MODELING THE EFFECTS OF CROP SPACING AND INORGANIC FERTILIZER ON THE POTATO TUBER YIELD AND SIZE USING FIRST ORDER TWO-LEVEL FACTORIAL DESIGN

BY

RONALD KAPKIAI KAPTICH

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN BIOSTATISTICS IN SCHOOL OF SCIENCE OF UNIVERSITY OF ELDORET, KENYA

2022

DECLARATION

Declaration by the candidate

This thesis is my original work and has not been submitted for any academic award in any institution; and shall not be reproduced in part or full, or in any format without prior written permission from the author and/or University of Eldoret.

Signature …………………………………… Date: 14th January 2022

Name Ronald Kapkiai Kaptich

REG NO: SC/PGM /005/12

Declaration by the Supervisors

This thesis has been submitted with our approval as University Supervisors.

Signature………………………………….. Date: 18th January 2022

Dr. Betty Chemutai Korir
Mathematics & Computer Science Department
(University of Eldoret)

Signature ………………………………….. Date: 17th January 2022

Dr. Julius Kipruto Koech
Mathematics & Computer Science Department
(University of Eldoret)

DEDICATION

My research thesis is dedicated to my entire family, particularly my brother John Kimeli, and my mother Salina Ruto.

ABSTRACT

The essential nutrients for growth and productivity to all living organisms, specifically plants are Nitrogen, Phosphorus and Potassium. However, there are other factors that contribute to optimum yield of crops; these factors are land availability, farming techniques, crop spacing, organic fertilization and climatic conditions. The current research study investigated the optimal levels of potato tuber yield and size, recorded the impact of crop spacing and inorganic fertilizers (nitrogen and phosphorus) as factors of interest that are known to affect the production of potato crop, and to compare the model fit using both full and fractional factorial experiment. A two-level full factorial and the fractional factorial experiments $\left(2^3\right)$ with three replicates were employed to measure the impact of the selected factors on the potato tubers. The study used the Randomized Complete Block Design (RCBD), where land acted as blocks and treatments randomized within blocks. The first order models were fitted by using the method of least squares. The data collected was subjected to data analysis using descriptive statistics and Inferential Statistics ANOVA utilizing R statistical software. The descriptive statistics was presented by use of frequency distribution tables. Results indicate that the highest average optimum yield was 18.64 t ha^{-1} when nitrogen and phosphorous were supplied at the higher rates of 80 kg ha^{-1} and 155 kg ha^{-1} respectively with crop spacing of 65 cm by 20 cm and lowest average yield was 12.12 t ha^{-1} when nitrogen and phosphorus were supplied at lower rates of 40 kg per hectare and 77 kg per hectare respectively with spacing of 75 cm by 30 cm. Furthermore, the average optimum size of potato tuber was recorded as 12.18 cm when nitrogen, and phosphorus was supplied at 40 kg per hectare, and 155 kg per hectare with crop spacing of 75 cm by 30 cm and smallest average size of potato tuber was recorded as 8.74 cm when nitrogen, and phosphorus was supplied at lower rate of 40 kg per hectare and 77 kg per hectare respectively with spacing of 65 cm by 20 cm. The effect crop spacing shows a negative linear effect on the yield of potato tubers only but significant on both yield and size of potato tuber whereas nitrogen (N) and phosphorus (P) shows positive linear effects on both the yield and size of potato tuber with phosphorus being significant in all models. Additionally, the use of fractional factorial experiment gave better model fit $\left(R^2 > 80\%\right)$ when compared to full factorial experiment $\left(R^2 \cong 60\%\right)$. The obtained results are close to the national estimates on the yield of potato tuber which stands at 14 tons hectare and the global average of 17.2 tons per hectare respectively. The current study will be important in designing the necessary interventions within country in order to improve production of potato crop.

