark brown	Dark brown	Greyish brown
Soil colour (15-30 cm)	Light brown	Light brown	Reddish brow
Soil depth	Deep (>100 cm)	Deep (> 100 cm)	Shallow (< 100cm)
Vegetative cover	Maize,beans, tomato,indigeneous trees	Maize,beans, tomato,indigeneous trees	Potato, cabbage, kales, scattered trees
Depth of water table	>3m	>3m	<3m
Soil type	Nitisol	Nitisol	Planosol
Source: Jaetzold *et al.*, 2011 and Jaetzold ; Schimidit, 2009 and direct observations			

4.6.2 Relating tuber yields (t ha^{-1}) with soil and plant available phosphorus in test sites

The results show there is a very strong correlation between mean tuber yields with mean site soil available phosphorus. There was a perfect inverse correlation between small grade yield and soil available phosphorus at planting (r = -1.0) and harvesting (r = -1.0). This trend was related with the site; small grade yield was lowest at Saboti, followed by Ainabkoi and highest at Lari. There was also a perfect correlation between large grade yield and soil available phosphorus at planting (r = +1.0) and harvesting (r = + 1.0). Further, there was a perfect correlation between overall seed yield and soil available phosphorus at planting (r = +1.0) and harvesting (r = +1.0). This yield was greatest at Saboti, least at Lari and average at Ainabkoi. There was a perfect correlation between overall seed yield of shangi (r = +1.0) and potato plant tuber phosphorus. There was also a positive correlation between overall seed yield of Unica (r = +0.6) and potato plant tuber phosphorus (Fig 2).

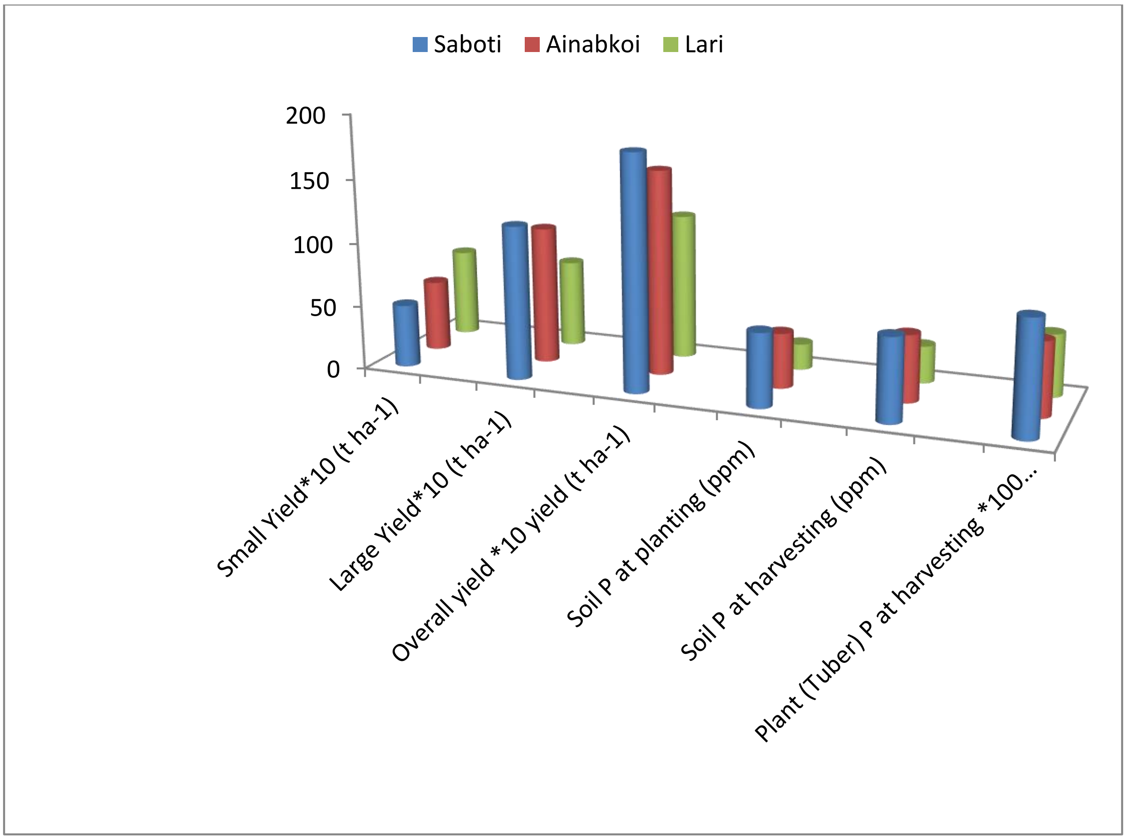

Figure 2: Relating tuber yields (t ha^{-1}) with soil and plant available phosphorus in test sites

4.6.3 Relating variety's small, large and overall grade yields with soil available phosphorus

Small grade yield of Shangi and Unica

Results show that correlation between small grade yield of Shangi and soil available phosphorus at planting (r = -0.8) and harvesting (r = -0.7) and hence the test sites was strongly negative. This yield was lowest at Saboti and highest at Ainabkoi and average at Lari. The trend for small grade yield of Unica was in contrast to that of small grade yield of Shangi. The correlation between small grade yield of Unica and soil available phosphorus at planting (r = +1.0) and harvesting (r = +1.0) and hence the test sites was perfectly positive. The small grade yield of Unica was highest at Saboti, average at Ainabkoi and least at Lari. Correlation between small grade yield of Shangi and potato plant tuber phosphorus was perfectly negative (r= -1.0). Correlation between Unica and potato plant (tuber) phosphorus was also perfect (r = + 1.0) (Fig. 2, 3 & 4).

Large grade yield

Mean large grade yield of Shangi variety was highest at Saboti test site followed by Lari and Ainabkoi. Correlation between mean large grade yield and soil available phosphorus at planting (r= +0.7) and harvesting (r = +0.7) was positive. Mean large grade yield of Unica was highest at Ainabkoi followed by Saboti and least at Lari. Correlation between it and soil available phosphorus at planting (r = +0.8) and harvesting (r = +0.8) was positive. There was also a positive correlation between large grade yield of Shangi (r = +0.9) and Unica (r = +0.5) and potato plant (tuber) total phosphorus (Fig. 2, 3 & 4).

Overall grade yield

Mean overall grade yield of Shangi (sum of large and small yield) was highest at Saboti, average Ainabkoi and least at Lari. Correlation between this yield and soil available phosphorus at planting (r = +0.9) and harvesting (r = +0.9) was strongly positive. Overall grade yield of Unica (sum of large and small yield) was highest at Ainabkoi, average at Saboti and least at Lari. Correlation between this yield and soil available phosphorus at planting (r = +0.9) and harvesting (r = +0.9) was strongly positive. Further, correlation between overall yield of Shangi and Unica and potato total plant (tuber) phosphorus was = +1.0 and +0.6, respectively (Fig. 2, 3 & 4).

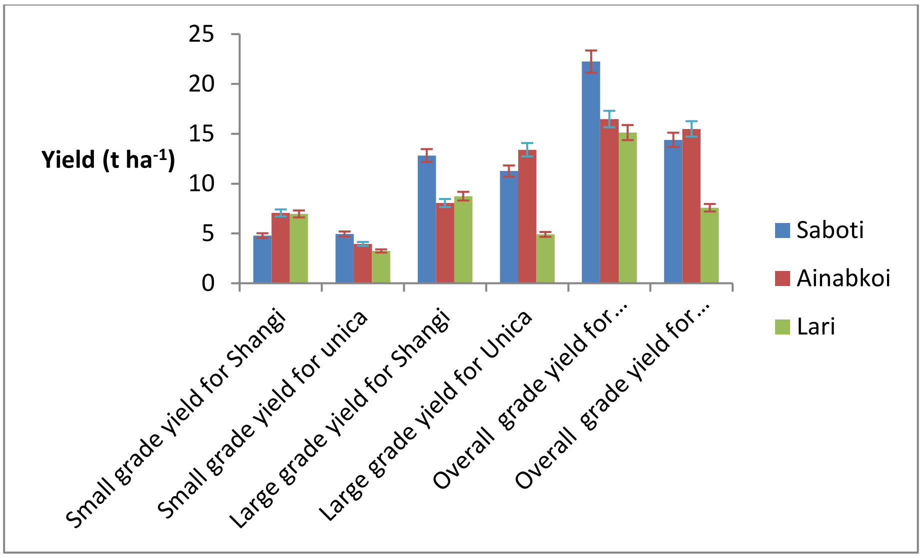

Figure 3: Yield (t ha^{-1}) of different grade of potato seed

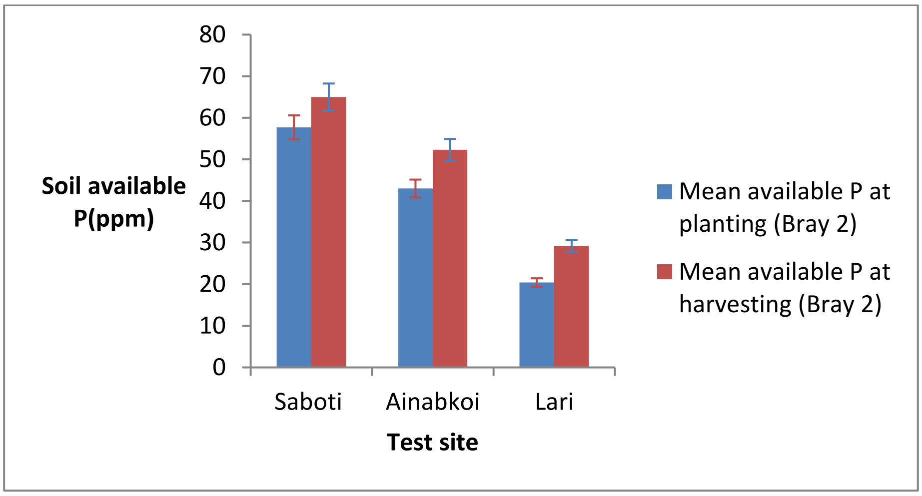

Figure 4: Mean site available phosphorus

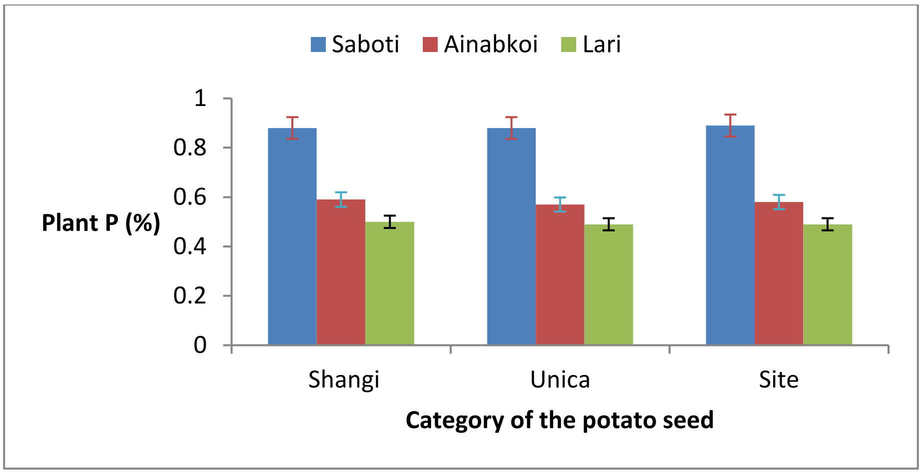

Figure 5: Mean variety plant (tuber) phosphorus (%) at the test sites at harvesting

4.6.4 Comparisons of final germination percentage of the sites

Lari had the highest final germination percentage (97.9%). There was not much difference between the mean final germination percentage of Saboti (93.7%) and Ainabkoi (92.3%). Final germination percentage of Shangi was lowest in Saboti (88.1%), average in Ainabkoi (90.1 %) and highest at Lari (97.9 %). In all the test sites, Unica had better final percentage germination than Shangi (Fig 5).

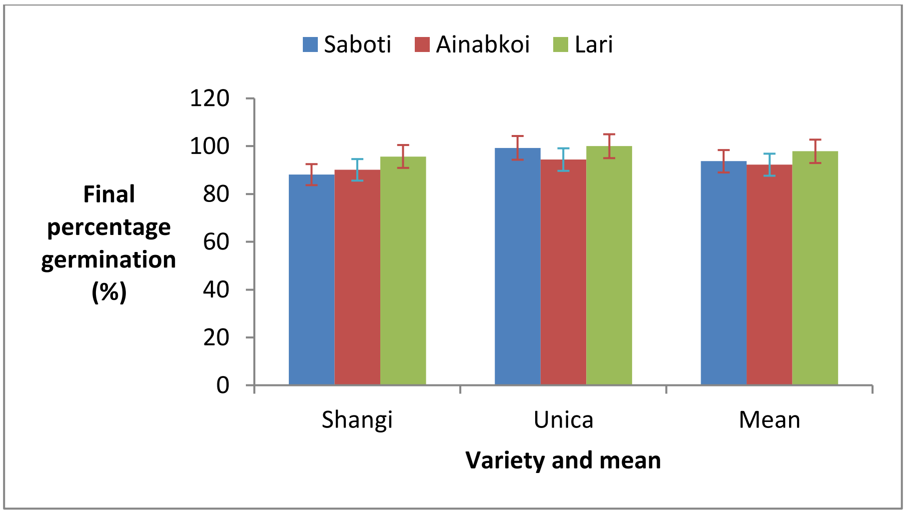

Figure 6 Final germination percentage (%) of varieties

4.6.5 Comparisons of phosphorus use efficiency of varieties and sites

From the results, mean phosphorus use efficiency of Unica was less than that of Shangi in all the test sites. The highest phosphorus use efficiencies for Shangi (92.9) and Unica (11.3) were realised at Lari and Ainabkoi, respectively. Overall, phosphorus use efficiency in Lari (48.8 kg kg^{-1}) was the highest while that of Saboti (-159 kg kg^{-1}) was the lowest (Table 38).

Table 38: Comparisons of site based phosphorus use efficiency

Test site	Mean phosphorus use efficiency (kg kg^{-1})		
	Shangi	**Unica**	**Site phosphorus use efficiency**
Saboti	0	-317	**-159**
Ainabkoi	23.1	11.3	**17.2**
Lari	92.9	4.8	48.8

4.6.6: Comparisons of average tuber weight (g tuber^{-1})

From the results, average weight of small and large grade seed tuber of Unica was greater than that of Shangi in all the test sites. At Ainabkoi and Lari, average weight of overall grade potato seed of Unica was greater than that of Shangi. At Saboti test site the average weight of overall grade potato seed were almost the same but Shangi's (55.6 g tuber^{-1}) weight was slightly greater than Unica's (53.1 g tuber^{-1}) weight. The least observed average tuber weight (25.3 g tuber^{-1}) was at Saboti in Shangi while the largest average tuber weight (85.5 g tuber^{-1}) was recorded at Ainabkoi in Unica (Figure 9 & Appendix LI).

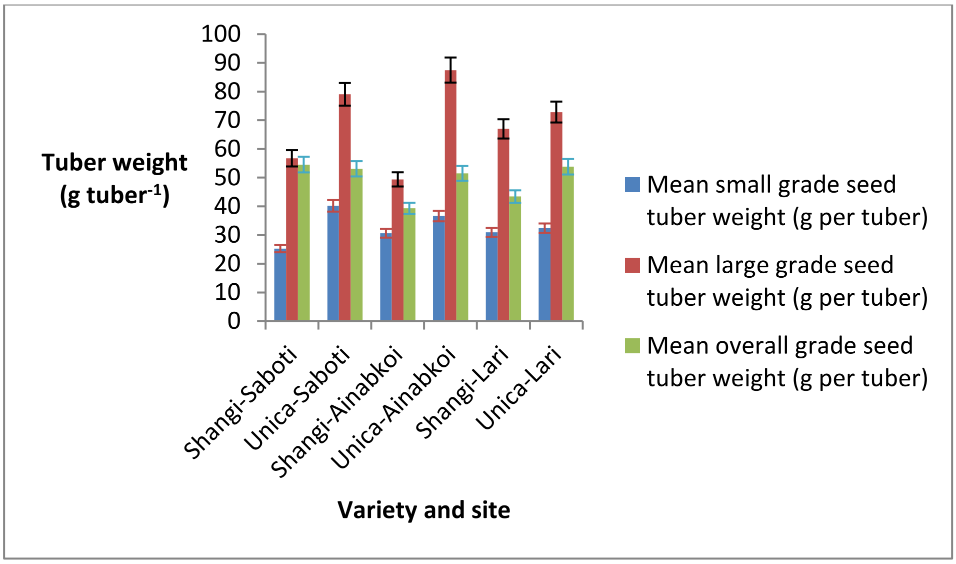

Figure 7: Average tuber weight (g tuber^{-1}) of test varieties.

CHAPTER FIVE

DISCUSSION

5.1 Influence of phopshorus rate on soil available and potato plant tuber phosphorus

5.1.1 Influence of phosphorus rate on soil available phosphorus at harvesting

At Saboti, there was a build up of soil available phosphorus from a mean of 57.7 ppm to 65.0 ppm Bray 2 phosphorus during the growing season. Two factors may have contributed to this build up: potatoes are shallow rooted hence were unable to utilise all the available soil phosphorus and the growing season was short making the plant attain physiological maturity before utilizing all the available soil phopshorus. There was a positive correlation between phosphorus rate application and soil available phopshorus. Soil available phopshorus at harvesting increased with phosphorus rate upto 61.7 ppm and 103.3 ppm Bray 2 phosphorus realised at 60 kg ha^{-1} and 120 kg ha^{-1} phosphorus for Shangi and Unica, respectively.

At Ainabkoi, there was a build up of soil available phosphorus from a mean of 43.0 to 52.0 ppm Bray 2 phosphorus during the growing season. Two factors may have contributed to the buid up: potatoes have shallow roots that could not extract the nutrients below the root zone and the growing season of potato of about three months was short for all the available phosphorus to be utilised. There was a positive correlation between phosphorus rate application and soil available phopshorus. Soil available phopshorus at harvesting increased with phosphorus rate upto 91.8 and 92.8 ppm Bray 2 phosphorus realised at 60 and 90 kg ha^{-1} phosphorus for Shangi and Unica, respectively.

At Lari, **t**here was a build up of soil available phosphorus from a mean of 20.4 to 29.2 ppm Bray 2 phosphorus during the growing season. The short growing season of potato and their shallow rooting sytem may have limited the amount of soil available phosphorus taken up by the potatoes resulting in the build up of soil available phosphorus. For Shangi, soil available phosphorus increased with application of phosphorus upto 46.6 ppm at a rate of 60 kg ha^{-1} phosphorus, while for Unica, highest soil available phosphorus (54.2 ppm Bray 2 phosphorus) was realised without application of phosphorus fertilizer (0 P). Due to low soil pH (4.6), the aluminium and iron ions may have precipitated some of the phosphorus applied. This explains why soil available phopshorus in the three test sites both at planting and harvesting was least at Lari. Okalebo *et al.*, 2002 in their trials in the highlands of Kenya noted that soil phosphorus fixation is dominant in soils whose pH is below 5.5

5.1.2 Influence of phosphorus rate on potato plant tuber phosphorus at harvesting

At Saboti, highest potato plant tuber phosphorus of Shangi (0.93 % phosphorus) and Unica (1.08 % phosphorus) was realised at 0 and 90 kg ha^{-1} phosphorus, respectively. Unica's higher yielding and feeding potential (NPCK, 2019) may have enabled it extract more nutrients than Shangi. Thus, additional phosphorus in the soil was beneficial in the plants especially Unica. For Shangi, the high residual soil available phosphorus (57.7 ppm Bray 2 phosphorus) at planting may have contributed to the tuber phosphorus.

At Ainabkoi, highest potato plant tuber phosphorus of both Shangi (0.67 % phosphorus) and Unica (0.62 % phosphorus) was realised with 0 phosphorus ha^{-1} fertilizer. The high inherent soil phosphorus (43.0 ppm Bray 2 phosphorus) may have contributed to this outcome.

At Lari, highest potato plant tuber phosphorus of Shangi (0.61 % phosphorus) and Unica (0.61 % phosphorus) was realised at 30 and 60 kg ha^{-1} phosphorus, respectively. This site had low soil fertility of 20.4 ppm Bray 2 phosphorus at planting and addition of phosphorus would be beneficial to plant phosphorus. Unica being a heavy feeder and yielder needed more phosphorus than Shangi (NPCK, 2019).

5.2 Influence of phosphorus on quantity of potato seed

In this section, the attributes of potato seed quantity discussed are weight in tonnes per hectare and number of tubers per hectare. The grades of seed discussed are overall, small and large.

5.2.1 Influence of phosphorus on overall quantity of potato seed

At Saboti, yield of potato seed in both Absolute control and 0 phosphorus ha^{-1} treatments was greater than their corresponding yield in “ware” treatments. However, potato seed yield from 30 to 120 kg ha^{-1} phosphorus treatments was lower than their corresponding yield from “ware” treatments (Akoto *et al.,* 2020). This accounts for overall negative correlation (r = -0.6) between phosphorus rate and its seed tuber yield. Apparently, as phosphorus rate increased, the potato seed converted to “ware” potatoes (Akoto *et al.,* 2020). This negative correlation is mainly from the correlation between phosphorus rate and yield of Unica (r = - 0.6). Thus. Absolute control phosphorus rate for Shangi and 0 phosphorus ha^{-1} rate for Unicafavoured the seed size grade potato at physiological maturity resulting in overall highest yield of 33.3 t ha^{-1} and 33.7 t ha^{-1} for Unica and Shangi, respectively. However, overall highest yield of “ware” potato (26.3 t ha^{-1}) yield was realised with application of 90 kg ha^{-1} phosphorus. As much as correlation between phosphorus rate and seed yield of Unica and Shangi was negative, correlation between phosphorus rate and “ware” yield of the same varieties was positive. Thus, increased phosphorus fertilizer application favoured “ware” potato production (Akoto *et al*., 2020). Although soil available phosphorus was adequate (45 ppm Mehlich 3 or 57.5 ppm Bray 2) at Saboti for Shangi and Unica potato seed yields, it was not so for the “ware” potato yields of the two varieties. Highest “ware” yield of Unica (40.5 t ha^{-1}) was realised at 90 kg ha^{-1}. This is further explained by less negative (r = - 0.2) and more negative (r = - 0.6) correlation between phosphorus rate and Shangi and Unica potato seed tuber yields, respectively. Khalid *et al.*, 2003 noted that different varieties of potatoes yielded differently in response to phosphorus application. From studies done in Ethiopia by Israel *et al.*, 2012 on the influence of nitrogen and phosphorus on potato production, it was found that phosphorus rate of 60 kg ha^{-1} and nitrogen rate of 165 kg ha^{-1} gave optimum yields. Allison *et al.*, 2001 in his studies on potato crop in the Rift Valley region of Kenya found declining response to phosphorus with its increasing application rates.

Phosphorus rate at Saboti significantly influenced potato seed tuber number resulting in highest number of Shangi from phosphorus rate of 120 kg ha^{-1} (502, 219 tubers ha^{-1}). Highest tuber number of Unica (414, 812 tubers ha^{-1}) and highest mean tuber number (405, 183 tubers ha^{-1}) were realised with the Absolute control rates. There was minimal correlation between tuber yield of Shangi and its tuber numbers (r = + 0.1). This explains why highest yield of Shangi was realised in Absolute control treatments while highest tuber numbers of the same variety was attained at 120 kg ha^{-1} phosphorus. Correlation between Unica’s tuber yield and number was +0.7 while overall correlation between tuber yield and numbers was +0.6. Correlation coefficients between phosphorus rate and overall tuber numbers, beween the same rate and Shangi’s and Unica.s tuber number were -0.5, +0.4 and -0.8, respectively. This is similar to the findings of Zelalem *et al.,* 2009 who found that there was a positive correlation between total tuber yield and total tuber number and that phosphorus application had no significant influence on both of them. The author however noted that phosphorus had significant influence on marketable tuber yield. The author further noted that lack of response to phosphorus application may be due to its fixation and other environmental factors.

At Ainabkoi, interaction bweeen phosphorus and variety significantly influenced yields at Ainabkoi. Highest yields of Shangi and Unica were realised at phosphorus rate of 60 kg ha^{-1} (20.0 t ha^{-1}) and 30 kg ha^{-1} (18.9 t ha^{-1}), respectively. Overall highest yield (18.9 t ha^{-1}) was realised at a phosphorus rate of 90 kg ha^{-1}. Correlation between phosphorus rate and overall, Shangi's and Unica's yield were +0.7, +0.7 and +0.3, respectively. These results are similar to those of Grewal and Trehan (1993) who collected data on potato yield and found that optimum application of phosphorus ranged between 17 kg ha^{-1} to 77 kg ha^{-1} with yield response of 1 to 7.7 t ha^{-1}. Also Hahlin (1992) conducted similar studies on potatoes using three phosphorus rates of 0, 45 and 90 kg ha^{-1} phosphorus. He found a positive correlation between phosphorus application and yield. He concluded that the optimum phosphorus rate was 90 kg ha^{-1} phosphorus.

At Ainabkoi, varieties' tuber numbers differed significantly. Phosphorus rate had significant influence on tuber numbers of potato seed. Highest production of Shangi (452, 696 tubers ha^{-1}), Unica (300, 862 tubers ha^{-1}) and overall (376, 779 tubers ha^{-1}) were realised at phosphorus rate of 120 kg ha^{-1}. Correlation between phosphorus rate and tuber numbers was positive (r = +0.4). Phosphorus rate also correlated positively with tuber numbers of Shangi (r = +0.7) and Unica (r = +0.4). There was also a positive correlation (r = +0.2) between overall yield and overall tuber number of the test varieties. Correlation between yield and tuber number of Shangi was + 0.8 while correlation between yield and tuber number of Unica was 0.0. Zelalem *et al.,* 2009 noted that phosphorus may or not influence tuber number. These findings are similar to the current finding at Ainabkoi. From Yara international (2016 & 2019) adequate supply of phosphorus to potato crop influences the number of tubers produced. However optimum phosphorus rate application is difficult to find as it depends on the soil type and on the soil test results (Yara International, 2016 & 2019). As much as soil test results for soil samples taken at planting indicated that there was sufficient soil available phosphorus (40 ppm Mehlich phosphorus or 58.5 ppm Bray 2 phosphorus) to support the potato crop, there is need to add more phosphorus. Potatoes are known to have shallow roots (KEPHIS, 2016). Apparently; the potatoes were not able to extract all the available soil phosphorus in the soil profile, thus the need to add more phosphorus.

At Lari, initial soil available phosphorus status was below the critical level of (30 ppm Mehlich phosphorus). The study farm was surrounded with maize that was purplish in colour; suggesting inadequate soil available phosphorus. The water table of the site was high (1-3 m) necessitating construction and maintenance of drainage channels. There were indications of illuviation as the colour of the top soil was greyish brown. There was a strong correlation between phosphorus rate and tuber yield (r = +0.9). Correlation between phosphorus rate and Shangi's yield (r= +0.9) was very strong while the correlation between phosphorus rate and Unica's yield was average (r = +0.4). Overall, test potatoes needed application of 90 kg ha^{-1} phosphorus to produce highest significant yields (15.3 t ha^{-1}). Shangi and Unica needed additional phosphorus to produce their highest significant yields at physiological maturity. Hence both of them needed 90 kg ha^{-1} phosphorus to produce highest yields of 20.1 t ha^{-1} and 10.4 t ha^{-1}, respectively. Alverez *et al.*, 1999 conducted a similar study in Mexico by testing 13 different applications of phosphorus ranging between 0 and 207 phosphorus ha^{-1}. They found 90 kg ha^{-1} phosphorus to be optimum application. In a similar study conducted by Zelalem *et al.*, 2009 in the central highlands of Ethiopia, phosphorus application of 20 kg ha^{-1} was optimum for potato production. Correlation between yields and tuber numbers was positive (r = + 0.9). In his studies, Israel *et al.*, 2012 found that phosphorus application of 60 kg ha^{-1} was optimum for potato production. From Birturkan (2016), phosphorus needed for optimum potato production was 135 kg ha^{-1}. This is confirmed by Eklorf (2007) who has said that there are several factors that contribute to fertilizer recommendations on potatoes which include soil type, nutrient availability, and economic factors of an area, moisture supply and variety. It is therefore important to base crop fertilizer requirements on soil test results (Yara International, 2019).

At Lari, phosphorus rate had significant and positive influence on the total tuber number produced. There was also positive (r = +0.8) correlation between phosphorus rate and mean tuber number of Shangi (r= + 0.8) and Unica (r = +0.5). The Correlation between tuber yield and tuber number was perfectly positive for Shangi (r= + 1.0) but very weak for Unica (r = - 0.1). It was very strong in general (r = + 0.9). In general, highest numbers were realised at 60, 30 and 60 kg ha^{-1} phosphorus with production of 296294, 162962 and 452812 tubers ha^{-1}, respectively. Shangi (348349 tubers ha^{-1}) and Unica (140900 tubers ha^{-1}) significantly differed in their tuber numbers. Yara International (2019) noted that phosphorus influenced on tuber number produced by potato. Zelalem *et al.*, 2009 noted conflicting findings on the effect of phosphorus on tuber numbers. The author noted that phosphorus may or not influence tuber numbers. Yara International, 2016 noted that while potatoes are very responsive to fresh soil phosphate, the economic optimum rate is often very difficult to define and hence rates will depend on soil type and soil test results.

5.2.2 Influence of phosphorus on small grade quantity of potato seed

At Saboti, the trend for small grade potato seed yield reveals that Unica potato seed converted to “ware” potatoes since the correlation between phosphorus rate and Unica’s small grade potato tuber yield was negative. However, the trend of Shangi potato production was the opposite since there was a positive correlation between phosohorus rate and small grade potato seed yield. The trend of small grade number of potato seed tubers produced in Saboti was similar to its yield whereby Correlation beween phosphorus rate and Shangi’s/Unica’s yield was positive/negative, respectively. Unica variety potato seed production therefore may not need additional phosphorus while Shangi potato seed production may need additional phosphorus to give highest yields. Unica variety is a heavy feeder with tendencies to overgrow the seed size grade (NPCK, 2019).

At Ainabkoi, phosphorus and variety influenced small grade seed yield of Unica and Shangi significantly. With respect to tuber number production, it was only varieties that influenced it significantly. Correlation between phosphorus rate and yield of test varieties was positive. Correlation between phosphorus rate and tuber numbers of Shangi was positive while correlation between the same rate and tuber numbers of Unica was negative. Highest small grade yield was realised at phosphorus rate of 120 kg ha^{-1} while highest tuber number was realised in the Absolute controls. Apparently, fertilizer application resulted in fewer and weighty potato seed in Ainabkoi.

At Lari, there was significant influence of phosphorus rate on both yield and tuber number of potato seed. There was also positive correlation between phosphorus rate and both tuber yield and tuber number of potato seed. Among the three sites, Lari had the least available phosphorus and pH at planting time. Thus this test farm needed very high application of phosphorus of 60 and 90 kg ha^{-1} to produce the highest yields of

19.0 and 10.4 t ha^{-1} of Shangi and Unica, respectively. However, it needed phosphorus application rate of 60 kg ha^{-1} and 30 kg ha^{-1} for the production of the highest tuber numbers of Shangi and Unica, respectively. Yara International (2019) reported that phosphorus rate influences tuber setting and number.

Guluma (2020) reported that small size seed tubers in comparison to large size seed tubers have lower yields due to delayed emergence, low sprout vigor, number and food reserve. In the event of disease control challenges in seed potatoes, mother plants produce unhealthy small size potatoes (Striik & Wiersema, 1999) which are are more prone to transmitting diseases than large size tubers.

5.3.3 Influence of phosphorus on large grade quantity of potato seed

At Saboti, highest production of both yield and number of potato seed tubers from the test varieties were realised from the Absolute controls. Correlation between phosphorus rate and tuber's yield was negative. Hence additional nitrogen and phosphorus were not needed for the production of potato seed in Saboti. This may have been due to the high available soil phosphorus at planting in this site. As much as soil fertility levels had declined compared to previous years (Komen, 2016), what was available was sufficient for potato seed production. The negative correlation was due to increased production of “ware" yield as the rate of phosphorus increased (Akoto *et al.,* 2020). Hence, higher rates favoured “ware” potato production.

At Ainabkoi, there was significant influence of phosphorus rate on variety and phosphorus rate mean yield of the potato seed. There was also positive correlation between phosphorus rate and yields of both test varieties and tuber number of Unica. Soil fertility in Kenya has been declining (Muthoni, 2016; Mugo *et al.,* 2016). Due to the declining soil fertility, additional phosphorus was needed to realise the highest yields. For tuber number, additional phosphorus was needed for Unica but not Shangi. The available soil phosphorus at planting at Ainabkoi was lower in comparison to Saboti but higher than that of Lari.

At Lari, phosphorus and varieties had significant influence on Shangi's and Unica's tuber yield and number. Phosphorus also correlated positively with the yield and tuber numbers produced by Shangi and Unica. The highest yield and number of tubers produced was achieved with phosphorus rate of 60 kg ha^{-1}. At planting time, Lari had low available soil phosphorus necessitating additional phosphorus for producing the highest yield and number of tubers. Some young maize plants planted near the potato seed were noted to be purple in colour confirming that indeed phosphorus was deficient in the test site.

Yara International (2019) reported that variety and phosphorus rate have varying effect on tuber yield and number which is in agreement with the current study sites. At the same spacing, large grade seed gives higher yields of tubers than small grade seed. However, they produce small size tubers comparatively. Large grade seed also posses greater number of sprouts per tuber, thus they give rise to a greater number of true plantles per hill (Gluma, 2020). The greater the number of true plants per hill, the greater the number of tubers produced and smaller will be their individual size (Bates, 2009). Big tubers are vigorous at germination and have better yields (Guluma, 2020).

5.3 Influence of phosphorus on quality of potato seed

Seed quality is the possession of seed with the required genetic and physical purity that is accompanied with physiological soundness and health status (Choudhary and Viji (2016). It can also be defined as the sum total of all the characters that determine tuber suitability for the intended purpose e.g. propagation, processing or fresh consumption

(Komen, 2016). The parameters investigated for potato seed quality were specific gravity, number of eyes per tuber and final germination percentage. The basis for this evaluation was that the higher the final germination percentage and specific gravity the more qualitative the potato seed. Further, the potato seed whose number of eyes per tuber was in the range of four to six had the desired quality (KEPHIS, 2016).

5.3.1 Influence of phosphorus on specific gravity of potato seed

Specific gravity and dry matter content of potatoes or total solids of potatoes are positively correlated, hence indicative of each other. Talburt and Smith (1959), noted this correlation using an empirical formula: Percentage (%) dry matter = (24.182 ± 0.035) + (211.04 ± 3.33) (SG-1.0988). This empirical relationship is widely used by the British potato council to evaluate potatoes for processing (Komen, 2016).

(Gould, 1995) reported that specific gravity of potato is directly related to dry matter content. The mean specific gravity of Unica was not statistically different from that of Shangi implying that the dry matter content of the two was the same. From NPCK (2019), the dry matter accumulation of Shangi (21.4%) is not so different from that of Unica (21.0%). Correlation between phosphorus rate and mean specific gravity was -0.6. The correlation between phosphorus rate and the specific gravity of Shangi was -0.3 while the correlation between phosphorus rate and specific gravity of Unica was -0.5. Correlation between tuber yield and tuber specific gravity was weak (r = -0.2). Unica maximised its specific gravity at phosphorus rate of 30 kg ha^{-1} (1.085) while Shangi maximised its specific gravity (1.060) at 0 phosphorus rate. Generally increased phosphorus application in Saboti was detrimental to the specific gravity of potato seed since it had negative correlation with specific gravity (r = - 0.6), yield (r = - 0.6) and tuber numbers (r = -0.5). This influenced overall maximization of specific gravity (1.0675) at 30 kg ha^{-1} application of phosphorus. Over fertilising and over irrigating can result in lower specific gravities in tubers (DPIRD, 2019). This implies that increased fertilizer application may not necessarily optimize the specific gravity of potatoes. This outcome is implied by the reports of Human, 1961 and Sparrow *et al.,* 1992. Human (1961) reported an increase in specific gravity in response to an increase in applied phosphorus in potato tubers. However, Sparrow *et al.* (1992) noted non-significant influence in percent dry matter of potato tubers due to increased phosphorus application. At planting time zinc was low (2.5 ppm Mehlich phosphorus) at Saboti. This may have contributed to phosphorus having more influence on the specific gravity of unica variety of potatoes in the same site since the uptake mechanism and the role of zinc and phosphorus are similar. Mailer *et al.*, 1989 in his studies on potatoes noted that phosphorus and site and their interactions significantly influenced potatoes' specific gravity. Studies on potato by Freeman *et al.,* 1998 noted some cases where the phosphorus fertilizer promoted a great increase in size and yield of potato tuber but reduced their specific gravity.

At Ainabkoi, phosphorus rate significantly influenced the specific gravity of potatoes with highest specific gravity (1.0690) being realised at phosphorus rate of 120 kg ha^{-1}. Interaction between phosphorus rate and variety was significant with Shangi and Unica optimizing their specific gravity at phosphorus rate of 120 kg ha^{-1}. The highest specific gravity for the two varieties was 1.0608 and 1.0772, respectively. There was also a weak correlation between potato yield and specific gravity (r = + 0.2). However, correlation between phosphorus rate and mean (r = +0.6), Shangi's (r = + 0.4) and Unica's (r = +0.7) specific gravities were positive. The specific gravity of Shangi (1.0542) and unica (1.0450) differed significantly. Zelalem *et al.,* 2009 noted that there are conflicting findings on the influence of phosphorus on potato specific gravity. This may be occasioned by many factors that contribute to potato specific gravity like variety and other soil nutrients like zinc which is known to be antagonistic to phosphorus. The department of environment and primary studies (1995) reported that phosphorus may not have a marked effect on dry matter accumulation; it may if anything increase it. This department further reported that the water-holding capacity, drainage, structure, fertility, and temperature of a soil can all affect dry matter separately, or they can antagonise each other with the result that they can cancel out the benefits of other factors. Phosphorus has various effects on tuber quality, since it functions in cell division, synthesis and storage of starch in the tubers (Houghland, 1960). Hence, it can increase the size and percentage of dry matter (indicated by specific gravity) of the tubers (Freeman *et al.,* 1998; Rosen *et al.,* 2014).

At Lari, phosphorus had no significant influence on the specific gravity of potatoes. Interaction between phosphorus and variety significantly (p = 0.007) influenced seed specific gravity in Lari. Highest specific gravity of Shangi (1.1018) was realised with phosphorus rate of 120 kg ha^{-1} while that of Unica (1.0880) was realised with phosphorus rate of 60 kg ha^{-1}. There was positive (r = +0.7) correlation between phosphorus rate and its mean specific gravity. There was also positive correlation between phosphorus rate and specific gravity of Shangi (r = +0.5) and Unica (r = +0.2).There was also strong correlation between tuber yield and mean (r = +0.6), Shangi's (r = +0.3) and Unica's (r = +0.6) specific gravity. This site had inadequate available phosphorus in its soil (25 ppm Mehlic phosphorus) at planting. However it had adequate zinc (8.58 ppm Mehlich zinc) unlike the other test sites. Zinc has similar functions like phosphorus. This may have compromised the overall influence of phosphorus on the dry matter accumulation. The department of environment and primary studies (1995) reported that phosphorus may not have a marked effect on dry matter content. However, it may if anything increas it. The specific gravity of Shangi was however higher than that of Unica. This is confirmed by NPCK (2019) that noted the dry matter accumulation of Shangi and Unica to be 21.4% and 21%, respectively. Mailer *et al.,* 1989 in his studies on potatoes noted that there was significant difference in the specific gravity of varieties. Also, phosphorus has various effects on tuber quality, since it functions in cell division and synthesis and storage of starch in the tubers (Houghland, 1960). Hence, it can increase the size and percentage of dry matter (indicated by specific gravity) of the tubers (Freeman *et al.,* 1998; Rosen *et al.,* 2014).

5.3.2 Influence of phosphorus on final germination percentage (%) of potato seed

At Saboti, the average final germination percentage of Shangi was 88.9 % while that of Unica was 100%. As much as this difference was not statistically significant, Unica was noted to have better cooping capacities to climate change impacts which included attacks of pests like aphids and diseases like potato blight. Waikwa (2018) noted Unica as one of the new varieties in Kenya which is more tolerant to diseases, higher yielding and more tolerant to harsh conditions than older varieties. There was positive correlation between phosphorus rate and mean (r = +0.5), Shangi's (r = +0.5) and Unica's (r = +0.5) final percentage germination.

At Ainabkoi, there was no significant difference between the final germination percentages of the two test varieties. Phosphorus rate did not significantly influence the germination percentage of the potato seed. However, the final germination percentage of Shangi (88.1%) was lower than that of Unica (96.1%). This was due to Unica being more resistant to pests and diseases than Shangi. There was a positive correlation (r = +0.7) between phosphorus rate and mean (r = +0.7), Shangi's (r = +0.1) and Unica's (r = +0.5) final germination percentage.

At Lari, there was no significant influence of phosphorus rate, variety and their interaction on the final germination percentage of the two test varieties. The final germination percentage of Unica (100%) was higher than that of Shangi (75.6 %) due to the former being more resistant to pests and diseases. Also, there was a small positive (r = +0.1) correlation between phosphorus rate and mean (r = +0.1) and Shangi's (r = +0.1) final germination percentage.

5.3.3 Influence of phosphorus on number eyes tuber^{-1} of potato seed

At Saboti, interaction between phosphorus rate and variety influenced the number of eyes tuber^{-1} of the test varieties (p= 0.045). Further, the correlation between phosphorus rate and mean (r = +0.2), Shangi's (r = +0.2) and Unica's (r = +0.2) number of eyes tuber^{-1} were weakly positive. At Ainabkoi the number of eyes tuber^{-1} of varieties differed significantly (p = 0.034). Interaction between phosphorus rate and variety significantly (p=0.005) influenced the number of eyes tuber^{-1} of test varieties. At this site there was a very weak negative correlation (r = - 0.1) between phosphorus rate and its mean number of eyes tuber^{-1}. There was also negative correlation between phosphorus rate and the average number of potato eyes tuber^{-1} for Shangi (r = -0.6) and Unica (r = -0.3). At Lari phosphorus, varieties and interaction between phosphorus and variety had no significant difference on the number of eyes tuber^{-1}. Correlation between phosphorus rate and number of eyes tuber^{-1} of Shangi (r = +0.1) was positive while correlation between the same rate and Unica's number of eyes (r = -0.8) was negative. As much as the number of eyes tuber^{-1} of potatoes is a genetic function that is related to variety, the size of a potato and soil nutrients like available phosphorus affects this number (Nielson *et al.*, 1989). The bigger the potato the more the number of eyes tuber^{-1}. In all the test sites there was a weak and/or negative correlation between phosphorus rate and varieties' number of eyes per tuber. Thus, Absolute control treatments or zero phosphorus treatments (Lari's Unica only) produced potatoes closer to the recommended range of four to six eyes per potato seed tuber (KEPHIS, 2016). Potatoes with more than six eyes tuber^{-1} may be useful as seed if they are sliced to smaller ones as they may not be economical to plant. High standards of hygiene and sanitation are required if they are sliced. This may not be within the reach of an ordinary potato farmer who is the end user of seed tubers. Potatoes with less than four eyes tuber^{-1} may be too small for seed. In the event of heavy rainfall, they will tend to rot bringing high losses to farmers. In studies on potato seed productivity by Nielson *et al.,* 1989 noted that there was a relationship between the potato tuber size and number of eyes tuber^{-1}. Since phosphorus application influenced potato seed tuber's size, it consequently influenced the tuber's number of eyes. Harris (1978) noted that there is a positive correlation between potato size and number of eyes tuber^{-1} in way that the increase in eyes diminishes as the size of the potato increases. It is also noted that phosphorus rate positively influenced the number of potato tubers produced. The lowest numbers of eyes were still above the recommended number of four to six eyes per potato (KEPHIS, 2016). NPCK, 2019 noted differences in the number of eyes tuber^{-1} of potatoes based on the potatoes genetic constitution.