TABLE OF CONTENT

Contents page number

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND ACRONYMS

RCBD:	Randomized Complete Block Design
cm:	Centimeter
m:	meters
mm:	millimeters
^{0}C :	Degree Celsius
ANOVA:	Analysis of variance
GDP:	Gross Domestic Product
GOK:	Government of Kenya
FAO:	Food and Agriculture Organization
DAP:	Diammonium Phosphate
CAN:	Calcium of ammonium nitrogen
RSM:	Response Surface Methodology
N:	Nitrogen
P:	Phosphorus
K:	Potassium
S:	Inter and intra row spacing

TSP:	Triple superphosphate
Ha:	Hectare
ha^{-1}:	Per hectare
Kg:	Kilo grams
t:	Tons
P_2O_5	Phosphorous V Oxide
MOA:	Ministry of Agriculture
DF:	Degrees of Freedom
IFA:	International Fertilizer Industry Association
CIP:	International Potato Centre
PPM:	Potato Production Manual
pH:	Potential of Hydrogen

ACKNOWLEDGEMENTS

First and foremost, I would like to thank the Almighty God for blessing me with good health, determination and endurances in composing my thesis. I want to appreciate the efforts of my university supervisors who contributed immensely in guiding me from the beginning to the end of this research thesis. I would thank the University of Eldoret for enabling me to study and fulfill my dream to further studies, and all the staff members in the Department of Mathematics and Computer Science for the academic and moral support. I acknowledge Dr. Betty Korir and Dr. Julius Koech for their vast knowledge on the subject, for the expert guidance and providing me with both professional and moral support during the entire course of my graduate program. I want to express my gratitude to the farmers of Kabiemit village in Nandi County for their cooperation in providing the information in collection of data and labour that was very necessary in planting and harvesting of the potatoes. And to all my friends and my colleagues, thank you for your valuable advice and guidance throughout my studies. Finally, I appreciate my family for the financial support that they accorded me when needed.

CHAPTER ONE

INTRODUCTION

1.0 Introduction

The Irish potato, *Solanum Tuberosum L.*, is a common species produce for food and cash crop in many countries around the World (Mengui et al., 2019). The Irish potato (*Solanum Tuberosum L.*) is currently the world's fourth most important food crop (FAOSTAT, 2016). The potato tuber was originally domesticated in South America in what is known as central Peru and Bolivia about 800 years ago and it was originally grown in Spain at the end of 16th century and by the year 1570 it had spread to other parts of Europe. In the years between 1588 and 1593 it had extended to British Isles and England (Tunio et al., 2019).

Agriculture is a significant part of Kenya's economy, accounting for around 26% of the country's GDP (Gitau et al., 2009). In Kenya, potato farming has grown in popularity; more than a third of Kenya's agricultural produce is exported, accounting for 65 percent of the country's overall exports (GOK, 2007). In Kenya, the Irish potato (*Solanum tuberosum L.*) is the second important food crop after maize, and it contributes significantly to poverty alleviation through revenue production and job creation. Around 80% of Kenyans work in agriculture, with the majority of them being small-scale subsistence farmers who rely on rain to produce their basic crops (Ann, 2009).

Potato was introduced to Kenya in the late 1800s by European colonial farmers in the Kiambu, Murang'a, and Nyeri areas. Local Kenyan farmers started growing in the 1920s, with Kerr's Pink being the most popular variety at the time (CIP, 2019). The

National Agricultural Laboratories in Kabete began potato variety research and seed potato production in 1903, and the Plant Breeding Station in Njoro began in 1927. Due to increased urbanization and a growing population, there is a worldwide and, more importantly, local demand, which explains the popularity of fast food such as French fries, potato crisps (chips), and other similar items. Carbohydrate is essential nutrients, protein, vitamins, and minerals, as well as other nutrients, are abundant in tubers (Sriom et al., 2017).

Nyandarua, Nakuru, Elgeyo Marakwet, Meru, Nyeri, Kiambu, Taita Taveta, Narok, Bomet, Trans Nzoia, Bungoma, Uasin Gishu, West Pokot, Kisii, Nyamira, Kirinyaga, Murang'a, Baringo, Nandi, Laikipia, and Kericho are among the major Irish potato-growing region in Kenya highland.