5.4 Influence of phosphorus on its use efficiency

At Saboti, phosphorus rate influenced its use efficiency. The correlation between phosphorus rate and Shangi's (r = +0.5) and Unica's (r = +0.9) phosphorus use efficiency were positive. The most efficient phosphorus rate for Shangi was achieved with the application of 60 kg ha^{-1} phosphorus. The phoshotus use efficiency for Unica was negative. Thus the phosphorus applied to Unica was not useful for production Unica's potato seed tubers. However, it was useful for production of ware potato tubers

(Akoto *et al.,* 2020). Most seed potato tubers overgrew into ware potato tubers (Akoto *et al.,* 2020). At Ainabkoi, phoshorus rate influenced its use efficiency. The correlation between phosphorus rate and Shangi's (r = 0.4)/ Unica's (r = -0.2) phosphorus use efficiency were weak. The most efficient phosphorus rate was achieved with the application of 30 kg ha^{-1} phosphorus. At Lari, phosphorus rate and interaction between phosphorus rate and variety did not influency its use efficiency. The correlation between phosphorus rate and Shangi's (r = -1.0) and Unica's (r = -0.7) phosphorus use efficiency were strong and negative. The most efficient phosphorus rate was achieved with the application of 30 kg ha^{-1} phosphorus for Shangi and Unica varieties.

At the highest phosphorus use efficiency the applied phosphorus fertilizer is useful to the plant unlike the higher rates of phosphorus applications. Nyiraneza *et al.,* 2017 noted that potato varieties may or may not differ in their phosphorus use efficiency. The author reported that response to fertilizer application reduced with phosphorus rate of application up to a critical level beyond which there was no response. This confirms the current study findings in Saboti, Ainabkoi and Lari where the efficiency of phosphorus application and hence the response of potato to it reduced with increased phosphorus rate.

5.5 Comparisons of key parameters at the test sites

5.5.1 Comparison of qualitative parameters

The soil type of Saboti and Ainabkoi were classified as nitisols. They were more fertile as compared to soils of Lari. They also had more clay in the sub soil, were deep and had dark brown colour. The brown colour of these soils indicates that they had sesquioxides. The particles of clay in the subsurface horizon were sub angular and blocky with shiny peds. They therefore had an argillic B horizon which is a diagnostic horizon for nitisols (FAO-UNESCO, 1974 & WRB, 2014). The soils supported various crops and livestock, due to their being overworked, leaching and erosion of nutrients, the soils were substantially exhausted. This explains the use of both organic and mineral fertilizers in crop production in these test sites. Due to their low pH, they have a likelyhood of phosphorus fixation. The soils of Lari were classified as planosols (FAO-UNESCO, 1974; WRB, 2014 & Gachene and Kimaru, 2013). They are part of the central highlands of Kenya on a plateau with very high water table, thus there is water logging in the area. The surface horizon was noted to be grey in colour, a sign of eluviation and illuviation of clay while the sub surface horizon was reddish brown in colour, indicating the presence of iron oxides. There was abrupt change in the colours of the top-surface and sub-surface horizons. Farmers in the area had dug drainage channels and planted horticultural crops like potato. Leaching of soil nutrients especially phosphorus was evident as young maize crop planted in the area was purple in colour.

5.5.2 Comparison of tuber yields (t ha^{-1}) with soil available and plant available phosphorus (ppm)

There was a perfect negative correlation ($r = -1.0$) between small grade yield and soil available phosphorus at planting and harvesting. Saboti had the lowest; Lari had the highest while Ainabkoi had the average yield of small grade potato seed. Soil available phosphorus at planting and harvesting time was highest at Saboti, followed by Ainabkoi and least at Lari. Lower soil phosphorus levels therefore favoured the yields of small grade potatoes.

5.5.3 Comparisons of variety's yields with soil available and plant total phophorus

For small grade yield of Shangi, the lesser the soil fertility the more was the yield. For the overall grade yield of Shangi, high fertility favoured the yield. Also, for Unica's small grade yield; high fertility favoured its yield. Overall, the seed yield of Shangi was greater than that of Unica. The uptake of phosphorus by the potatoes was higher at Saboti in comparison to Ainabkoi and Lari. Unica is known to be a heavy feeder whose tubers have a tendency to overgrow the seed size to become "ware" potato tubers (NPCK, 2019). This is unlike Shangi that maximized on soil fertility to yield more seed grade potato tubers.

5.5.4 Comparisons of final germination percentage of the test sites

In all the test sites, the final germination percentage of Unica was greater than that of Shangi. This was due to Unica being more resistant or tolerant to disease attacks like late blight disease. From field observations, there was more tolerance to disease attacks in Lari than Saboti or Ainabkoi. Low temperatures slowed down disease and pest attack at Lari as compared to Saboti and Ainabkoi that were warmer during the season.

5.5.5 Comparison of the phosphorus use efficiencies of the test sites

The mean phosphorus use efficiency of Unica was less than that of Shangi since Unica produced more "ware" potatoes than Shangi. Unica is known to be a heavy feeder (NPCK, 2019) whose tubers have tendencies to overgrow the seed size grade to become "ware" tubers. This is unlike Shangi that maximized on soil fertility to yield more seed grade potato tubersIn general, there was a negative correlation between site soil fertility and phosphorus use efficiency. The higher the soil fertility, the smaller the seed potato phosphorus use efficiency. Potato grown in soils rich in phosphorus may maximize on applied soil phosphorus to become ware (Akoto *et al.,* 2020).

5.5.6 Comparison of the average tuber weight of varieties in test sites

The least average seed weight per tuber was realised with Shangi in all the test sites and in all seed categories except for the overall seed grade weight of Unica in Saboti which was slightly lighter than that of Shangi. Apprently, an average Unica tuber is not only bigger in size than an average Shangi tuber (NPCK, 2019), but also heavier than the same Shangi tuber. Seed farmers who grow Unica for seed have to be more keen on dehaulming the variety at the right physiological stage to avoid it becoming “ware” and hence more uneconomical for seed.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

Overall seed yield

There was significant influence of phosphorus on overall seed grade tuber yield in the three test sites. The correlation between mean overall yield, Shangi's overall yield and Unica's overall tuber yield of potatoes and the available soil phosphorus status of the sites at planting was significant. For highest overall tuber yields, Shangi and Unica of Saboti, Ainabkoi and Lari require Absolute control & 0 kg ha^{-1} phosphorus; 60 & 30 kg ha^{-1} phosphorus and 60 & 90 kg ha^{-1}, phosphorus, respectively.

Small grade seed yield

For maximum small grade tuber yields of Shangi and Unica; Saboti, Ainabkoi and Lari needed phosphorus rates of 60 kg ha^{-1} and 0; 120 kg ha^{-1} and 30 kg ha^{-1} and 120 kg ha^{-1} and 120 kg ha^{-1} phosphorus, respectively.

Large grade seed yield

For maximum large grade tuber yields of Shangi and Unica; Saboti, Ainabkoi and Lari needed phosphorus rates of Absolute control & 0; 90 kg ha^{-1} & 120 kg ha^{-1} and 60 kg ha^{-1} & 60 kg ha^{-1} phosphorus, respectively.

Quality of the potato seed

Interaction between phosphorus rate and variety influenced specific gravity of potato seed at all the test sites. The final germination percentage of Unica was greater than that of Shangi, although the difference was not statistically significant. In all the test sites, the average number of eyes of both test varieties was more than 4 eyes with Shangi having more eyes than Unica. The least number of eyes was realised in Absolute control plots apart from Lari's Unica that produced the least number of eyes in the 0 phosphorus plots.

Phosphorus use efficiency

Maximum phosphorus use efficiency at Saboti, Ainabkoi and Lari were realised at phosphorus application rates of 0, 30 and 30 kg ha^{-1} phosphorus, respectively. The highest mean phosphorus use efficiency was realised at Lari, followed by Ainabkoi and Saboti. The lower the applied/available phosphorus the higher the phosphorus use efficiency.

6.2 Recommendations

Overall grade potato seed production

Farmers in Saboti may not need to apply phosphorus for Shangi's and Unica's overall potato seed production.

Farmers in Ainabkoi may apply 60 and 30 kg ha^{-1} phosphorus for Shangi's and Unica's overall potato seed seed production, respectively.

Farmers in Lari may apply 60 and 90 kg ha^{-1} phosphorus for both Shangi's and Unica's overall potato seed production, respectively.

Small grade potato seed production

Farmers in Saboti may apply 60 kg ha^{-1} phosphorus for Shangi's small grade potato seed production. They however may not need to apply phosphorus for Unica's small grade potato seed production. Farmers in Ainabkoi may apply 120 kg ha^{-1} phosphorus for Shangi's and 30 kg ha^{-1} phosphorus for Unica's small grade potato seed seed production.Farmers at Lari test site may apply 120 kg ha^{-1} phosphorus for both Shangi's and Unica's small grade potato seed production.

Large grade potato seed production

Farmers in Saboti may not need to apply phosphorus for Shangi's large grade potato seed production. However, they may apply nitrogen and not phosphorus for Unica's large grade potato seed production. Farmers in Ainabkoi may not need to apply nitrogen and phosphorus for large grade potato seed production. Farmers at Lari may apply 60 kg ha^{-1} phosphorus for both Shangi's and Unica's large grade potato seed production.

Recommendation based on quality of potato seed

Farmers need to grow potato varieties (like Unica) that have good quality attributes: more resistant to pest and disease attack; more final percentage germination; number of eyes near range of four to six eyes. For farmers who value varieties with short dormancy period, Shangi is recommended. Further research is needed on the influence of phosphorus on the specific gravity of seed potatoes.

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APPENDICES

Appendix I: ANOVA for influence of phosphorus on soil available phosphorus (ppm) at harvesting at Saboti

Variate: Available phosphorus rate (ppm) at Saboti

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	754.6	377.3	2.46	
Blocks.whole plots stratum					
Variety	1	893.9	893.9	5.83	0.137
Residual	2	306.5	153.2	0.97	
Blocks.whole plots.sub plots stratum					
Phosphorus	5	3553.1	710.6	4.48	0.007
Phosphorus.variety	5	2207.8	441.6	2.78	0.046
Residual	20	3172.6	158.6		
Total	35	10888.4			

Appendix II: ANOVA for influence of phosphorus on soil available phosphorus (ppm) at harvesting at Ainabkoi

Variate: Available phosphorus rate (ppm) at Ainabkoi)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	613.8	306.9	0.56	
Blocks.whole plots stratum					
Variety	1	2131.1	2131.1	3.91	0.187
Residual	2	1090.5	545.2	0.63	
Blocks.whole plots.sub plots stratum					
Phosphorus	5	15050.0	3010.0	3.50	0.020
Phosphorus.variety	5	9170.8	1834.2	2.13	0.103
Residual	20	17185.0	859.2		
Total	35	45241.2			

Appendix III: ANOVA for influence of phosphorus on soil available phosphorus (ppm) at harvesting at Lari

Variate: Available phosphorus rate (ppm) at Lari

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	981.1	490.5	2.18	
Blocks.whole plots stratum					
Variety	1	109.0	109.0	0.49	0.558
Residual	2	449.1	224.5	1.77	
Blocks.whole plots.sub plots stratum					
Phosphorus	5	1980.0	396.0	3.11	0.031
Phosphorus.variety	5	3539.7	707.9	5.57	0.002
Residual	20	2542.8	127.1		
Total	35	9601.6			

Appendix IV: ANOVA for influence of phosphorus on potato plant phosphorus (%) at harvesting at Saboti

Variate: Potato plant tuber phosphorus (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	0.001363	0.000681	0.22	
Blocks.whole plots stratum					
Variety	1	0.002026	0.002026	0.66	0.502
Residual	2	0.006158	0.003079	0.75	
Blocks.whole plots.sub plots stratum					
Phosphorus	5	0.170394	0.034079	8.36	<.001
Phosphorus.variety	5	0.095224	0.019045	4.67	0.005
Residual	20	0.081573	0.004079		
Total	35	0.356737			

Appendix V: ANOVA for influence of phosphorus on potato plant phosphorus (%) at harvesting at Ainabkoi

Variate: Potato plant tuber phosphorus (%)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	0.006892	0.003446	0.30	
Blocks.whole plots stratum					
Variety	1	0.005519	0.005519	0.48	0.561
Residual	2	0.023130	0.011565	2.14	
Blocks.whole plots.sub plots stratum					
Phosphorus	5	0.135769	0.027154	5.02	0.004
Phosphorus.variety	5	0.111381	0.022276	4.12	0.010
Residual	20	0.108245	0.005412		
Total	35	0.390934			

Appendix VI: ANOVA for influence of phosphorus on potato plant phosphorus (ppm) at harvesting at Lari

Variate: Potato plant tuber phosphorus (%)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	0.006374	0.003187	0.23	
Blocks.whole plots stratum					
Variety	1	0.000233	0.000233	0.02	0.909
Residual	2	0.028092	0.014046	2.36	
Blocks.whole plots.sub plots stratum					
Phosphorus	5	0.132088	0.026418	4.44	0.007
Phosphorus.variety	5	0.067344	0.013469	2.26	0.087
Residual	20	0.119018	0.005951		
Total	35	0.353149			

Appendix VII: ANOVA on influence of phosphorus on overall potato seed yield (t ha^{-1}) at Saboti

Variate: Overall yield in tonnes per ha					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	10.62	5.31	0.20	
Blocks.whole plots stratum					
Variety	1	556.86	556.86	20.91	0.045
Residual	2	53.27	26.63	1.75	
Blocks.whole plots.sub plots stratum					
Phosphorus	5	920.06	184.01	12.08	<.001
Phosphorus.variety	5	1290.48	258.10	16.94	<.001
Residual	20	304.63	15.23		
Total	35	3135.92			

Appendix VIII: ANOVA on influence of phosphorus on overall potato seed yield (t ha^{-1}) at Ainabkoi

Variate: Overall yield in tonnes per ha					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	50.49	25.24	3.16	
Blocks.whole plots stratum					
Variety	1	8.91	8.91	1.12	0.402
Residual	2	15.97	7.99	0.57	
Blocks.whole plots.sub plots stratum					
Phosphorus	5	143.09	28.62	2.02	0.119
Phosphorus.variety	5	229.72	45.94	3.25	0.026
Residual	20	282.71	14.14		
Total	35	730.90			

Appendix IX: ANOVA on influence of phosphorus on overall potato seed yield (t ha^{-1}) at Lari

Variate: Overall seed yield in tonnes per ha					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	10.336	5.168	1.01	
Block.whole block stratum					
Variety	1	512.609	512.609	100.31	0.010
Residual	2	10.221	5.110	0.54	
Block.whole block.Sub plot stratum					
Phosphorus	5	375.520	75.104	7.98	<.001
Phosphorus.variety	5	233.696	46.739	4.97	0.004
Residual	20	188.225	9.411		
Total	35	1330.606			

Appendix X: ANOVA on influence of phosphorus on overall tuber number ha^{-1} at Saboti

Variate: Overall tuber number per ha					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	3.349E+09	1.675E+09	0.38	
Blocks.whole plots stratum					
Variety	1	1.682E+11	1.682E+11	38.41	0.025
Residual	2	8.757E+09	4.379E+09	0.80	
Blocks.whole plots.sub plots stratum					
Phosphorus	5	9.644E+10	1.929E+10	3.54	0.019
Phosphorus.variety	5	1.422E+11	2.843E+10	5.22	0.003
Residual	20	1.089E+11	5.444E+09		
Total	35	5.278E+11			

Appendix XI: ANOVA on influence of phosphorus on overall tuber number ha^{-1} at Ainabkoi

Variate: Overall tuber number per ha					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	4.988E+09	2.494E+09	1.26	
Blocks.whole plots stratum					
Variety	1	2.158E+11	2.158E+11	109.19	0.009
Residual	2	3.953E+09	1.977E+09	2.66	
Blocks.whole plots.sub plots stratum					
Phosphorus	5	2.159E+10	4.317E+09	5.80	0.002
Phosphorus.variety	5	1.022E+10	2.043E+09	2.75	0.048
Residual	20	1.488E+10	7.442E+08		
Total	35	2.715E+11			

Appendix XII: ANOVA on influence of phosporus on overall tuber numbers ha^{-1} at Lari

Variate: Overall tuber number per ha					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	4.394E+09	2.197E+09	1.11	
Blocks.whole plots stratum					
Variety	1	3.873E+11	3.873E+11	194.85	0.005
Residual	2	3.975E+09	1.988E+09	1.03	
Blocks.whole plots.sub plots stratum					
Phosphorus	5	1.002E+11	2.005E+10	10.37	<.001
Phosphorus.variety	5	8.088E+10	1.618E+10	8.36	<.001
Residual	20	3.868E+10	1.934E+09		
Total	35	6.155E+11			

Appendix XIII: ANOVA for influence of phosphorus on small grade potato seed yield (t ha^{-1}) at Saboti

Variate: Small grade yield in tonnes per ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	28.619	14.309	1.17	
Block.whole plot stratum					
Variety	1	0.239	0.239	0.02	0.902
Residual	2	24.441	12.221	1.85	
Block.whole plot.sub plot stratum					
Phosphorus rate	5	149.290	29.858	4.52	0.006
Phosphorus rate.variety	5	109.565	21.913	3.32	0.024
Residual	20	132.024	6.601		
Total	35	444.178			

Appendix XIV: ANOVA for influence of phosphorus on small grade potato seed yield (t ha^{-1}) at Ainabkoi

Variate: Small grade yield in tonnes per ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	1.0382	0.5191	0.32	
Block.whole plot stratum					
Variety	1	86.8558	86.8558	52.88	0.018
Residual	2	3.2848	1.6424	1.70	
Block.whole plot.sub plot stratum					
Phosphorus rate	5	41.8307	8.3661	8.65	<.001
Phosphorus rate.variety	5	40.8531	8.1706	8.44	<.001
Residual	20	19.3523	0.9676		
Total	35	193.2150			

Appendix XV: ANOVA for influence of phosphorus on small grade potato seed yield (t ha^{-1}) at Lari

Variate: Small grade yield in tonnes ha^{-1}

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.039	0.019	0.48	
Block.whole plot stratum					
Variety	1	178.647	178.647	4426.77	<.001
Residual	2	0.081	0.040	0.04	
Block.whole plot.sub plot stratum					
Phosphorus rate	5	74.573	14.915	13.74	<.001
Phosphorus rate.variety	5	37.776	7.555	6.96	<.001
Residual	20	21.717	1.086		
Total	35	312.832			

Appendix XVI: ANOVA for influence of phosphorus on small grade potato seed number ha^{-1} at Saboti

Variate: Small grade tuber number ha^{-1}

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	8.474E+08	4.237E+08	0.33	
Block.whole plot stratum					
Variety	1	3.936E+10	3.936E+10	30.21	0.032
Residual	2	2.605E+09	1.303E+09	0.87	
Block.whole plot.sub plot stratum					
Phosphorus rate	5	2.784E+10	5.567E+09	3.73	0.015
Phosphorus rate.variety	5	4.161E+10	8.322E+09	5.57	0.002
Residual	20	2.988E+10	1.494E+09		
Total	35	1.421E+11			

Appendix XVII: ANOVA for influence of phosphorus on small grade potato seed tuber number (tubers ha^{-1}) at Ainabkoi

Variate: Small grade tuber number ha^{-1}					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	4.502E+09	2.251E+09	0.73	
Block.whole plot stratum					
Variety	1	1.352E+11	1.352E+11	43.79	0.022
Residual	2	6.176E+09	3.088E+09	1.76	
Block.whole plot.sub plot stratum					
Phoshorus rate	5	1.878E+10	3.755E+09	2.14	0.103
Phosphorus rate.variety	5	1.205E+10	2.411E+09	1.37	0.277
Residual	20	3.514E+10	1.757E+09		
Total	35	2.119E+11			

Appendix XVIII: ANOVA for influence of phosphorus on small grade potato seed number (tubers ha^{-1}) at Lari

Variate: Small grade tuber number ha^{-1}					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	2.330E+09	1.165E+09	1.00	
Block.whole plot stratum					
Variety	1	1.959E+11	1.959E+11	167.89	0.006
Residual	2	2.334E+09	1.167E+09	1.26	
Block.whole plot.sub plot stratum					
Phosphorus rate	5	4.820E+10	9.641E+09	10.41	<.001
Phosphorus rate.variety	5	3.558E+10	7.116E+09	7.68	<.001
Residual	20	1.853E+10	9.265E+08		
Total	35	3.029E+11			