1.1 Potato Production and the varying climatic conditions

The potato plant (*Solanum tuberosum L.*) is grown on every continent, in more than one hundred and thirty nations, and in a wide range of climates conditions. Potatoes thrive in temperate and tropical settings, with optimal temperatures of 18 to 20 degrees Celsius. When temperatures drop below 10^{o}C and rise beyond 30 ^{0}C , the tuber's growth is severely slowed. If tuber initiation is delayed, it is due to high temperatures at the time of planting. Over 500 mm of water is necessary for higher yields over a typical growth season of 120–150 days (FAO, 2019). As a result, without farmer management adaptation to climate change, such as adjusting planting dates or types, potato yields may decline in locations that are already marginal for potato development due to water scarcity or rising temperatures (Raymundo et al., 2018).

Potatoes are a high-yielding, resource-intensive crop that requires a variety of balanced plant nutrients to grow and thrive. Nitrogen (N), phosphorus (P) and potassium (K) are three of the most crucial nutrients for potato growth (Pervez et al., 2013).

Irish potatoes thrive in well-drained and aerated loose loamy and sandy loam soils that are rich in organic matter and have a Potential of Hydrogen (pH) range of 5 to 6.5. Rooting depth is limited by impermeable soil layers, which has an impact on productivity. The crop thrives in areas with regular rainfall of 850–1400 mm per year at altitudes of 1400–3000 m above sea level. Certified seeds tubers of 24 – 45 mm in diameter with 4 - 5 sprouts in each potato tuber seed and should be used at the rate of (10 – 12) bags of 50 kg each per hectare. They are attacked by pests like (late blight, Aphids and Potato tuber moth) and diseases such (nematodes and bacterial wilt). The fungicides are used to control diseases and pests. The weeding and ridging should be done after the potato plant is above the soil. Harvesting season is done in 3 to 4 months after planting. There are two planting and harvesting seasons per year.

1.2 The potato farming in Kabiemit, Nandi County

Potato cultivation is done on a limited scale in Kabiemit, mostly for local use. The first ploughing is done one to two months before the rainy season, and the second ploughing is done two to five weeks later to enrich the soil and break it down into smaller pieces. The first rainy season is generally between April and May, while the second rainy season is between August and September. Farmers use (100–200) kg per hectare of Diammonium Phosphate (DAP) or TSP fertilizer during planting, depending on the farmer's financial situation, and (50–100) kg per hectare of Calcium of ammonium nitrogen (CAN) or Urea fertilizer at planting or one month after germination. To prevent blight, BM Enrich® kill pesticide is sprayed on the day of planting, and Ridomil® is sprayed after germination. Two weeks after emerging, weeding is done and repeated again two weeks after the first weeding. Ridging occurs one month after germination during the second weeding, when the plants begin to bloom. In Nandi County, harvesting takes place between June to August for the first planting season, and between November to January for the second planting season. Farmers gather between 10 and 30 tons per hectare in a single planting season on average.

1.3 The problem of statements

The region of Kabiemit in Nandi County is characterized by restricted land, low rainfall or inadequate irrigation, inadequate inorganic and organic fertilizers application, and poor farming techniques resulting to poor and low production of potato tubers. Farmers in Kenya have experience the decline in potato production. The main factor contributing to decline of potato production is soil erosion and leaching of inorganic fertilizers nitrogen and phosphorus (Okalebo, 2009).

There are other researches which have been done on the effects of crop spacing and fertilizers but with no optimum required levels of crop spacing (Israel, Ali and Solomon, 2016; Dagne et al. 2018; and Burton, 1989). The research done by (Koech et al., 2017) to optimize the yield and size of potato (solanum tuberrosum L.) tuber using a first order response methodology and second order rotatable design with three independent variables nitrogen, phosphorus and potassium was expensive since it involves many plots. The effect of inter and intra- row spacing was not investigated thus there is need to find the optimal level of crop spacing using first order response surface model. The second order model gave the optimal levels for the effects than first order model but it is complicated to understand and expensive model as compared to first order model. This study sought to model the impact of crop spacing, and inorganic fertilizer (nitrogen and phosphorus) on the output and size of the potato tuber using the two-level full and fractional factorial design by applying the first order response surface methodology. Furthermore, optimum levels of the factors (inputs) were determined.