Appendix XIX: ANOVA for influence of phosphorus on large grade potato seed yield (t ha^{-1}) at Saboti

Variate: Large grade yield in tonnes ha^{-1}

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	51.426	25.713	9.35	
Block.whole plot stratum					
Variety	1	21.826	21.826	7.93	0.106
Residual	2	5.502	2.751	0.39	
Block.Whole plot.Sub plot stratum					
Phosphorus rate	5	873.119	174.624	24.80	<.001
Phosphorus rate.variety	5	391.184	78.237	11.11	<.001
Residual	20	140.806	7.040		
Total	35	1483.863			

Appendix XX: ANOVA for influence of phosphorus on large grade potato seed yield (t ha^{-1}) at Ainabkoi

Variate: Large grade yield in tonnes ha^{-1}

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	4.205	2.103	0.72	
Block.whole plot stratum					
Variety	1	258.076	258.076	88.05	0.011
Residual	2	5.862	2.931	1.19	
Block.whole plot.sub plot stratum					
Phosphorus rate	5	192.060	38.412	15.59	<.001
Phosphorus rate.variety	5	25.002	5.000	2.03	0.118
Residual	20	49.285	2.464		
Total	35	534.490			

Appendix XXI: ANOVA for influence of phosphorus on large grade potato seed yield (t ha^{-1}) at Lari

Variate: Large grade yield in tonnes per ha					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	2.499	1.249	0.99	
Block.whole plot stratum					
Variety	1	132.386	132.386	104.95	0.009
Residual	2	2.523	1.261	0.52	
Block.whole plot.sub plot stratum					
Phosphorus rate	5	255.290	51.058	21.01	<.001
Phosphorus rate.variety	5	138.335	27.667	11.38	<.001
Residual	20	48.606	2.430		
Total	35	579.639			

Appendix XXII: ANOVA for influence of phosphorus on large grade potato seed number (tubers ha^{-1}) at Saboti

Variate: Large grade tuber number ha^{-1}					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	1.943E+09	9.713E+08	0.93	
Block.whole plot stratum					
Variety	1	6.271E+10	6.271E+10	60.27	0.016
Residual	2	2.081E+09	1.041E+09	3.26	
Block.whole plot.sub plot stratum					
Phosphorus rate	5	1.282E+11	2.564E+10	80.42	<.001
Phosphorus rate.variety	5	2.513E+10	5.027E+09	15.77	<.001
Residual	20	6.375E+09	3.188E+08		
Total	35	2.264E+11			

Appendix XXIII: ANOVA for influence of phosphorus on large grade potato seed number (tubers ha^{-1}) at Ainabkoi

Variate: Large grade tuber number per ha					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	1.953E+09	9.763E+08	21.87	
Block.whole plot stratum					
Variety	1	8.666E+08	8.666E+08	19.41	0.048
Residual	2	8.927E+07	4.464E+07	0.08	
Block.whole plot.sub plot stratum					
Phosphorus rate	5	5.874E+10	1.175E+10	21.81	<.001
Phosphorus rate.variety	5	5.613E+10	1.123E+10	20.84	<.001
Residual	20	1.077E+10	5.387E+08		
Total	35	1.286E+11			

Appendix XXIV: ANOVA for influence of phosphorus on large grade potato seed number (tubers ha^{-1}) at Lari

Variate: Large grade tuber number ha^{-1}					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	9.400E+08	4.700E+08	0.38	
Block.whole plot stratum					
Variety	1	3.596E+10	3.596E+10	28.82	0.033
Residual	2	2.495E+09	1.248E+09	2.77	
Block.Whole plot.sub plot stratum					
Phosphorus rate	5	4.559E+10	9.117E+09	20.23	<.001
Phosphorus rate.variety	5	3.156E+10	6.311E+09	14.00	<.001
Residual	20	9.014E+09	4.507E+08		
Total	35	1.256E+11			

Appendix XXV: ANOVA on influence of phosphorus on potato seed specific gravity (g g^{-1}) at Saboti

Variate: Specific gravity (g g^{-1})					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	0.00002222	0.00001111	0.33	
Blocks.whole plots stratum					
Variety	1	0.00040000	0.00040000	12.00	0.074
Residual	2	0.00006667	0.00003333	1.50	
Blocks.whole plots.sub plots stratum					
Phosphorus	5	0.00105556	0.00021111	9.50	<.001
Phosphorus.variety	5	0.00193333	0.00038667	17.40	<.001
Residual	20	0.00044444	0.00002222		
Total	35	0.00392222			

Appendix XXVI: ANOVA on influence of phosphorus on specific gravity (g g^{-1}) of potato seed at Ainabkoi

Variate: Specific gravity (g g^{-1})					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	0.00010556	0.00005278	4.75	
Blocks.whole plots stratum					
Variety	1	0.00080278	0.00080278	72.25	0.014
Residual	2	0.00002222	0.00001111	0.25	
Blocks.whole plots.sub plots stratum					
Phosphorus	5	0.00368056	0.00073611	16.26	<.001
Phosphorus.variety	5	0.00222222	0.00044444	9.82	<.001
Residual	20	0.00090556	0.00004528		
Total	35	0.00773889			

Appendix XXVII: ANOVA on influence phosphorus on specific gravity (g g^{-1}) of potato seed at Lari

Variate: Specific gravity (g g^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	0.0006933	0.0003466	23.96	
Blocks.whole plots stratum					
Variety	1	0.0014125	0.0014125	97.65	0.010
Residual	2	0.0000289	0.0000145	0.10	
Blocks.Whole plots.sub plots stratum					
Phosphorus	5	0.0011939	0.0002388	1.69	0.184
Phosphorus.variety	5	0.0031055	0.0006211	4.39	0.007
Residual	20	0.0028326	0.0001416		
Total	35	0.0092667			

Appendix XXVIII: ANOVA on influence of phosphorus on number of eyes tuber $^{-1}$ at Saboti

Variate: Average number of eyes per tuber

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	0.6667	0.3333	0.43	
Blocks.whole plots stratum					
Variety	1	2.7778	2.7778	3.57	0.199
Residual	2	1.5556	0.7778	1.32	
Blocks.whole plots.sub plots stratum					
Phosphorus	5	6.0000	1.2000	2.04	0.117
Phosphorus.variety	5	8.2222	1.6444	2.79	0.045
Residual	20	11.7778	0.5889		
Total	35	31.0000			

Appendix XXIX: ANOVA on influence of phosphorus on number of eyes tubers^{-1} at Ainabkoi

Variate: Average number of eyes per tuber						
Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2		0.2859	0.1429	0.10	
Blocks.whole plots stratum						
Variety	1		40.4496	40.4496	28.31	0.034
Residual	2		2.8579	1.4289	2.84	
Blocks.whole plots.sub plots stratum						
Phosphorus	5		12.4867	2.4973	4.96	0.005
Phosphorus.variety	5		4.1953	0.8391	1.67	0.191
Residual	19	(1)	9.5747	0.5039		
Total	34	(1)	66.2017			

Appendix XXX: ANOVA on influence of phosphorus on number of eyes tuber^{-1} at Lari

Variate: Average number of eyes per tuber					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	0.8472	0.4236	0.30	
Blocks.whole plots stratum					
Variety	1	22.5625	22.5625	16.16	0.057
Residual	2	2.7917	1.3958	2.93	
Blocks.whole plots.sub plots stratum					
Phosphorus	5	1.0347	0.2069	0.43	0.819
Phosphorus.variety	5	4.6458	0.9292	1.95	0.131
Residual	20	9.5278	0.4764		
Total	35	41.4097			

Appendix XXXI: ANOVA on influence of phosphorus on final germination percentage (%) at Saboti

Variate: Final germination percentage (%)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	1651.97	825.99	1.04	
blocks.whole plots stratum					
Variety	1	942.72	942.72	1.18	0.390
Residual	2	1591.56	795.78	8.40	
blocks. whole_ plots. Sub_ plots stratum					
Phosphorus	5	913.09	182.62	1.93	0.134
Phosphorus. variety	5	582.72	116.54	1.23	0.332
Residual	20	1894.22	94.71		
Total	35	7576.29			

Appendix XXXII: ANOVA on influence of phosphorus on final germination percentage (%) at Ainabkoi

Variate: Final germination percentage (%)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	1286.9	643.5	37.12	
Blocks.whole plots stratum					
Variety	1	168.0	168.0	9.69	0.090
Residual	2	34.7	17.3	0.10	
Blocks.whole plots.sub plots stratum					
Phosphorus	5	171.5	34.3	0.20	0.957
Phosphorus.variety	5	1138.5	227.7	1.36	0.282
Residual	20	3356.2	167.8		
Total	35	6155.8			

Appendix XXXIII: ANOVA on influence of phosphorus on final germination percentage (%) at Lari

Variate: Final germination percentage (%)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	109.74	54.87	1.00	
Blocks.whole plots stratum					
Variety	1	168.04	168.04	3.06	0.222
Residual	2	109.74	54.87	1.31	
Blocks.whole plots.sub plots stratum					
Phosphorus	5	158.61	31.72	0.76	0.592
Phosphorus.variety	5	158.61	31.72	0.76	0.592
Residual	20	840.19	42.01		
Total	35	1544.92			

Appendix XXXIV: ANOVA on influence of phosphorus on its use efficiency of at Saboti

Variate: Phosphorus use efficiency at Saboti in kg kg^{-1}					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	3695.	1847.	1.34	
Blocks.whole plots stratum					
Variety	1	939224.	939224.	682.81	0.001
Residual	2	2751.	1376.	0.22	
Blocks.whole plots.sub plots stratum					
Phosphorus	3	636605.	212202.	34.69	<.001
Phosphorus.variety	3	119666.	39889.	6.52	0.007
Residual	12	73399.	6117.		
Total	23	1775340.			

Appendix XXXV: ANOVA on influence of phosphorus on its use efficiency at Ainabkoi

Variate: Phosphorus use efficiency at Ainabkoi in kg kg^{-1}

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	4230	2115.	0.77	
Block.whole block stratum					
Variety	1	1320.	1320.	0.48	0.559
Residual	2	5475.	2738.	2.19	
Block.whole block.sub plot stratum					
Phosphorus	3	43510.	14503.	11.60	<.001
Phosphorus.variety	3	111931.	37310.	5.58	0.002
Residual	12	15009.	1251.		
Total	23	103833.			

Appendix XXXVI: ANOVA on influence of phosphorus on its use efficiency at Lari

Variate: Phosphorus use efficiency in kg kg^{-1}

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	568.4	284.2	0.22	
Block.whole block stratum					
Variety	1	72832.6	72832.6	56.16	0.017
Residual	2	2593.9	1296.9	1.33	
Block.whole block.sub plot stratum					
Phosphorus	3	6866.7	2288.9	2.34	0.125
Phosphorus.variety	3	2060.5	686.8	0.70	0.568
Residual	12	11719.1	976.6		
Total	23	96641.2			

Appendix XXXVII: ANOVA for influence of phosphorus on yield (t ha^{-1}) of "ware" potatoes at Saboti

Variate: "Ware" potato tuber yield in tonnes per ha						
Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2		631.81	315.91	1.75	
Blocks.whole plots stratum						
Variety	1		1221.38	1221.38	6.77	0.121
Residual	2		360.79	180.40	5.41	
Blocks.whole plots.sub plots stratum						
Phosphorus	5		666.68	133.34	4.00	0.023
Phosphorus.variety	5		554.73	110.95	3.33	0.041
Residual	12	(8)	399.96	33.33		
Total	27	(8)	3224.35			

Appendix XXXVIII: ANOVA for influence of phosphorus on "ware" potato tuber numbers (tubers ha^{-1}) at Saboti

Variate: Saboti "ware" potato tuber number per ha					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	9.046E+08	4.523E+08	1.41	
Blocks.whole plots stratum					
Variety	1	2.936E+10	2.936E+10	91.51	0.011
Residual	2	6.417E+08	3.209E+08	0.37	
Blocks.whole plots.sub plots stratum					
Phosphorus	5	1.095E+11	2.189E+10	25.05	<.001
Phosphorus.variety	5	1.323E+10	2.646E+09	3.03	0.034
Residual	20	1.748E+10	8.740E+08		
Total	35	1.711E+11			

Trends in Kenya's potato production

Appendix XXXIX: Kenya's potato production since 2007 to 2018

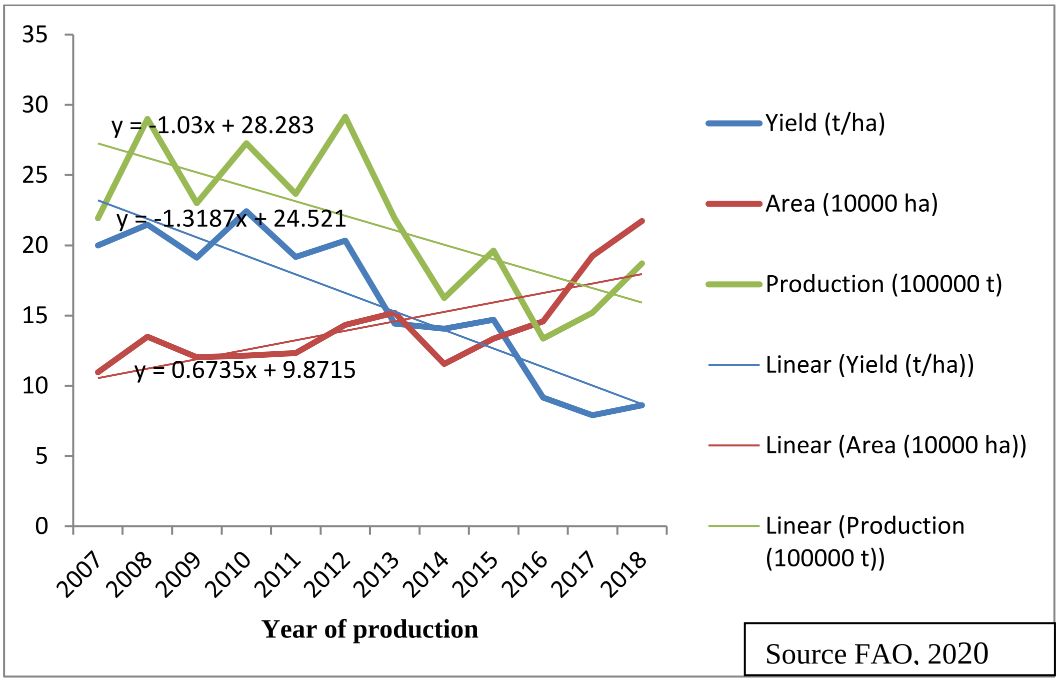


Figure 8: Potato production trend in Kenya from 2007 to 2018

Appendix XL: Kenya's potato area, yield and production from 1961 to 2018

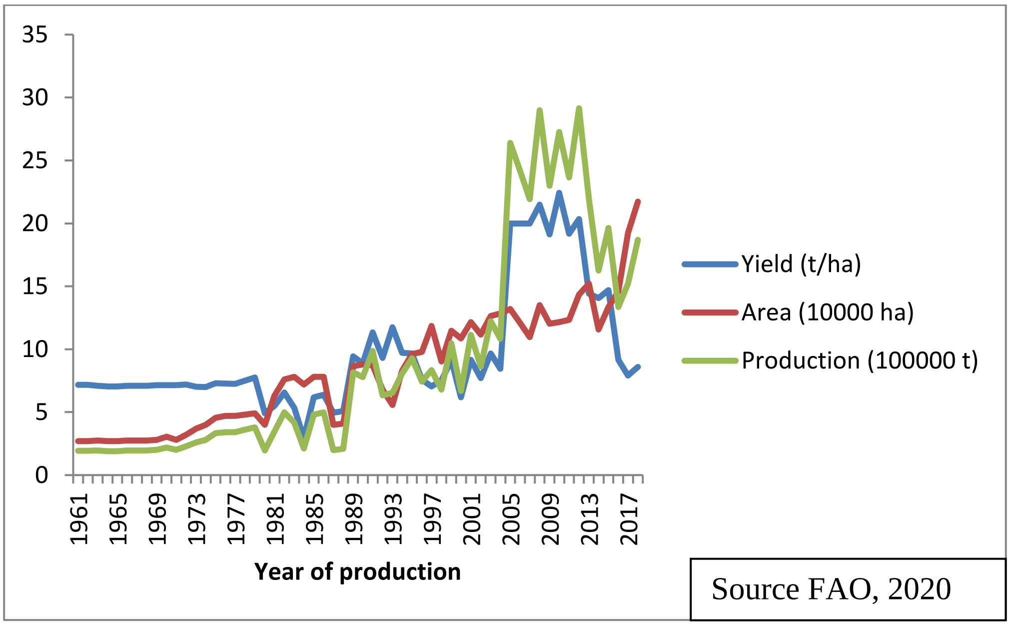


Figure 9: Kenya's potato production trend from 1961 to 2018

Appendix XLI: Kenya's potato production, area and yield trend from 1961 to 2018

(a) Kenya's potato production

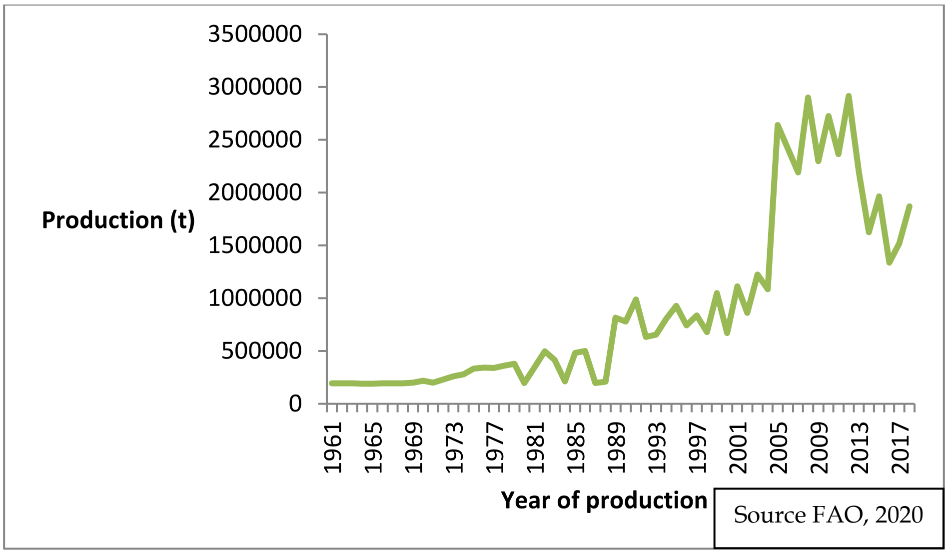


Figure 10: Kenya's potato production from 1961 to 2018

(b) Kenya's area under potato from 1961 to 2018

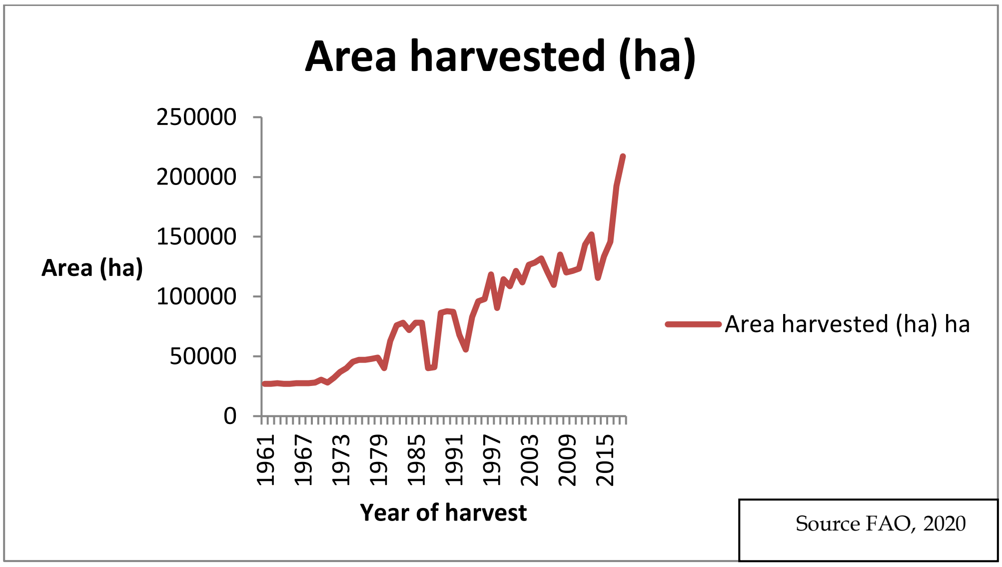


Figure 11: Kenya's area under production from 1961 to 2018

(c) Kenya's potato yield from 1961 to 2018

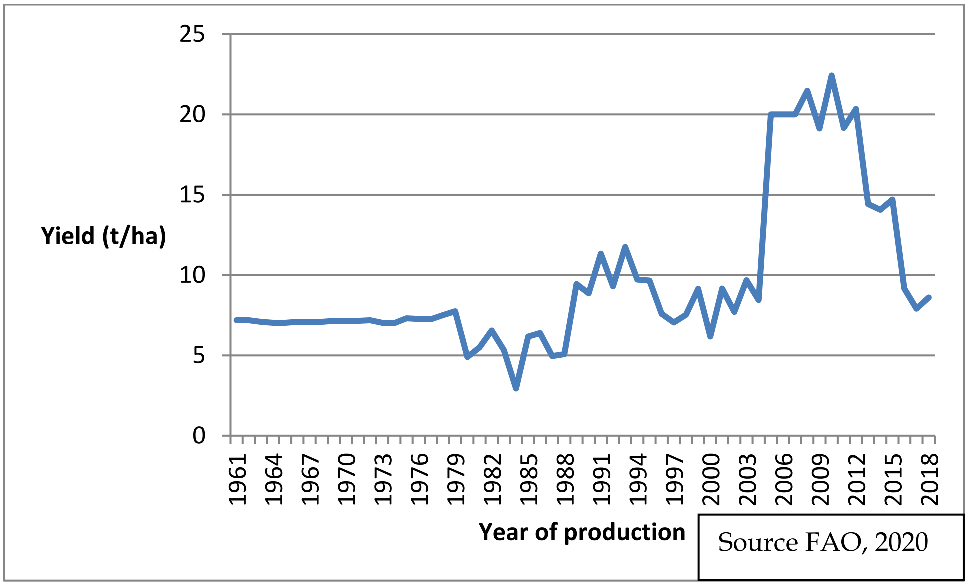


Figure 12: Potato yield in Kenya from 1961 to 2018

Appendix XLII: Available phosphorus indices

(a) Olsen phosphorus (bicarbonate extractable phosphorus mg/l) and soil phosphorus Index (2) (Phosphorus mg /l)