1.4 Justification of the study

According to the Kenyan Government (GOK, 2007), potatoes are one of the nation's most significant food crops. Despite a lot of research and development efforts on high-yielding varieties, the country's production and consumption potential is not meeting demand due to low productivity (Alumira and Obara, 2008). This crop has the potential to be both a source of money and a source of essential nutrients for humans. Irish potatoes have a high nutritional content. As a result, increased productivity will result in higher earnings and improved farmer welfare.

Research on the effect of spacing and fertilizer has been done but the optimum required levels of crop spacing have not been obtained. In Kenya, most farmers grow potatoes on a small scale due to limited land availability and hence they practice intercropping. Therefore, no farmer does the crop spacing, resulting in low yields. They apply a very small amount of inorganic fertilizer although optimum levels of nitrogen and phosphorus are known. This research study was conducted so that the required crop spacing and inorganic fertilizer can be established and will aid in improving average yield among farmers and also improve the economic benefit and thus minimize costs among the small-scale farmers in Nandi County.

1.5 The Overall Objective

The general objective was to optimize the yield and size of potato tuber by modeling the effects of crop spacing and inorganic fertilizer using both two-level full and fractional factorial design.

1.5.1 The Specific Objectives.

The specific objective of the study was to:

1. Estimate the optimum levels of crop spacing and inorganic fertilizer for potato tuber yield and size using a two-level full and fractional factorial design.
2. Determined the influence of inter and intra-row spacing of potato crops on yield and size of potato tuber using a first-order response surface model.
3. Fit an appropriate first order response model by leveraging the factors of crop spacing and inorganic fertilizer on the production and size of potato tubers.
4. Compare the model fit for the factors crop spacing and inorganic fertilizer on potato tuber yield and size using both full and fractional factorial experiment.

1.5.2. Research Hypotheses

1. H_0: There are no optimal levels of crop spacing and inorganic fertilizer that increase the yield and size of potato tuber using a two-level full and fractional factorial design.

   H_1: There exist optimal levels of crop spacing and inorganic fertilizer that increase the yield and size of potato tuber using a two-level full and fractional factorial design.
2. H_0: There is no significant relationship between crop spacing and the yield or size of potato tuber using a two-level full and fractional factorial design

H_2 : There is a significant relationship between crop spacing and the yield or size of potato tuber using a two-level full and fractional factorial design

3. H_0 : There is no significant effect on the factors crop spacing, and inorganic fertilizer on the output and size of potatoes tubers using a first order response model

   H_3 : There is a significant effect between the factors crop spacing and the inorganic fertilizer with the yield and size potato tuber using a first order response model

4. H_0 : There is no significant difference in the model fit with use of the factors crop spacing and inorganic fertilizer when using both the full and fractional factorial designs.

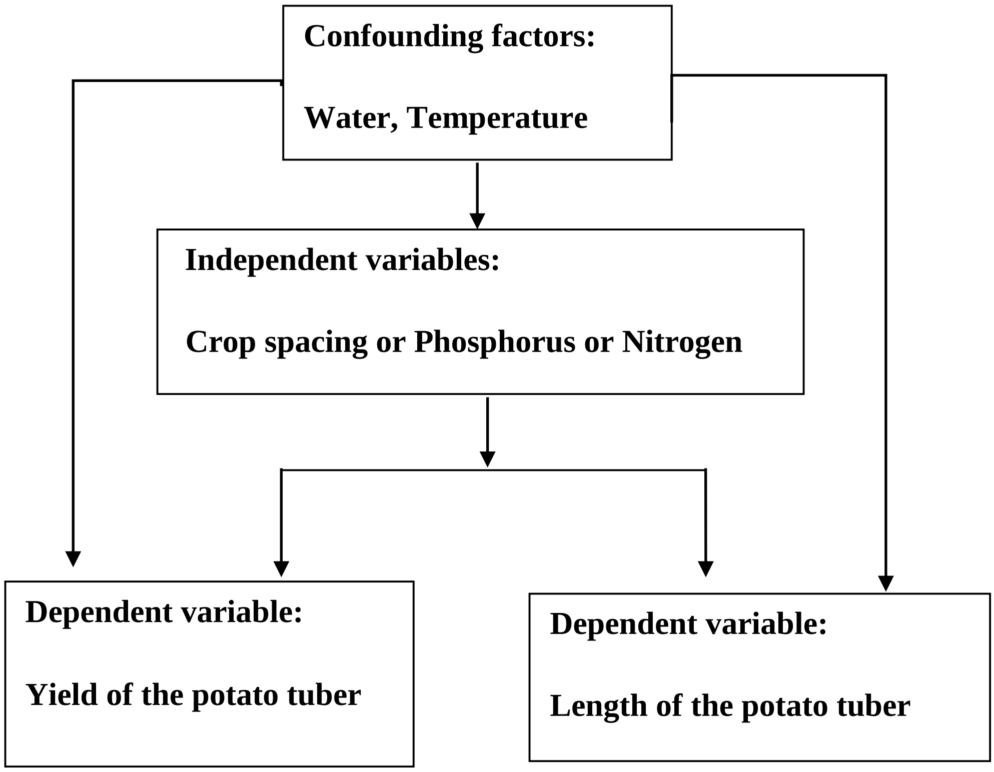
   H_4 : There is a significant difference in the model fit with the use of the factors crop spacing and inorganic fertilizer when using both the full and the fractional factorial design.

1.6 Research's Purpose

The research was undertaken in one of the land of a willing farmer in Kabiemit village, Nandi County, which is situated on the highland regions in Kenya. It involves the farmers who grows potato tuber. The Potato certified seeds was sown during raining season in a farmer’s field. The fertilizers used by farmers are phosphorus (P) supplied by (Triple superphosphate) TSP and nitrogen (N) from urea and also the inter and intra-row crop spacing (independent variables). There are three factors in two levels with three replications. This was a factorial experiment commonly known as randomized complete block design. At harvesting, tuber weight was recorded, and was averaged to give the total yield and the length of potato tuber recorded (dependent variable).

1.7 Theoretical Framework

Table 1.1: The link between the dependent variables and the treatment level factors/independent variables



1.8 Assumptions/limitation of the study

The following assumptions/limitation made were necessary; enough rainfall during the study period, the plots assumed to have uniform soil fertility and soil texture, and the area is situated in the highlands; therefore, the tropical climatic conditions were assumed to be favorable for the growth of potato crop.

The experimental blocks were assumed to be equal and administration of the treatments nitrogen, phosphorus and crop spacing was done in a random manner. Treatment was experimented in one block and there after replicated three times so as to minimize the effect of missing data.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction.

The chapter reviews the relevant literature pertaining to the utilization of resources that were used in the crop planting and production of potato tubers (*Solanum Tuberosum*

L.), the applications of experimental designs response surface methodology (RSM), in particular the factorial design, and the areas in which the technique has been applied. The required materials and inputs necessary for the growth and production of potatoes are also discussed.

2.1 Response surface Methodology (RSM) Technique

Response Surface Methodology (RSM) (Dette and Yuri, 2014; Myers, Douglas, Anderson, and Cook, 2009) is a set of approaches for examining and recognizing the relationship between a given answer (s) and a set of independent factors, with the primary goal of improving the response. In other words, it comprises of mathematical and statistical strategies for maximizing dependent variables based on some interesting independent variables. The basic goal when "about proper" levels of components are connected is to optimize the response. Estimates of "proper" factor levels are those assumed to yield the best outcome (s). We can see that y is a function of the independent variables, which are the factors of interest, if we take it to be the interest response. x_1,

$x_1, x_2, x_3, \ldots, x_k$

$$y = f(x_1, x_2, \ldots, x_k) + \varepsilon \text{ for } k \text{ factors} \ldots\ldots \quad (2.1)$$

In this scenario, the error term is assumed to be normally distributed with a mean of zero and variance σ^2 of one.

RSM is a set of experimental methodologies, statistical inference, and mathematical approaches that allow a researcher to perform a thorough empirical investigation of the system of interest. (Box and Wilson 1951) published a study that sparked first interest in the set of approaches. These techniques have been utilized several times to improve an operation.