Phosphorus mg l^{-1}	Soil phosphorus index	Remarks
0-9	0	Most crops will respond to phosphorus application
10-15	1	Potatoes and some crops will respond to phosphorus application
16-25	2	Critical phosphorus = 26 mg l^{-1}
26-45	3	Few crops will respond to phosphorus application
46-70	4	Very few crops especially in soils where phosphorus is easily fixed will respond to phosphorus application

Source: Ekelof (2007)

(b) **P AL (Ammonium laktatacetat extracted phosphorus mg/100g) and soil phosphorus index (phosphorus mg /100g)**

Phosphorus mg l^{-1}	Soil phosphorus index	Remarks
< 2.0	1	
2.0 – 4.0	2	
4.1 - 8.0	3	Recommended phosphorus for potatoes =70 kg ha^{-1}
8.1-16.0	4	
>16.0	5	

Source: Ekelof (2007)

Appendix XLIII: Agro ecological zones of Kenya

AEZ	Altitude (masl)	Temperature (°C)	Rainfall (mm)	Moisture Index (%)	% Surface
TA	> 2800	2-10	1100 – 2700	> 80	
UH1 & UH2	2350 -2800	10-15	900-1600	65-80	
LH	2000-2350	15-18	900-1600	50-65	
UM	1500-2000	18-21	600-1350	40-50	
LM	1000-1500	21-24	450-900	25-40	15
IL	750 -1000	24	550	15-25	Intermediate lands
CL	< 1500				

Sources: NAAIAP, 2014; Jaetzold *et al.,* 2011; Jaetzold & Schimidt, 2009

Appendix XLIV: Nitosols (N) from FAO-UNESCO 1974

These are soils having an argillic B horizon with a clay distribution where the percentage of clay does not decrease from its maximum amount by as much as 20 percent within 150 cm of the surface; lacking a mollic A horizon; lacking an albic E horizon; lacking the tonguing which is diagnostic for the padzoluvisols; lacking ferric and vertic properties; lacking plinthite within 125 cm of the surface; “lacking an aridic moisture regime”. Eutric nitosols (Ne) Nitosols having a base saturation of 50 percent or more (by NH_2Oac) throughout the argillic B horizon within 125 cm of the surface. Dystric nitosols (Nd) are nitosols having a base saturation of less than 50 percent (by NH_2Oac) in at least a part of the argillic B horizon within 125 cm of the surface; lacking a high organic matter content in the B horizon and lacking an umbric A horizon. Humic nitosols (Nh) are nitisols having a base saturation of less than 50 percent (by NH_2Oac) in at least a part of the argillic B horizon within 125 cm of the surface; having an umbric A horizon or a high organic matter content in the B horizon, or both.

Appendix XLV: Facts about planosols

Planosols have Albic E horizon, overlying a slowly permeable horizon within 125 cm of the surface for example an agillic or a natric B horizon showing an abrupt textural, a heavy clay, a frag pan exclusive of a spodic B horizon, showing hydromorphic properties at least in part of the E-horizon. They are soils with a bleached, light-coloured, eluvial surface horizon that shows signs of periodic water stagnation and abruptly overlies dense, slowly permeable subsoil with significantly more clay than the surface horizon (WRB, 2014).

Eutic planosols have a BS of at least 50% within 125 cm of the soil surface plus Ochric A- Horizon. Dystic planosols have a BS of less than 50% and ochiric A horizon. Other types of planosols include mollic, humic, solodic and gelic (USDA-UNESCO soil classification 1974). Since these soils are poor in fertility, they require addition of plant nutrients like nitrogen, phosphorus and potasium. They occur typically in wet low-lying areas that can support either grass or open forest vegetation. They are poor in plant nutrients, however, and their clay content leads to both seasonal waterlogging and drought stress. Under careful management they can be cultivated for rice, wheat, or sugar beets, but their prin*cip*al use is for grazing. Occupying about 1 percent of the total continental land area on Earth, they are found mainly in Brazil, northern Argentina, South Africa, eastern Australia, and Tasmania. They occupy 130 million ha of the Earth's surface.

Appendix XLVI: Planosols (W) from FAO-UNESCO 1974

Planosols are soils having an albic E horizon overlying a slowly permeable horizon within 125 cm of the surface (for example, an argillic or natric B horizon showing an abrupt textural change, a heavy clay, a fragipan), exclusive of a spodic B horizon; showing hydromorphic properties at least in a part of the E horizon. Eutric Planosols (We): Planosols having an ochric A horizon and having a base saturation of 50 percent or more (by NH_4Oac) throughout the slowly permeable horizon within 125 cm of the surface, but having no more than 6 percent sodium in the exchange complex throughout; lacking permafrost within 200 cm of the surface. Dystric planosols (Wd): Planosols having an ochric A horizon and having a base saturation of less than 50 percent (by NH_4Oac) in at least a part of the slowly permeable horizon within 125 cm of the surface, but having no more than 6 per-cent sodium in the exchange complex throughout; lacking permafrost within 200 cm of the surface. Mollic planosols (Wm): Planosols having a mollic A horizon or a eutric histic H horizon; having no more than 6 per-cent sodium in the exchange complex of the slowly permeable horizon; lacking permafrost within 200 cm of the surface.Humic planosols (Wh): Planosols having an umbric A horizon or a dystric histic H horizon; having no more than 6 percent sodium in the exchange complex of the slowly permeable horizon; lacking permafrost within 200 cm of the surface.

Appendix XLVII: Argillic B horizon (Bt) from FAO-UNESCO 1974

An argillic B horizon is one that contains illuvial layer-lattice clays. This horizon forms below an eluvial horizon, but it may be at the surface if the soil has been partially truncated.

The argillic B horizon has the following properties:

1. If an eluvial horizon remains, the argillic B horizon contains more total and more fine clay than the eluvial horizon, exclusive of differences which may result from a lithological discontinuity. The increase in clay occurs within a vertical distance of 30

cm or less: if any part of the eluvial horizon has less than 15 percent total clay in the fine earth (less than 2 mm) fraction, the argillic B horizon must contain at least 3 percent more clay (for example, 13 percent versus 10 percent); if the eluvial horizon has more than 15 percent and less than 40 percent total clay in the fine earth fraction, the ratio of the clay in the argillic B horizon to that in the E horizon must be 1.2 or more; if the eluvial horizon has more than 40 percent total clay in the fine earth fraction, the argillic B horizon must contain at least 8 percent more clay (for example, 50 percent versus 42 percent).

2. An argillic B horizon should be at least one tenth the thickness of the sum of all overlying horizons, or more than 15 cm thick if the eluvial and illuvial horizons are thicker than 150 cm. If the B horizon is sand or loamy sand, it should be at least 15 cm thick; if it is loamy or clayey, it should be at least 7.5 cm thick. If the B horizon is entirely composed of lamellae, the lamellae should have a thickness of 1 cm or more and should have a combined thickness of at least 15 cm.

3. In soils with massive or single grained structure the argillic B horizon has oriented clay bridging the sand grains and also in some pores.

4. If peds are present, an argillic B horizon either:

Shows clay skins on some of both the vertical and horizontal ped surfaces and in the pores, or shows oriented clays in 1 percent or more of the cross-section;

- if the B has a broken or irregular upper boundary and meets requirements of thickness and textural differentiation as defined under 1 and 2 above, clayskins should be present at least in the lower part of the horizon;
- if the B horizon is clayey with kaolinitic clay and the surface horizon has more than 40 percent clay, there are some clayskins on peds and in pores in the lower part of that horizon having blocky or prismatic structure; or
- if the B horizon is clayey with 2 to 1 lattice clays, clayskins may be lacking, provided there are evidences of pressure caused by swelling; or if the ratio of fine to total clay in the B horizon is greater by at least one third than the ratio in the overlying or the underlying horizon, or if it has more than 8 percent more fine clay; the evidences of pressure may be occasional slickensides or wavy horizon

boundaries in the illuvial horizon, accompanied by uncoated sand or silt grains in the overlying horizon.

5. If a soil shows a lithological discontinuity between the eluvial horizon and the argillic B horizon, or if only a plough layer overlies the argillic B horizon, the horizon need show clay skins in only some part, either in some fine pores or, if peds exist, on some vertical and horizontal ped surfaces. Thin sections should show that some part of the horizon has about 1 percent or more of oriented clay bodies, or the ratio of fine clay to total clay should be greater by at least one third than in the overlying or the underlying horizon.

6. The argillic B horizon lacks the set of properties which characterize the natric B horizon.

Appendix XLVIII: Preliminary soil test results by the N A R L at Kabete, Nairobi

	Soil Analytical Data											
Field	**Ainabkoi**				**Saboti**				**Lari**			
Lab. No/2019	3747		3748		3749		3750		3751		3752	
Soil depth cm	0-15 cm		15-30 cm		0-15 cm		15-30 cm		0-15 cm		15-30 cm	
Fertility status	**value**	**class**	**value**	**class**	**value**	**class**	**value**	**class**	**value**	**class**	**value**	**class**
Soil pH	5.62	Medium acid	5.59	Medium acid	5.83	Medium acid	5.67	Medium acid	4.60	Strong acid	4.83	Strong acid
Exchangeable acidity me%									0.4	adequate	0.4	adequate
Total nitrogen (%)	0.24	Adequate	0.18	Low	0.34	adequate	0.30	adequate	0.25	adequate	0.24	adequate
Total Organic carbon (%)	2.54	moderate	2.01	moderate	3.55	adequate	3.13	adequate	2.70	adequate	2.51	adequate
Phosphorus (ppm)	40	adequate	35	adequate	45	adequate	45	adequate	25	low	30	low
Potassium me%	2.03	high	2.03	high	1.00	high	0.41	adequate	0.71	adequate	0.69	adequate
Calcium me%	14.2	adequate	10.2	adequate	26.0	high	26.8	high	1.4	low	1.2	low

Magnesium me%	4.04	high	3.56	high	4.06	high	5.10	high	0.79	low	0.82	low
Manganese me%	0.64	adequate	0.67	adequate	0.96	adequate	0.62	adequate	0.48	adequate	0.36	adequate
Copper ppm	2.50	adequate	2.15	adequate	9.83	adequate	9.71	adequate	2.40	adequate	2.10	adequate
Iron ppm	16.2	adequate	17.8	adequate	16.1	adequate	17.2	adequate	220	adequate	224	adequate
Zinc ppm	4.31	low	3.84	low	2.46	low	1.40	low	8.58	adequate	5.29	adequate
Sodium me%	0.50	adequate	0.48	adequate	0.50	adequate	0.54	adequate	0.62	adequate	0.86	adequate

These results from National Agricultural laboratories at KALRO Kabete were released on 28th May, 2019

Appendix XLIX: Rainfall data (mm) of Saboti- Hon. N. Wekesa Weather Station

Day	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**
2	0	0	0	0	0	7.4	2.5	0
3	0	0	0	0	0	0	0	5.2
4	0	0	11	0	0	12	0	0
5	0	0	0	0	0	0	0	0
6	0	0	1.4	0	0	7	0	0
7	0	0	14.4	0	0	1.6	0	0
8	0	0	4.8	0	0	14.9	0	0
9	0	0	0	0	8	7.6	0	16.5
10	0	0	0	3.3	2.1	0	1.0	
11	0	0	0	10.8	4.5	0	6.4	46.5

12	0	0	0	0	8.5	2.4	3.1	1.1
13	0	0	0	0	6.4	1.8	4.0	1.2
14	0	0	0	0	0	1.4	0	0
15	0	0	0	0	0	7.6	0	43.3
16	0	0	0	0	0	2.2	26.7	2.3
17	1.9	0	0	0	0	3.4	0	1.5
18	0	0	0	0	0	0	0	12.2
19	3.3	0	0	0	0	0	0	16.2
20	0	0	0	0	0	0	0	18.2
21	0	0	0	0	27.3	14.6	20.4	1.7
22	0	0	0	4.4	0	0	0	10.9
23	0	0	0	40	2.5	2.4	1.3	4.5
24	0	7.2	0	0	3.7	1.0	0	0
25	0	5.5	0	0	12	18.8	0	7.1
26	0	0	0	1.4	0	1	0	0
27	0	0	5.7	4.2	0	7	0	1.2
28	0	0	0	0	0	6.5	0	0
29	0	0	0	0	0	3.3	0	0
30	0	0	0	41.2	0	29.5	0	2.7
31	0	0	0	0	1.0	0	4.8	0
1	0	0	0	0	7.3	9.6	5.1	0
Total	5.2	12.7	37.3	105.3	83.3	163	75.3	192.3

The potatoes were planted on 27th April, 2019 and harvested on 20th July; 2019. During this period 335.4 mm was received in 32 days.

Appendix L: Rainfall data for Lari (Kagwe tea factory)

	April 2019	**May 2019**
Rainfall (mm)	114.30	186.40
Wet days (no)	9	18

Appendix LI: Summary of the results

Variable	**Saboti**		**Ainabkoi**		**Lari**	
	Shangi	**Unica**	**Shangi**	**Unica**	**Shangi**	**Unica**
Mean available phosphorus (ppm) at Planting (Bray 2)	57.7	57.7	43.0	43.0	20.4	20.4
Mean available phosphorus (ppm) at planting (Mehlich 3)	45.0	45.0	40.0	40.0	25.0	25.0
Mean available phosphorus at harvesting (ppm)	60.0	70.0	65.0	44.6	60.0	52.3
Mean potato tuber plant phosphorus at harvesting (%)	0.88	0.88	0.59	0.57	0.50	0.49
Highest soil available phosphorus at harvesting (ppm)	61.7	103.3	91.8	92.8	46.7	54.2
Highest potato plant phosphorus at harvesting (%)	0.93	1.08	0.67	0.62	0.61	0.61
Phosphorus rate for highest soil available phosphorus at harvesting ($kg\ ha^{-1}$)	30	120	60	90	60	0

Phosphorus rate for highest potato plant phosphorus at harvesting (kg ha^{-1})	0	90	0	0	30	60
Mean overall seed yield (t ha^{-1}).	22.3	14.4	16.5	15.5	15.1	7.6
Mean small grade seed yield (t ha^{-1}).	4.8	5.0	7.1	4.0	7.0	2.5
Mean large grade seed yield (t ha^{-1}).	12.8	11.3	8.1	13.4	8.7	4.9
Mean overall tuber number ha^{-1}	407816	271109	419321	300862	348349	140900
Mean large grade tuber number ha^{-1}	225941	142468	162963	153150	130453	67242
Mean small grade tuber number ha^{-1}	189340	123209	230472	107897	224995	77448
Phosphorus rate for highest overall yield (kg ha^{-1})	AC	0	60	30	60	90
Highest overall seed yield (t ha^{-1})	33.7	33.3	20.0	18.9	19.0	10.4
Highest large grade yield phosphorus rate (kg ha^{-1})	AC	0	30	0	60	60
Highest large grade yield (t ha^{-1})	19.8	25.3	10.1	13.1	16.4	6.8
Highest small grade yield phosphorus rate (kg ha^{-1})	60	0	120	AC	120	120
Highest small grade yield (t ha^{-1})	11.0	9.5	10.1	4.6	7.0	2.5
Phosphorus rate for highest number of overall seed tubers ha^{-1}	60	AC	AC	AC	60	30
Highest no. of overall seed tubers ha^{-1}	469627	414812	402960	285430	454812	162962

Phosphorus rate for highest number of large grade seed tubers ha^{-1}	AC	AC	0	60	60	60
Highest no. of large grade seed tubers ha^{-1}	293964	254813	238305	223615	241916	91851
Phosphorus rate for highest number of small grade seed tubers ha^{-1}	60	0	AC	AC	60	30
Highest no. of small grade seed tubers ha^{-1}	290369	182221	272042	142221	309628	108147
Mean potato seed specific gravity (g g^{-1})	1.05444	1.06111	1.0542	1.0447	1.0862	1.0737
Mean potato seed number of eyes per potato	7	7	11	9	9	7
Mean potato final percentage germination (%)	88.1	99.3	90.1	94.4	95.7	100
Mean potato seed phosphorus use efficiency (kg kg^{-1})	0	-396	28.9	14.1	116.1	6.0
Highest phosphorus use efficiency	136	-226	31	109	145	19
Phosphorus rate for highest phosphorus use efficiency	60	90	30	30	30	60
Mean tuber weight (g) of small grade potato seed	25.3	40.2	30.6	30.6	30.9	32.4
Mean tuber weight (g) of large grade potato seed	56.7	79.0	49.4	87.5	67.0	72.9
Mean tuber weight (g) of overall potato seed	54.6	53.1	39.3	51.5	43.4	53.8

Appendix LII: Initial soil available phosphorus status (Bray 2) in the test sites

Test site	0-15 cm	15-30 cm
Saboti	57.7	31.9
Ainabkoi	43.0	21.0
Lari	20.4	5.7

Appendix LIII: Days to maturity of the test potatoes

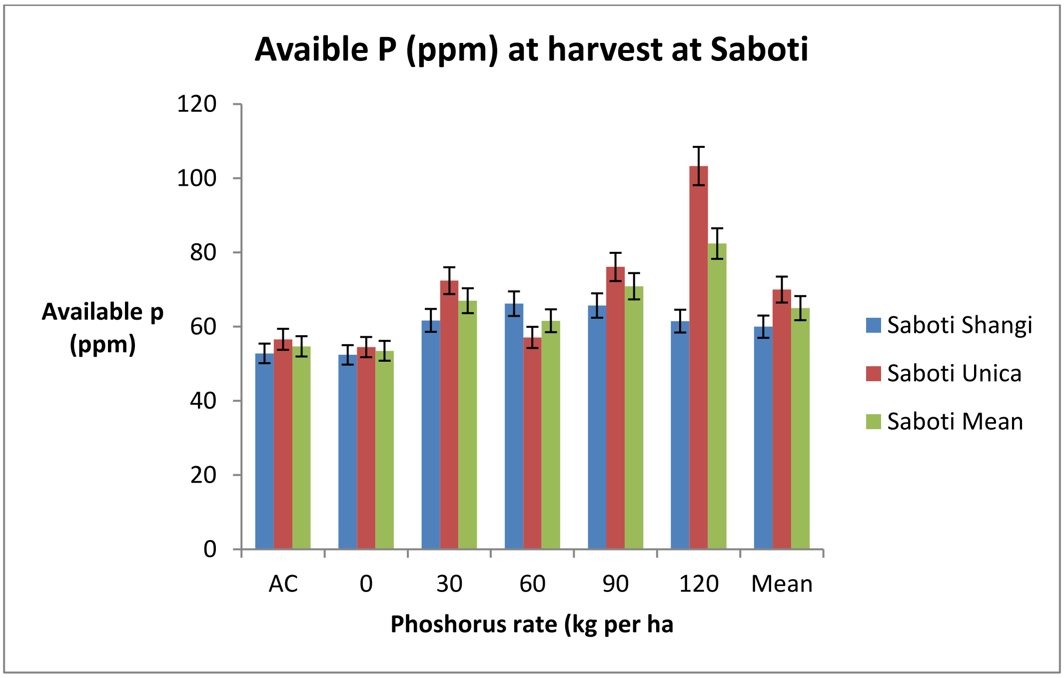
Test site	Saboti	Ainabkoi	Lari
Days to dehalming	76	76	85
Days to harvesting	86	89	115

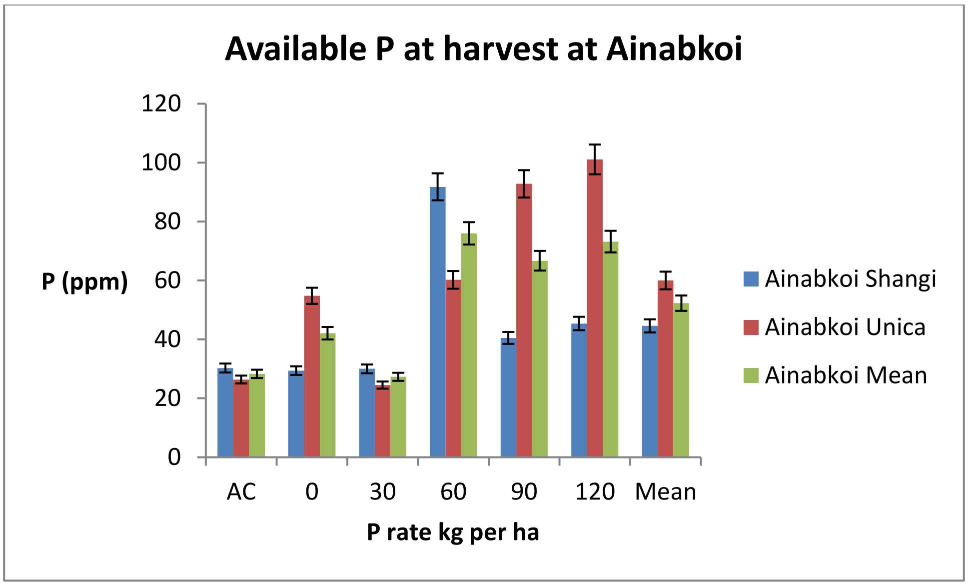
Appendix LIV: Duncan's multiple range test on phosphorus use fficiency at Saboti, Ainabkoi and Lari test sites