2.2 Randomized Complete Block Design (RCBD)

The most common design that may be examined using a two-way ANOVA is the randomized complete block design (RCBD) (Kutubi et al., 2021). A set of experimental units are grouped in this design to reduce variation within groups (blocks). The goal is to make the experimental error extend within each block. As a result, variations between blocks may be seen as coming from different sources of variation as they are not caused by treatments. Each block has a full set of treatments.

The RCBD is utilized to reduce the data's volatility (Lachin, 1988a). Within pre-established blocks, the RCBD paradigm randomly allocates units to treatment or control. Before grouping the sample, the blocking approach is designed to separate it into homogeneous subgroups based on a certain criterion (Hallstrom and Davis, 1988; Simon, 1979). Units are randomized to treatment or control conditions within blocks at random. This implies that each block may be seen as a single, identical trial within the study and that the complete experimental design is repeated as many times as there are blocks (Rosenberger and Lachin, 2002).

Blocking is the most used strategy for variance reduction design. A "block of units" is a group of identical units. It's possible that are in the same field plots, samples collected at the same time or units from the same supplier (Oehlert, 2010). The expected similar reactions from units inside a block are based on their commonalities. Separate blocks, on the other hand, have different units.

2.3 Factorial and Fractional Factorial Designs

The variables might be quantitative or qualitative in nature (George et al., 2005). Regular and irregular fractional factorial designs are two types of two-level fractional factorial designs (Tang and Deng, 1999). A collection of identifying contrasts can be used to identify a regular fractional factorial design. If only a limited number of resources are available for 2^{p-q} design, the trials to be conducted are selected by allocating q of the components to the interaction columns of the 2^{p-q} complete factorial model matrix. The extra q elements are referred to as added factors, whilst the p-q elements are regarded as vital factors (Franklin and Bailey, 1977; Cheng and Li, 1993; & Bingham and Sitter, 2001). That is, a 2^{p-q} regular fractional factorial design is obtained from the full factorial design, which is formed from the $p-q$ base factors and is known as the base factorial design.

In agricultural studies, grouping the experimental units into blocks, such as separate fields in a plant study, is generally beneficial to decrease unnecessary errors and enhance the precision of conclusions. As a result, blocked 2^{m-p} designs are frequently utilized to improve data gathering efficiency. (Bisgaard, 1994; Sun, Wu, and Chen 1997; Sitter, Chen, and Feder, 1997; Chen and Cheng, 1999; and Cheng and Wu, 2002) all worked on the criteria for optimum blocking schemes. Their methods produce the best estimates for models with main effects and block effects.

2.4 Previous Findings on Production of Potato tuber

Tuber yield, number, length, and tuber quality, can all be affected by a lack of water. Water shortages in the middle and late stages of growth season tend to reduce output less than those in the early stage; this varies by cultivars (Steduto et al., 2012).

Soil and air temperatures have an impact on potato development and tuber output. (Steduto et al., 2012) 15 to 18 degrees Celsius are the optimal soil temperature for tuber development. Potatoes need a diurnal temperature of 25 to 32 degrees Celsius and a night temperature of 12 to 18 degrees Celsius to grow. Temperatures in Kenya are almost ideal for potato cultivation; however temperatures below -2 degrees Celsius are conceivable in select growing locations, such as Kinangop, causing crop damage (Ballestrem and Holler, 1977). According (Winters and Miskimen, 1967), potatoes like a temperature range of 15.9 to 23.90 degrees Celsius.

The heavy rainfall at high altitudes over 1500 meters has little negative impact on the potato harvest since most soils are adequately drained. Although effective potato-growing at sea-level has been documented in Sri Lanka, soil and air temperatures in Mtwapa, on the coast, reach a critical stage of above $32^{0}C$ in April, May, and June, hampering normal potato development (Ballestrem and Holler, 1977).

Nitrogen and water have direct influence on potatoes production up to a certain point, after which the yield of potatoes declines as water and nitrogen levels rise. Phosphorus nutrients and water have direct influence on potatoes yields up to a point, although in a lower quantity than nitrogen and water. This is according to the data by (Muriithi, 2011).

One of the key aspects of nutrient management responsible for improving nutrient absorption and crop production is the availability of appropriate quantities of plant nutrients at correct period and at the right place in root zone. If the needed nutrients are given at the correct moment, the potato plant will mature depending on the following factors: emergence rate, number of stems per plant, stem height, canopy cover, and number of tubers per plant, tubers' grade yield, and overall tuber yield (Turamyenjirijuru et al., 2013).

Annett potato tuber yields more than B53 potato tuber and has high percentage of its tuber yield as compared to seed grades. Moreover, hill placement facilitates more efficient fertilizer use than broadcasting in the furrow at Kabete in Mombasa County (Mariga et al., 1980). The current recommendation seems to be higher than the most efficient fertilizer rate and Plant populations higher than 44444 plants per hectare don't significantly increase tuber yield but increases the proportion of the seed grades (Mariga et al., 1980).

Highland potatoes have been farmed for more than fifteen years in all of Kenya's counties, although farmers in Meru County have been cultivating the crop for longer than other counties. In all of the Counties, there was a positive connection between farm size and potato planting area. This means that larger farms dedicate larger amounts of land to potatoes (Muthoni et al., 2014).

In our former Central, Eastern, and Rift valley provinces, potato production is centered in the Kenyan highlands (1500 to 3000 m) under rain-fed conditions. These are the lands around Mt. Elgon, the Mau escarpment, the Aberdares range, the rift valley's borders, and Mt. Kenya's slopes (MoA, 2008; FAO, 2013).

In Kenya, clean potato seed is scarce, thus farmers rely on unofficial seed source such as farm-saved (self-supply), local market, or neighbors. The certified potato seeds are expensive due to scarcity of availability (Ayieko and Tschirley, 2006). Because of the non formal system, low-quality seeds are commonly used, hastening the spread of seed-borne diseases (Kinyua et al., 2001).

2.5 Recent findings on the production of Potato tuber

The first order response surface methodology study discovered that nitrogen, and phosphorus had a positive impact on potato tubers yield, with only phosphorus having a significant impact (Koech et al., 2017). On the size of potato tuber, phosphorus have a negative impact, whereas nitrogen has a positive one, with all not significant.

A second-order model was used to determine the experimental yields and size of potato tuber. The combination of the factors nitrogen and phosphorus had a non-significant positive influence on potato tuber production and a non-significant negative impact on the size of potato tuber (Koech et al., 2017).

The days of blooming and maturity are delayed by a high rate of nitrogen and a low rate of phosphorus. This is due to the plants height and number of stems per hill having a predisposition to initiate vegetative development. A higher nitrogen fertilization rate results in a faster canopy closure and a shorter growth period. Early crop development is aided by optimal Phosphorus application, while the responsiveness to Phosphorus application decreases over time (Belachew et al., 2016). The nitrogen and phosphorus mixture had a significant impact on the length of potato tuber, according to (Belachew et al., 2016). As the rate of nitrogen and phosphorus increases, the length of the potato tuber also increases.

The findings of (Firew et al., 2016) confirmed that nitrogen and phosphorus application affects potato yield. The authors discovered that applying nitrogen in excess of 56 kg per hectare reduces potato yield. The maximum tuber production was obtained at 56 kg N per hectare and 138 kg P per hectare.

Wubengeda et al., (2016) also conducted research to determine the appropriate irrigation and nitrogen fertilizer rates for potatoes. The data they gathered demonstrated that adding nitrogen and phosphate to the soil boosted potato yield. According to them, the highest tuber yield was achieved by applying N and P at rates of 206 kg N per hectare of urea and 244 kilogram P per hectare of DAP yielding 31.80 tons per hectare.

Nitrogen is necessary for maintaining higher haulm development, increased bulking rate, tuber quality, and more dry matter production, according to (Sandhu et al., 2014).