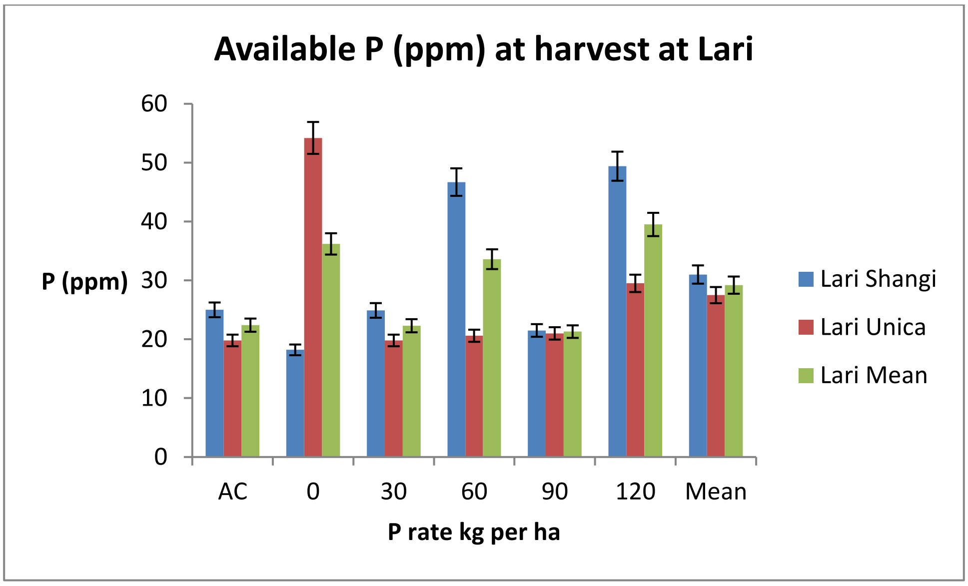
Phosphorus

Phosphorus rate (kg ha^{-1})	Mean PUE (kgkg^{-1})		
	Saboti	Anaibkoi	Lari
30	-478.3 a	70.0 c	76.1 a
60	-131.5 b	-46.2 a	77.6 a
90	-77.4 b	39.5b c	53.9 a
120	-105.6 b	22.7 b	36.7 a

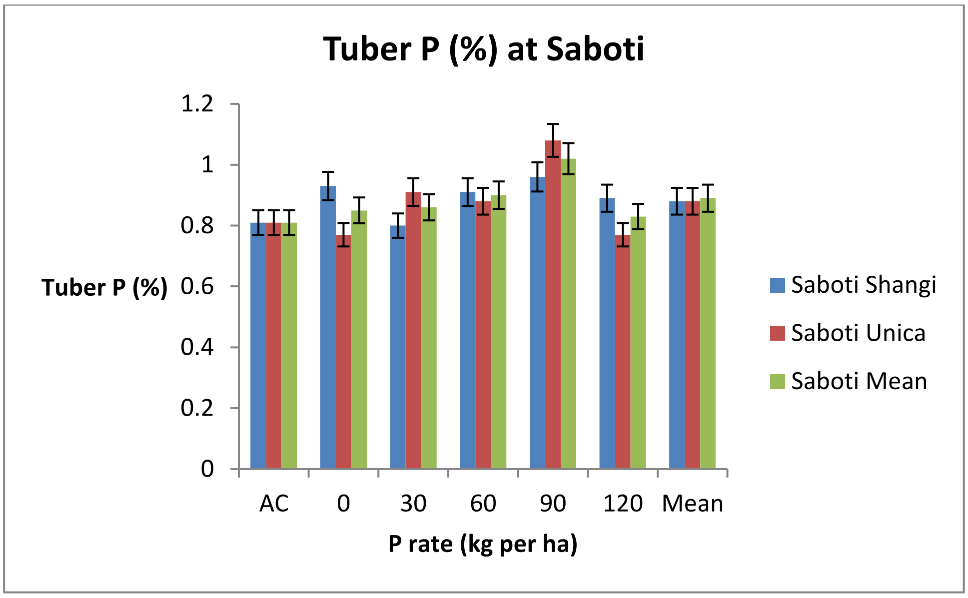
Appendix LV: Available phosphorus (Bray 2) (ppm) at harvesting in the test farms

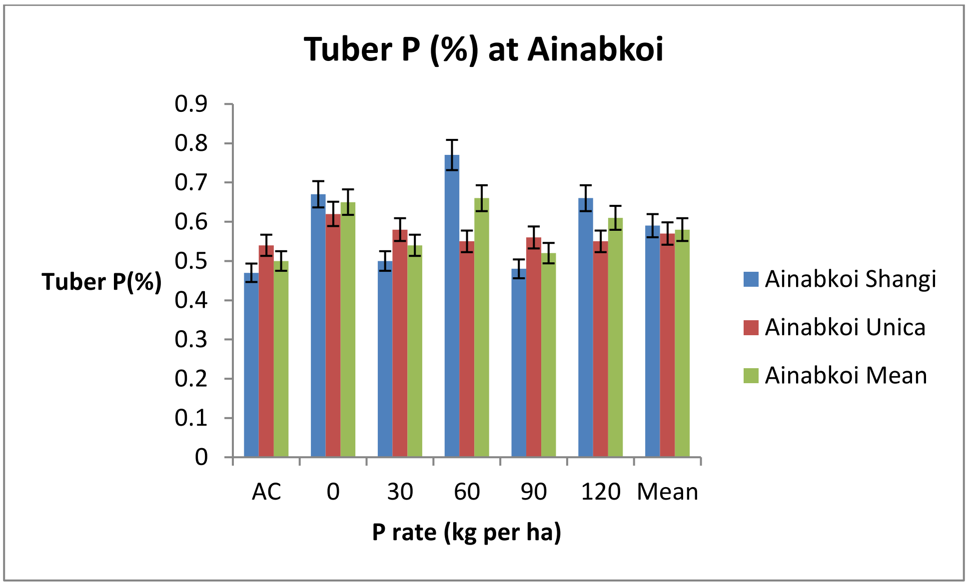


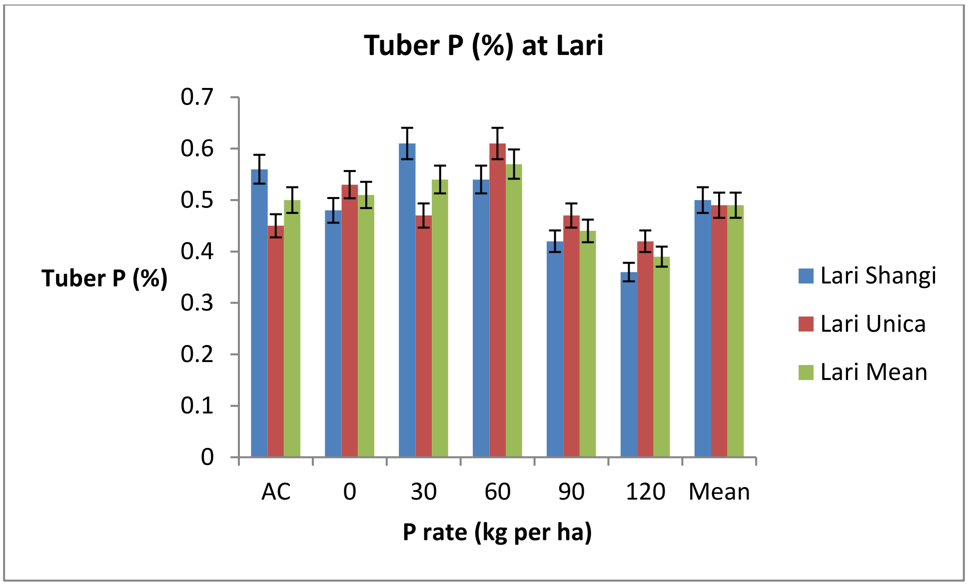

Available P at harvest at Ainabkoi
P (ppm)
120
100
80
60
40
20
0
AC
0
30
60
90
120
Mean
P rate kg per ha
Ainabkoi Shangi
Ainabkoi Unica
Ainabkoi Mean


Available P (ppm) at harvest at Lari
P (ppm)
60
50
40
30
20
10
0
AC
0
30
60
90
120
Mean
P rate kg per ha
Lari Shangi
Lari Unica
Lari Mean

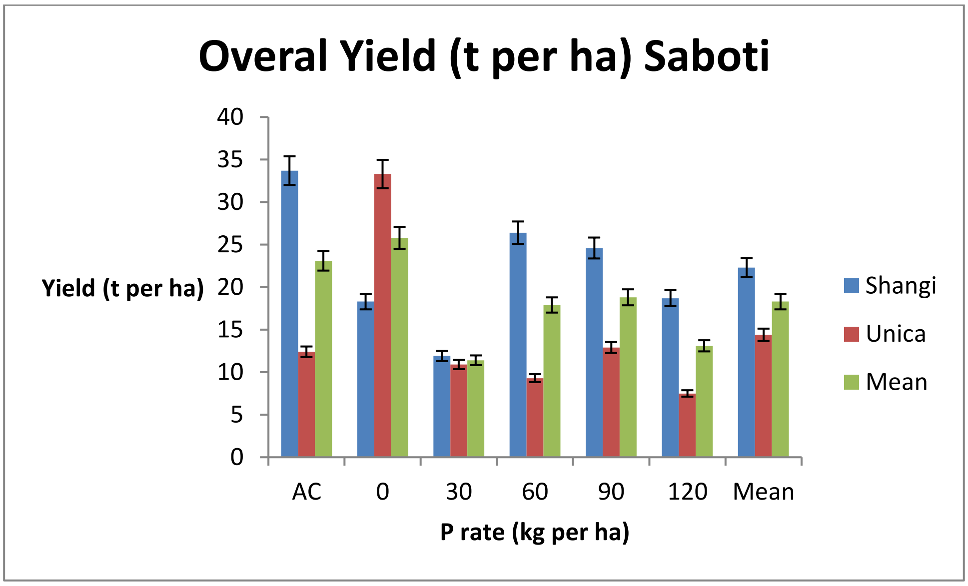
Appendix LVI: Potato tuber phosphorus (%) at harvest

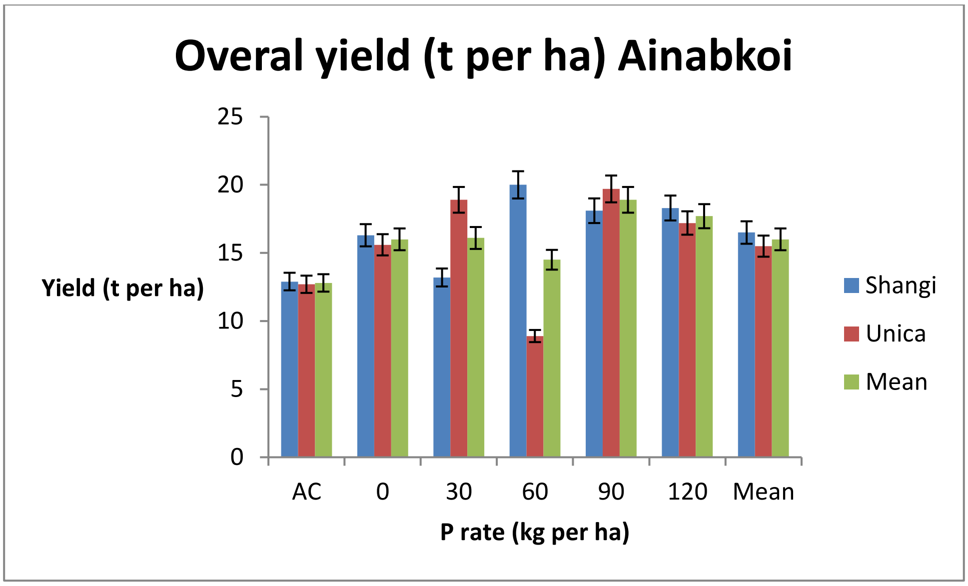


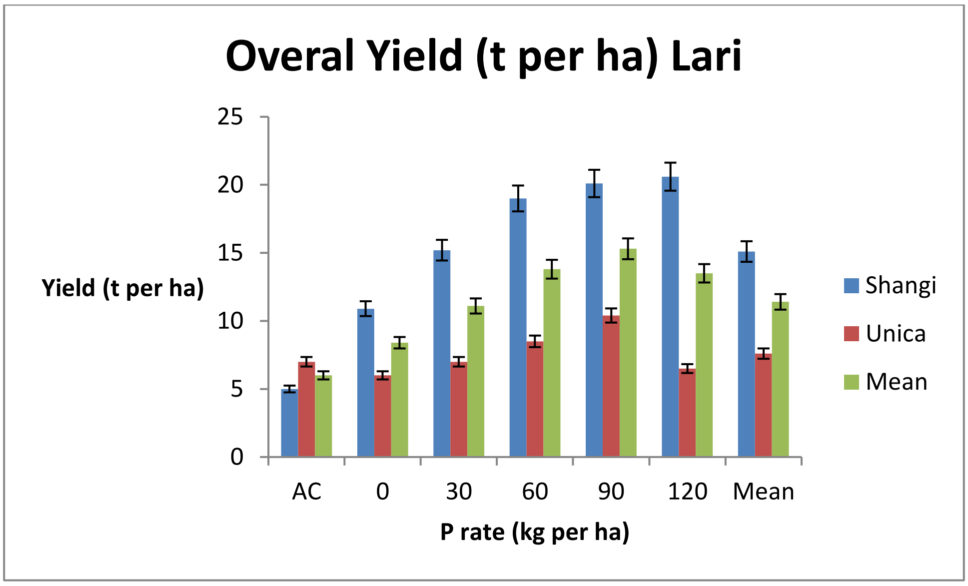




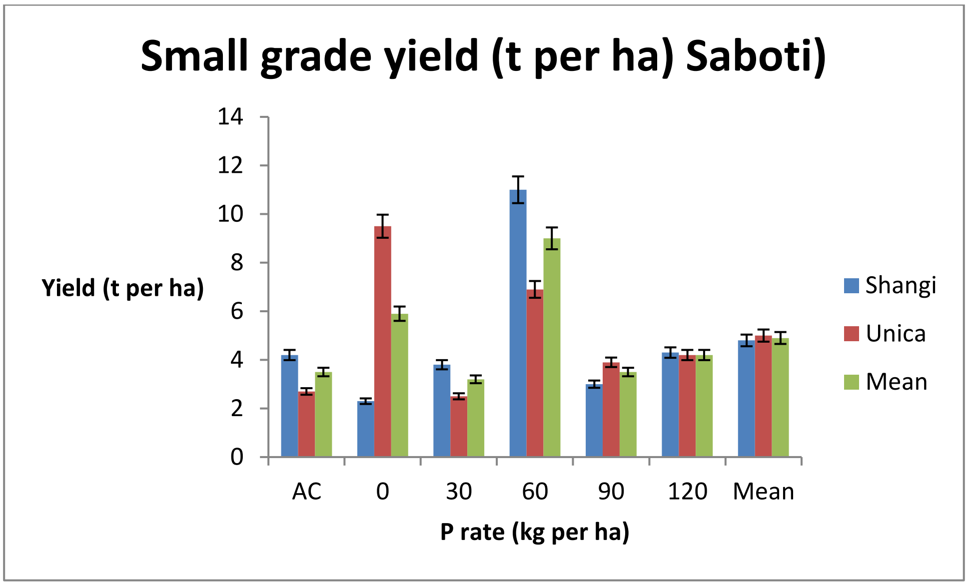
Appendix LVII: Overal yield (t per ha) in the test sites

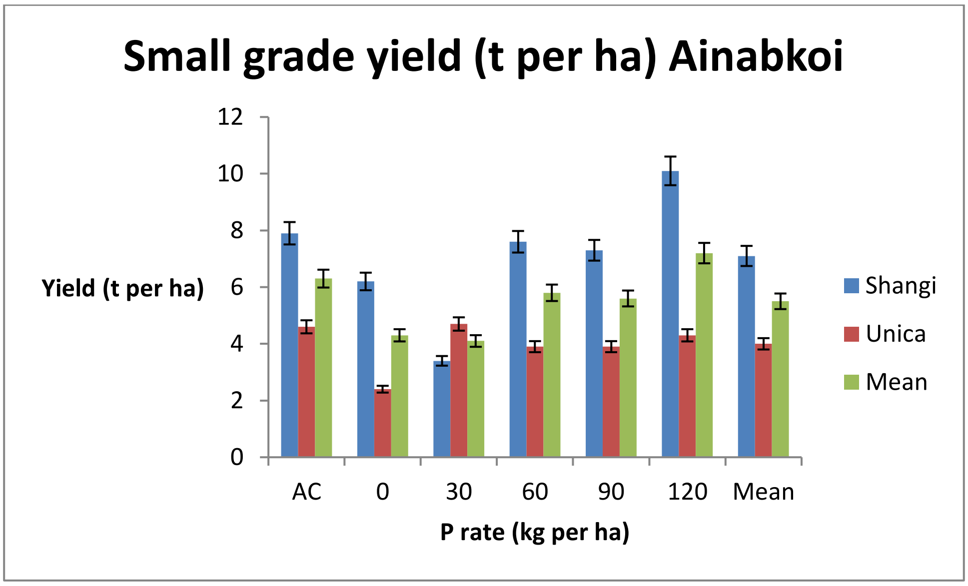


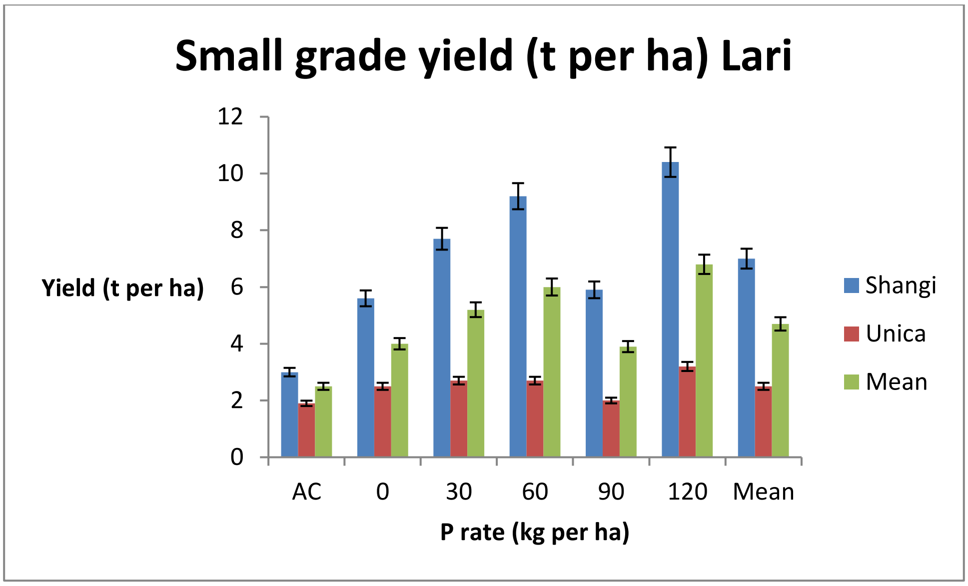

Overal yield (t per ha) Ainabkoi
Yield (t per ha)
25
20
15
10
5
0
AC
0
30
60
90
120
Mean
P rate (kg per ha)
Shangi
Unica
Mean


Overal Yield (t per ha) Lari
Yield (t per ha)
25
20
15
10
5
0
AC
0
30
60
90
120
Mean
P rate (kg per ha)
Shangi
Unica
Mean

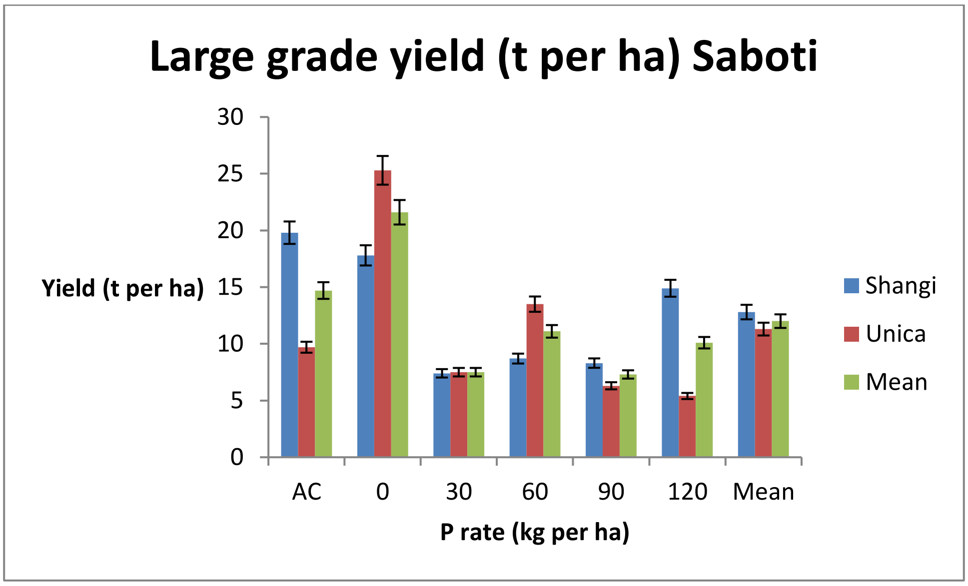
Appendix LVIII: Small grade yield (t per ha) in test sites

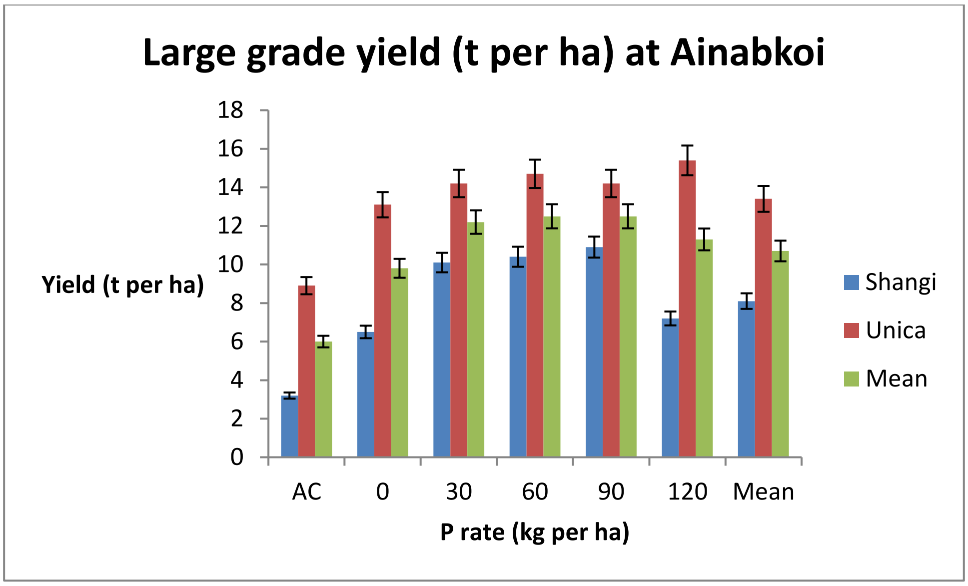


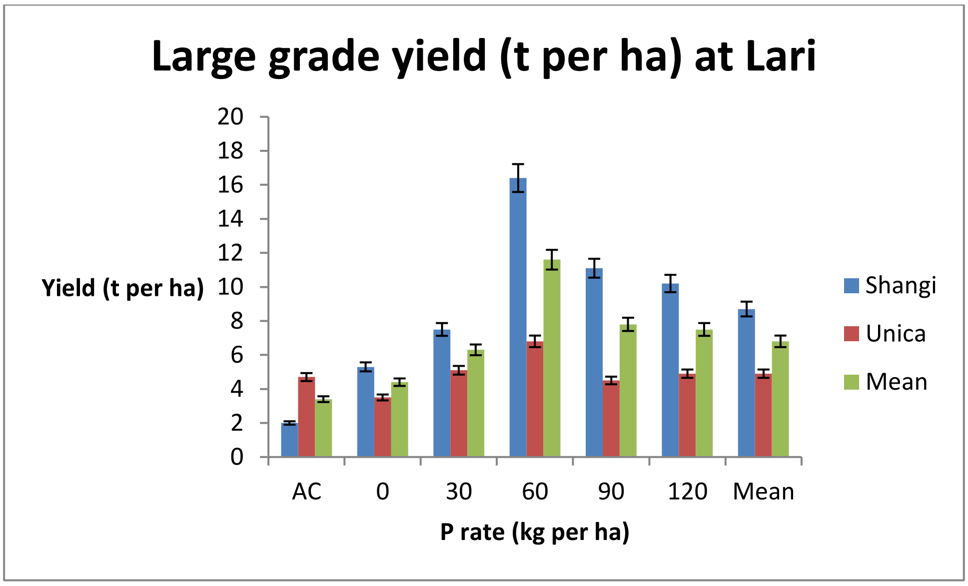




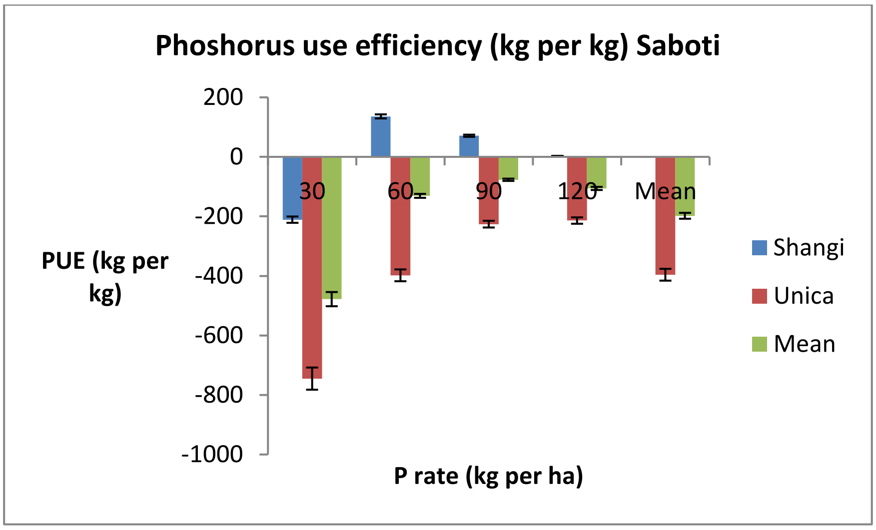
Appendix LIX: Large grade yield in the test sites

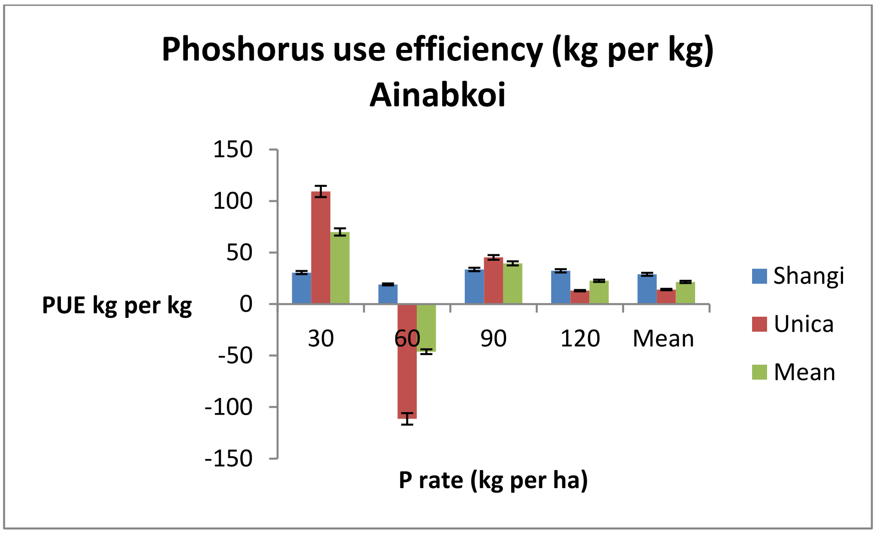


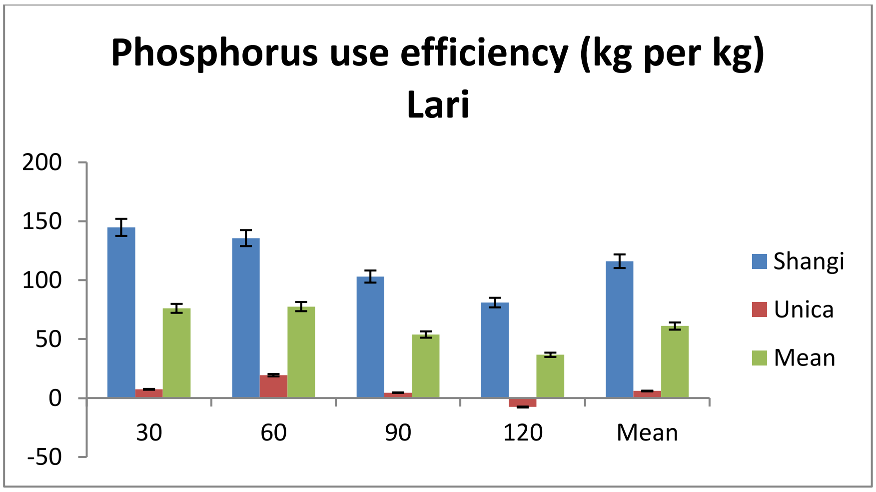

Large grade yield (t per ha) at Ainabkoi
Yield (t per ha)
18
16
14
12
10
8
6
4
2
0
AC
0
30
60
90
120
Mean
P rate (kg per ha)
Shangi
Unica
Mean


Large grade yield (t per ha) at Lari
Yield (t per ha)
20
18
16
14
12
10
8
6
4
2
0
AC
0
30
60
90
120
Mean
P rate (kg per ha)
Shangi
Unica
Mean

Appendix LX: Potato agronomic phosphorus use efficieny (kg kg^{-1}) in the test sites







Appendix LXI: Soil Test Interpretation for Mehlich - 3 Extraction Method (KARO, 2016)

Nutrient	Low	Medium	High
P (mg kg^{-1})	≤ 25	26-45	> 45
K(mg kg^{-1})	≤ 35	36-60	> 60
Mg (mg kg^{-1})	≤ 20	21-40	> 40

Appendix LXII: Correlations between phosphorus rate (kg ha^{-1}) and available soil phosphorus (ppm)

Phosphorus (kg ha^1)	1	-					
Saboti Soil P Shangi	2	0.7376*	-				
Saboti Soil P Uunica	3	0.8415**	0.3927	-			
Saboti Soil P Mean	4	0.9271**	0.6144*	0.9669**	-		
Ainabkoi Soil P Shangi	5	0.3616	0.6332*	-0.0959	0.0934	-	
Ainabkoi Soil P Unica	6	0.8676**	0.4802	0.6704*	0.7100*	0.2545	-
Ainabkoi Soil P Mean	7	0.8172**	0.6857*	0.4298	0.5601*	0.7195*	0.8547**
Lari Soil P Shangi	8	0.6428*	0.4882	0.4895	0.5548*	0.7164*	0.4289
Lari Soil P Unica	9	-0.2956	-0.5728*	-0.1681	-0.3017	-0.2938	0.1191
Lari Soil P Mean	10	0.2896	-0.0738	0.2692	0.2112	0.3474	0.4600
		1	2	3	4	5	6

Aainabkoi Soil P Mean	7	-			
Lari Soil P Shangi	8	0.6917*	-		
Lari Soil P Unica	9	-0.0724	-0.2812	-	
Lari Soil P Mean	10	0.5159*	0.5952*	0.6037*	-
		7	8	9	10

Number of observations: 6 * Strong Correlation ** Very Strong correlation

Appendix LXIII: Correlations between phosphorus rate (kg ha^{-1}) & tuber phosphorus (%)

Phosphorus (kg ha^{1})	1	-					
Saboti Tuber P Shangi	2	0.4270	-				
Saboti Tuber P Unica	3	0.3015	0.3160	-			
Saboti Tuber P Mean	4	0.4150	0.6634*	0.9189**	-		
Ainabkoi Tuber P Shangi	5	0.1990	0.4147	-0.4436	-0.1579	-	
Ainabkoi Tuber P Unica	6	-0.4438	0.2369	-0.1788	-0.0389	0.1538	-
Ainabkoi Tuber P Mean	7	0.1065	0.4548	-0.4577	-0.1531	0.9707**	0.3840
Lari Tuber P Shangi	8	-0.7349*	-0.6757*	0.0073	-0.2617	-0.2132	0.0728
Lari Tuber P Unica	9	-0.2453	0.3456	0.0398	0.1980	0.6719*	0.2223
Lari Tuber P Mean	10	-0.6603*	-0.2945	-0.0077	-0.1071	0.2122	0.2191
		1	2	3	4	5	6

Ainabkoi Tuber P Mean	7	-			
Lari Tuber P Shangi	8	-0.2112	-		
Lari Tuber P Unica	9	0.6584*	0.3407	-	
Lari Tuber P Mean	10	0.2191	0.8730**	0.7524**	-
		7	8	9	10

Number of observations: 6 * Strong Correlation ** Very Strong correlation

Appendix LXIV: Correlations Between phosphorus rate (kg ha^{-1}) and overall yield (t ha^{-1})

Phosphorus (kg ha^{-1})	1	-					
Saboti Overall Yield S	2	-0.1508	-				
Saboti Ooverall Yield U	3	-0.5896*	-0.1707	-			
Saboti Overall Yield M	4	-0.6062*	0.5430*	0.7347	-		
Ainabkoi Overall Yield S	5	0.6781*	0.0511	-0.1290	-0.0741	-	
Ainabkoi Overall Yield U	6	0.2877	-0.5869*	0.0579	-0.3546	-0.2447	-
Ainabkoi Overall Yield M	7	0.7073*	-0.5198*	-0.0230	-0.3769	0.4318	0.7687**
Lari Overall Yield Shangi	8	0.8852**	-0.3910	-0.4272	-0.6325*	0.7664**	0.2604
Lari Overall Yield Unica	9	0.4181	0.3226	-0.3664	-0.0882	0.4305	0.1036
Lari Ooverall Yield Mean	10	0.8618**	-0.2595	-0.4580	-0.5678*	0.7636**	0.2457
		1	2	3	4	5	6

Ainabkoi Overall Yield M	7	-			
Lari Ooverall Yield S	8	0.7482*	-		
Lari Overall Yield Unica	9	0.3824	0.4840	-	
Lari Overall Yield Mean	10	0.7332*	0.9778**	0.6566*	-
		7	8	9	10

Number of observations: 6 U= Unica S = Shangi M= Mean * Strong Correlation ** Very Strong correlation

Appendix LXV: Correlations between phosphorus rate (kg ha^{-1}) & the small grade tuber yields (t ha^{-1})

Phosphorus (kg ha^{-1})	1	-					
Saboti Small Yield S	2	0.1686	-				
Saboti Small Yield U	3	-0.2109	0.1579	-			
Saboti Small Yield M	4	-0.0182	0.8032**	0.7148	-		
Ainabkoi Small Yield S	5	0.5578*	0.1928	0.0559	0.1590	-	
Ainabkoi Small Yield U	6	0.2533	0.1776	-0.9320**	-0.4380	0.0169	-
Ainabkoi Small Yield M	7	0.5997*	0.2554	-0.2862	-0.0026	0.9301**	0.3827
Lari Small Yield Shangi	8	0.7176*	0.4523	0.1040	0.3718	0.2206	0.1096
Lari Small Yield Unica	9	0.4790	0.2551	0.1886	0.2811	0.1639	0.0098
Lari Small Yield Mean	10	0.6842*	0.4465	0.1093	0.3704	0.2199	0.1120
		1	2	3	4	5	6

Ainabkoi Small Yield M	7	-			
Lari Small Yield Shangi	8	0.2415	-		
Lari Small Yield Unica	9	0.1529	0.9061**	-	
Lari Small Yield Mean	10	0.2421	0.9975**	0.9313**	-
		7	8	9	10

Number of observations: 6 S= Shangi U = Unica M = Mean * Strong Correlation ** Very Strong correlation

Appendix LXVI: Correlations between phosphorus rate (kg ha^{-1}) and large grade tuber yields (t ha^{-1})

Phosphorus (kg ha^{-1})	1	-					
Saboti Large Yield S	2	-0.4296	-				
Saboti Large Yield U	3	-0.6218*	0.4013	-			
Saboti Large Yield M	4	-0.6455*	0.7705**	0.8930**	-		
Ainabkoi LargeYield S	5	0.4886	-0.9600**	-0.2321	-0.6335*	-	
Ainabkoi Large Yield U	6	0.7145*	-0.6691*	-0.1490	-0.4331	0.7908*	-
Ainabkoi Large Yiel M	7	0.6166*	-0.8780**	-0.2054	-0.5748*	0.9573**	0.9338**
Lari Large Yield S	8	0.6585*	-0.7183*	-0.1943	-0.4909	0.7901*	0.7720**
Lari Large Yield U	9	0.2992	-0.5338*	-0.3451	-0.5050*	0.4277	0.2881
Lari Large Yield M	10	0.6149*	-0.7153*	-0.2296	-0.5141*	0.7561*	0.7095*
		1	2	3	4	5	6

Ainabkoi Large Yield M	7	-			
Lari Large Yield S	8	0.8190**	-		
Lari Large Yield U	9	0.3814	0.7241*	-	
Lari Large Yield M	10	0.7698**	0.9911**	0.8094**	-
		7	8	9	10

Number of observations: 6 S = Shangi U = Unica M = Mean * Strong Correlation ** Very Strong correlation

Appendix LXVII: Correlations between phosphorus rate (kg ha^{-1}) and specific gravity (g g^{-1})

Phosphorus (kg ha^{-1})	1	-					
SabotiS.G.Shangi	2	-0.1086	-				
Saboti S.G.Unica	3	-0.4589	-0.4419	-			
Saboti S.G.Mean	4	-0.5869*	0.0091	0.8859**	-		
AinabkoiS.G. Shangi	5	0.3534	0.4613	-0.6571*	-0.5645*	-	
AinabkoiS.G.Unica	6	0.6692*	-0.0558	0.0860	-0.0200	0.2755	-
Ainabkoi S.G. Mean	7	0.5864*	0.3241	-0.4569	-0.4366	0.8889**	0.6852*
Lari S.G.Shangi	8	0.5055*	0.2315	0.1720	0.2759	-0.0775	0.7881**
Lari S.G.Unica	9	0.2242	-0.4219	-0.3970	-0.7125*	0.3494	0.0779
Lari S.G.Mean	10	0.6765*	-0.2166	-0.2435	-0.4670	0.2811	0.7827**
		1	2	3	4	5	6

Ainabkoi S.G.Mean	7	-			
Lari S.G. Shangi	8	0.3175	-		
Lari S.G. Unica	9	0.3006	-0.4480	-	
Lari S.G. Mean	10	0.5853*	0.4445	0.6017*	-
		7	8	9	10

Number of observations: 6 S.G= Specific Gravity * Strong Correlation ** Very Strong correlation

Appendix LXVIII: Correlations between phosphorus rate (kg ha^{-1}) and the number of eyes per tuber (eyes tuber^{-1})

Phosphorus (kg ha^{-1})_1	1	-					
Saboti_Eyes_Shangi	2	0.1000	-				
Saboti_Eyes_Unica	3	0.1464	0.2928	-			
Saboti_Eyes_Mean	4	0.5000*	0.2000	0.8783	-		
Ainabkoi_Eyes_Shangi	5	-0.5500*	0.2000	0.5855	0.4000	-	
Ainabkoi_Eyes_Unica	6	0.2767	0.6325*	0.6944*	0.7906**	0.5534*	-
Ainabkoi_Eyes_Mean	7	-0.4472	0.4472	0.6547*	0.4472	0.8944**	0.7071*
Lari_Eyes_Shangi	8	0.5534*	0.3162	0.4629	0.6325*	0.1581	0.5000*
Lari_Eyes_Unica	9	-0.5000*	-0.2000	-0.8783**	-1.0000**	-0.4000	-0.7906**
Lari_Eyes_Mean	10	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
		1	2	3	4	5	6

Aina_Eyes_Mean	7	-			
Lari_Eyes_Shangi	8	0.0000	-		
Lari_Eyes_Unica	9	-0.4472	-0.6325*	-	
Lari_Eyes_Mean	10	0.0000	0.0000	0.0000	-
		7	8	9	10

Number of observations: 6 * Strong Correlation ** Very Strong correlation

Appendix LXIX: Correlations between phosphorus rate (kg ha^{-1}) and percentage germination (%)

Phosphorus (kg ha^{-1})	1	-					
Saboti %G Shangi	2	0.5268*	-				
Saboti %G Unica	3	0.5000*	0.6858*	-			
Saboti %G Mean	4	0.5456*	0.9940**	0.7616**	-		
Ainabkoi %G Shangi	5	0.0502	-0.3445	-0.6738*	-0.4072	-	
Ainabkoi %G Unica	6	0.5340*	0.5624*	0.9123**	0.6383*	-0.7460*	-
Ainabkoi %G Mean	7	0.7205*	0.1604	0.1195	0.1625	0.5719*	0.1192
Lari %G Shangi	8	-0.6513*	-0.6581*	-0.4626	-0.6557*	0.4380	-0.6644*
Lari %G Unica	9	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Lari %G Mean	10	-0.6192*	-0.6357*	-0.4782	-0.6380*	0.4952*	-0.6890*
		1	2	3	4	5	6

Aina %G Mean	7	-			
Lari %G Shangi	8	-0.1450	-		
Lari %G Unica	9	0.0000	0.0000	-	
Lari %G Mean	10	-0.0908	0.9973**	0.0000	-
		7	8	9	10

Number of observations: 6 %G = Percentage germination * Strong Correlation ** Very Strong correlation

Appendix LXX: Correlations between phosphorus rate (kg ha^{-1}) and phosphorus use efficiency (kg kg^{-1})

Phosphorus rate (kg ha^{-1})	1	-					
Saboti PUE Shangi	2	0.4945	-				
Saboti PUE Unica	3	0.9205**	0.7687*	-			
Saboti PUE Mean	4	0.8036**	0.9072**	0.9664**	-		
Ainabkoi PUE Shangi	5	0.3806	-0.4486	0.1710	-0.0670	-	
Ainabkoi PUE Unica	6	-0.1841	-0.8340**	-0.4048	-0.6004*	0.8300**	-
Ainabkoi PUE Mean	7	-0.1483	-0.8169**	-0.3704	-0.5709*	0.8503**	0.9993**
Lari PUE Shangi	8	-0.9806**	-0.3316	-0.8518**	-0.6931*	-0.5505*	-0.0115
Lari PUE Unica	9	-0.6966*	0.2769	-0.3923	-0.1464	-0.8224**	-0.5117*
Lari PUE Mean	10	-0.9379**	-0.1706	-0.7537*	-0.5639*	-0.6495*	-0.1547
		1	2	3	4	5	6

Ainabkoi PUE Mean	7	-			
Lari PUE Shangi	8	-0.0477	-		
Lari PUE Unica	9	-0.5377*	0.8144**	-	
Lari PUE Mean	10	-0.1894	0.9861**	0.8994**	-
		7	8	9	10

Number of observations: 4 PUE = Phosphorus Use Efficiency * Strong Correlation ** Very Strong correlation

Appendix LXXI: Correlations between phosphorus rate (kg ha^{-1}) and overall potato tuber numbers

Phosphorus (kg ha^{-1})	1	-					
Saboti Overall N S	2	0.3888	-				
Saboti Overall NU	3	-0.7809**	-0.2144	-			
Saboti Overall N M	4	-0.5122*	0.3810	0.8214**	-		
Ainabkoi Overall N S	5	0.6512*	0.8715**	-0.3850	0.1445	-	
Ainabkoi Overall NU	6	0.1797	0.2233	0.4476	0.5542*	0.4098	-
Ainabkoi Overall N M	7	0.4157	0.5435**	0.1644	0.4731	0.7373*	0.9183**
Lari Overall N S	8	0.7806**	0.3664	-0.8963**	-0.6345*	0.6202*	-0.2197
Lari Overall N U	9	0.4724	0.2395	-0.6063*	-0.4341	0.0543	-0.4941
LariOverall N M	10	0.7997**	0.3778	-0.9272**	-0.6570*	0.5906*	-0.2753
		1	2	3	4	5	6

Ainabkoi Overall N M	7	-			
Lari Overall N S	8	0.1064	-		
LariOverall NU	9	-0.3424	0.3688	-	
LariOverall N M	10	0.0524	0.9916**	0.4860	-
		7	8	9	10

Number of observations: 6 N = Number S = Small U = Unica M= Mean * Strong Correlation ** Very Strong correlation

Appendix LXXII: Correlations between phosphorus rate (kg ha^{-1}) and small grade potato tuber numbers

Phoshorus (kg ha^{-1})	1	-					
Saboti Small Number Shangi	2	0.0360	-				
Saboti Small Number Unica	3	-0.5313*	-0.2285	-			
Saboti Small Number Mean	4	-0.2657	0.8349**	0.3451	-		
Ainabkoi Small N Shangi	5	0.3238	0.2821	-0.3819	0.0556	-	
Ainabkoi Small N Unica	6	-0.4472	0.1057	-0.3816	-0.1140	0.2216	-
Ainabkoi Small N Mean	7	-0.0343	0.2577	-0.4871	-0.0275	0.8244**	0.7346*
Lari Small N Shangi	8	0.6247*	0.5335*	-0.5292*	0.2153	-0.1199	-0.1644
Lari Small N Unica	9	0.4683	-0.5506*	-0.5402*	-0.8360**	-0.3063	-0.0573
Lari Small N Mean	10	0.6807*	0.3353	-0.6138*	-0.0235	-0.1867	-0.1621
		1	2	3	4	5	6

Ainabkoi Small N Mean	7	-			
Lari Small N Shangi	8	-0.1789	-		
Lari Small N Unica	9	-0.2464	0.2824	-	
Lari Small Number Mean	10	-0.2240	0.9687**	0.5117*	-
		7	8	9	10

Number of observations: 6 * Strong Correlation ** Very Strong correlation

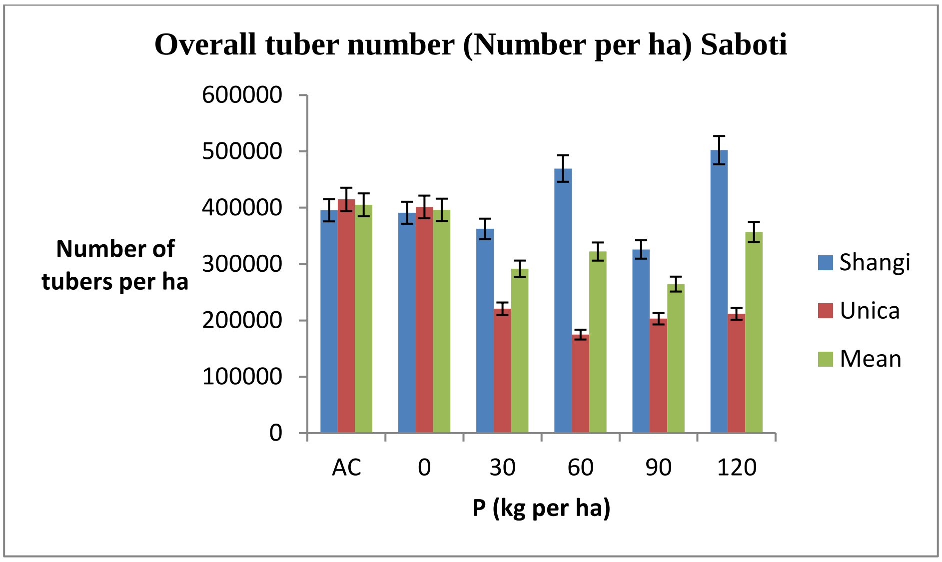
Appendix LXXIII: Correlations between phosphorus rate (kg ha^{-1}) and large grade potato tuber numbers

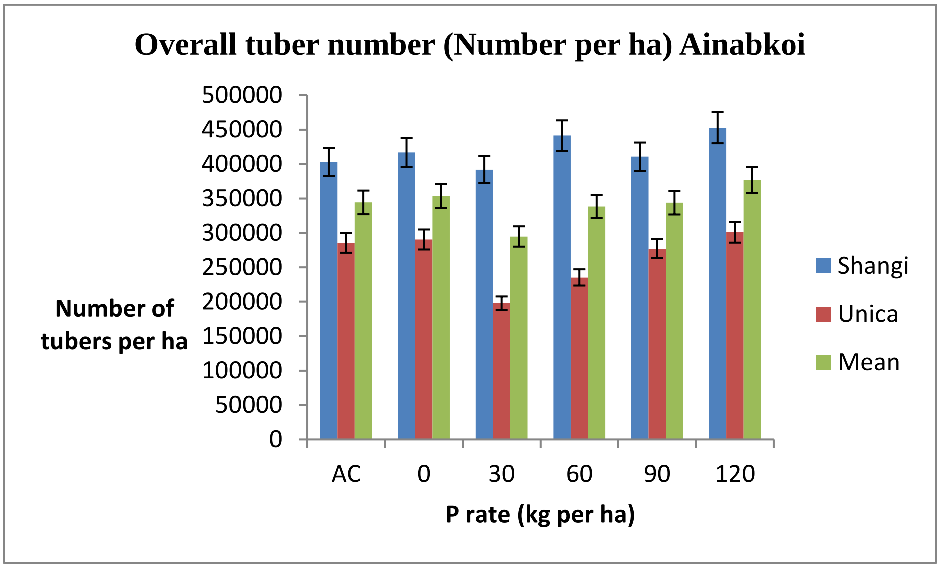
Phosphorus (kg ha^{-1})	1	-					
Saboti Large N Shangi	2	-0.3083	-				
Saboti Large N Unica	3	-0.3332	0.9403**	-			
Saboti Large N Mean	4	-0.2279	0.9822**	0.9770**	-		
Ainabkoi Large N Shangi	5	0.0755	-0.3226	-0.4294	-0.3821	-	
Ainabkoi Large N Unica	6	0.7153*	-0.3437	-0.4220	-0.3370	0.0234	-
Ainabkoi Large N Mean	7	0.4996*	-0.4613	-0.5921*	-0.5032*	0.7872**	0.6350*
Lari Large N Shangi	8	0.5939*	-0.5100*	-0.6957*	-0.5696*	0.6464*	0.7277*
Lari Large N Unica	9	0.0140	-0.3779	-0.4583	-0.4497	-0.2260	0.6435*
Lari Large N Mean	10	0.5308*	-0.5436*	-0.7277*	-0.6137*	0.5198*	0.8006**
		1	2	3	4	5	6

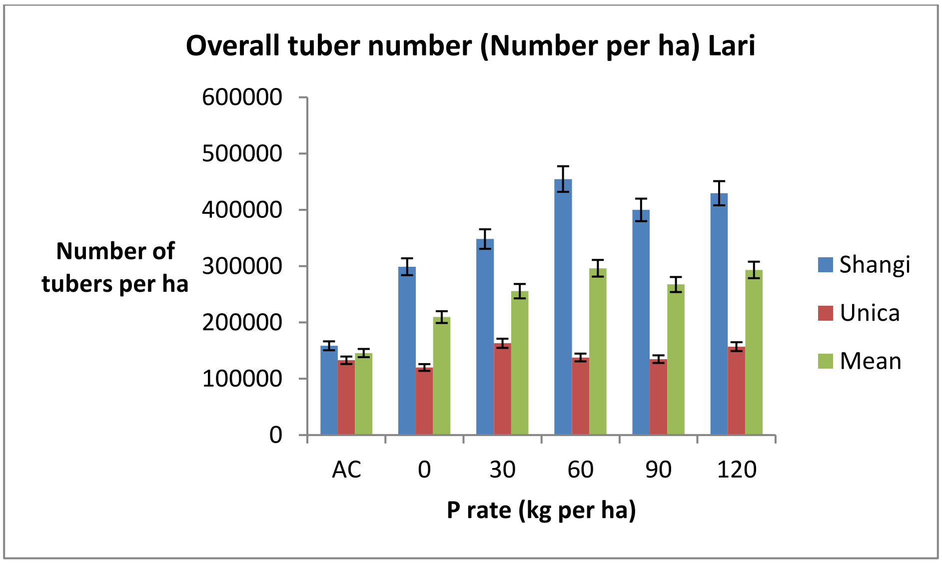
Ainabkoi Large N Mean	7	-			
Lari Large N Shangi	8	0.9484**	-		
Lari Large N Unica	9	0.2223	0.3612	-	
Lari Large N Mean	10	0.8955**	0.9747**	0.5606*	-
		7	8	9	10

Number of observations: 6 * Strong Correlation ** Very Strong correlation

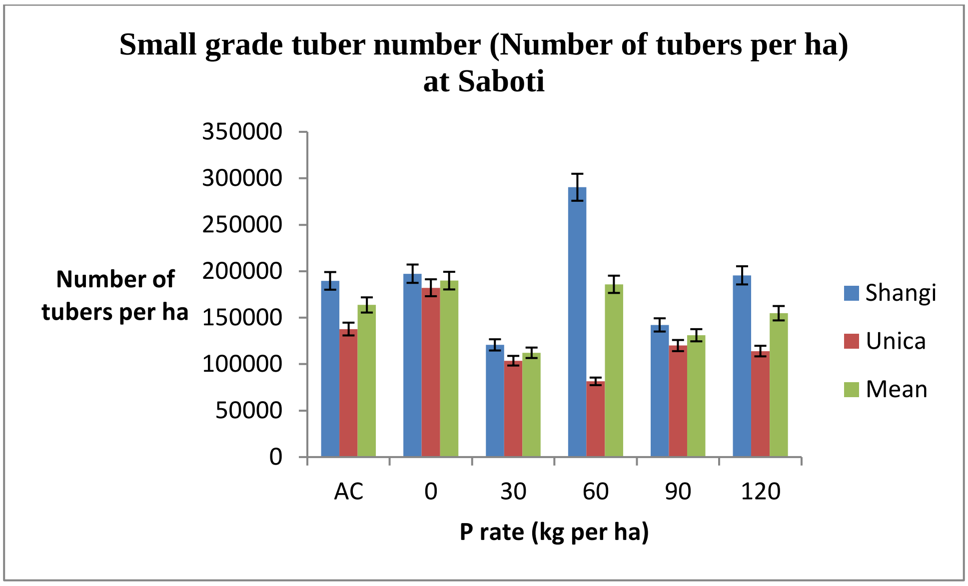
Appendix LXXIV: Overall tuber quantity (Number of tubers per ha)

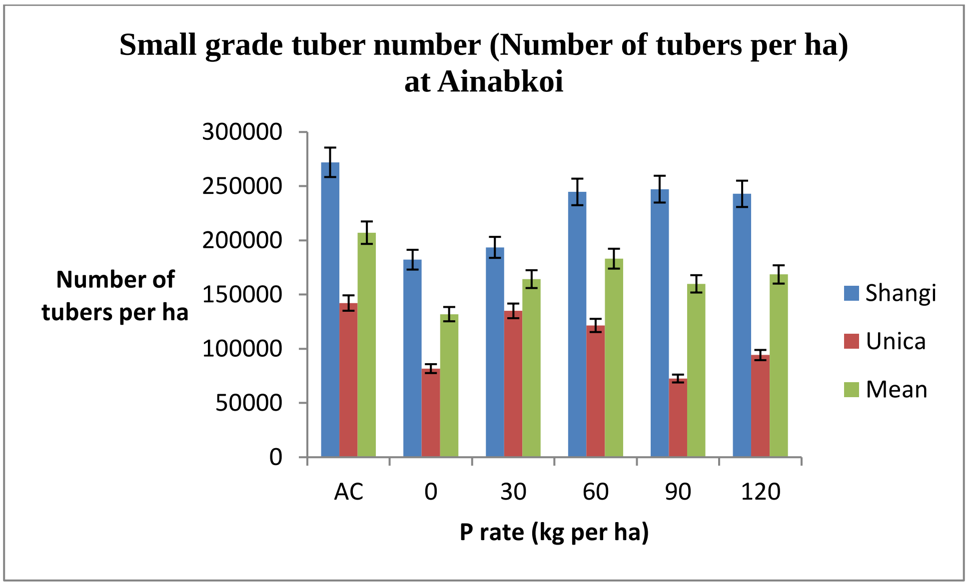


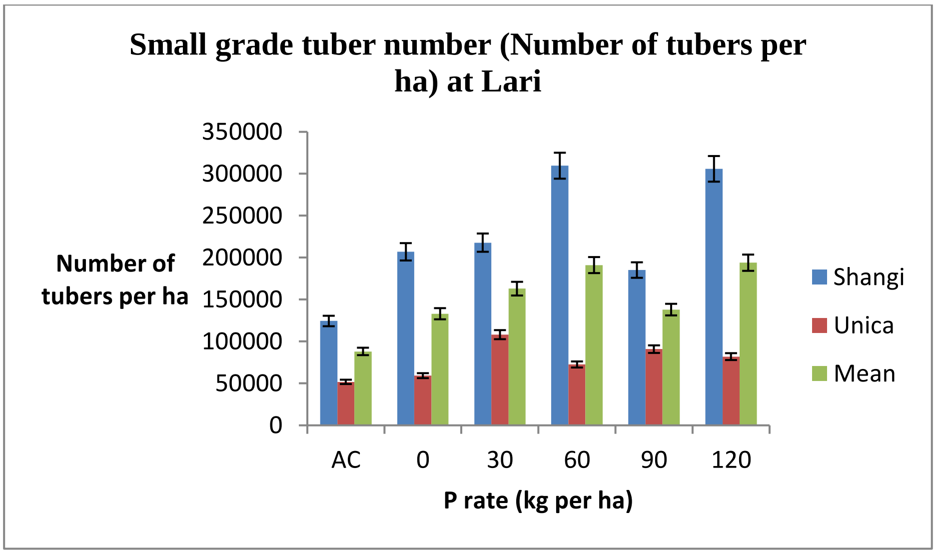




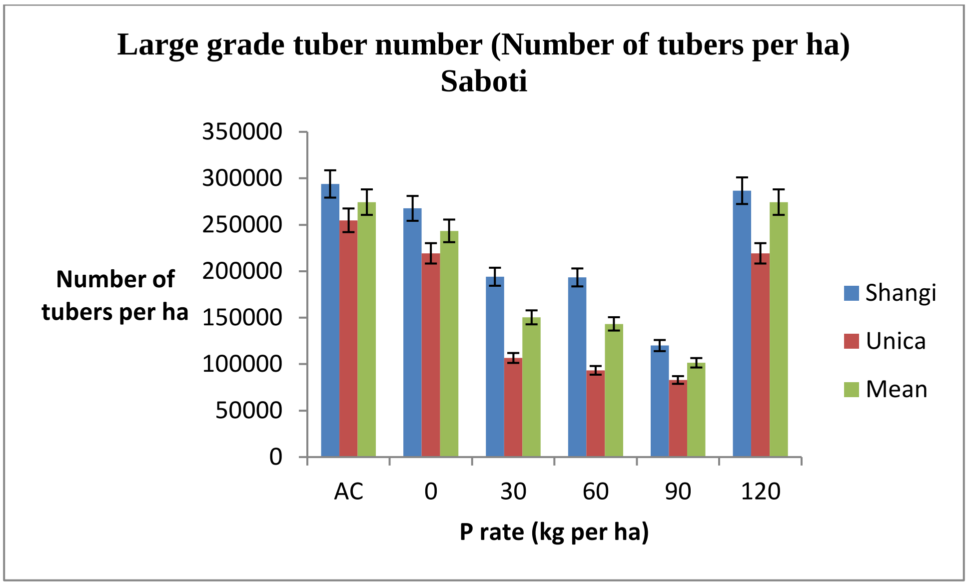
Appendix LXXV: Small grade tuber quantity (Number of tubers per ha)

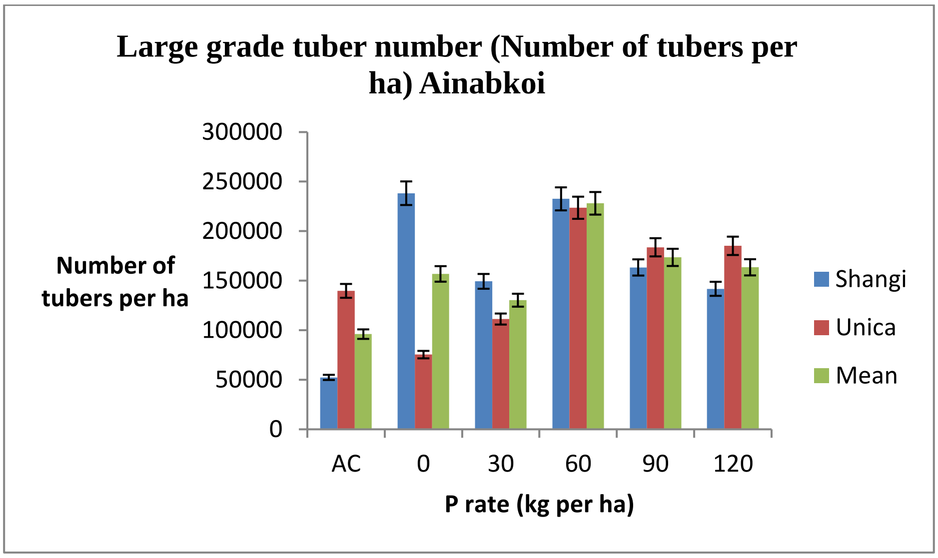


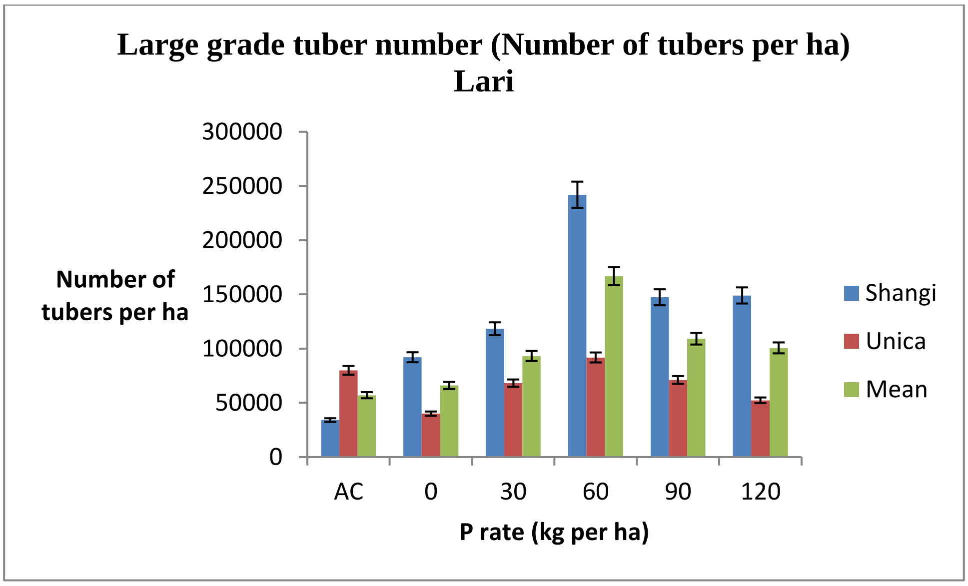




Appendix LXXVI: Large grade tuber quantity (Number of tubers per ha)







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