Plant disease, pests, and a variety of kinds of infection all lead to poor plant health, and output of potato tubers is insufficient due to limited resources (FAO, 2017). The formation of anaerobic conditions in potato tubers is induced by the presence of a water layer on the tuber surface. Pectolytic bacteria (found in suberised lenticels of most potato stocks) grow rapidly in such conditions and can cause soft rot. Tuber decay can occur if tubers are left moist for a period of time, leading to the spread of germs when tubers are handled and, in extreme cases, widespread tuber decay, resulting in the loss of whole stocks. (Elphinstone et al., 2018)

Soltani and Jaber, (2016) discovered that cutting back on irrigation water and fertilizer resulted in lower potato yields. Reduced evapotranspiration is to blame for the drop in output. On other hand, because nitrogen promotes the dispersion of roots and increase plant development, lowering nitrogen levels reduces performance. Reduced input resources result in a reduction in yield. By lowering water, the tuber yield decline slope is steeper than by reducing nitrogen.

2.6 The inputs for potato farming

The following are potato inputs that, when applied or received in sufficient quantities, improve potato output.

2.6.1 Inorganic Fertilizers

Nitrogen has been shown to improve potato yields by increasing the quantity of tubers produced, particularly big tubers (Hanley et al., 1965; Dubetz and Bole, 1975; Birch et al., 1967). Potato quality is influenced by nitrogen in a number of ways. (Ionas, 1975) discovered that nitrogen enhanced tuber dry matter and protein content while lowering the starch content acquired from phosphorus applications.

Increased nitrogen rates lowered tuber specific gravity and increased the frequency of tubers with light colored skins, according to (Painter, Ohms and Walz, 1977), whereas excess nitrogen impacted flavor and tuber texture, according to (Birch et al., 1967).

The potatoes need a high amount of soil nutrients due to its underdeveloped and shallow root structure. The crop's growth and development are stunted, and both the production and quality of tubers suffer as a result of improper fertilization management (FAO, 2009).

Potatoes nutrition management system that work are designed to make sure that all important plant nutrients are accessible in the right amounts and at the right period for the best results (Stark et al., 2004).

In comparison to cereal crops, potatoes have a fairly high fertilizer need. It reacts well to fertilizer application and produces a high output per unit area and time (Bationo et al., 2012).

To promote quick, consistent tuber growth and normal tuber development, potatoes require appropriate amounts of key nutrients throughout the growing season. Plant nutrition has a considerable impact on tuber quality. Both tops and tubers are stripped of substantial amounts of nitrogen. This indicates that the element is most likely to be inadequate in typical agricultural soils and must be supplemented in sufficient amounts to achieve greater yield (Nand et al., 2011).

According to (Israel, Ali, and Solomon, 2016), when nitrogen and phosphorus were treated simultaneously, the maximum plant height was achieved. (Belachew et al., 2016) reported a similar finding, implying that the combined effects of nitrogen and phosphorus had a major impact on potato development. According to the author, increased phosphate and nitrogen treatments resulted in a 63 percent increase in plant height when compared to the control treatment.

In a study done in southeastern Ethiopia by (Israel, Ali, and Solomon, 2016), the maximum length was found when the nitrogen and phosphorus combination was applied at higher rate.

Phosphorus is not the most readily absorbed nutrient (Fernandes et al., 2011), however phosphate fertilizers have been used in large quantities since the plant is inefficient at phosphorous uptake, especially in soils deficient in this component (Dechassa, 2003). Phosphorus is required for potato development and is heavily translocated to the tubers during tuber bulking, when the amounts of phosphorus directed to the tubers are comparable to those taken up by the tubers (Fernandes et al., 2011). Phosphorus deficit can diminish the quantity and size of tubers produced greatly (Fernandes and Soratto, 2016; & Hopkins et al., 2010). As a result, phosphorus fertilizer must be managed to ensure that sufficient phosphorus is available in the soil to meet the crop's nutritional requirements.

2.6.2 Crop spacing

According to (PPM, 2013), the seeds should be sown in furrows with the sprouts pointing up, the planting depth and furrow depth should both be between 8 and 12 cm. Plant seed tubers in furrows with sprouts facing up at spacing of 75 cm between rows and 30 cm within plants for faster and more uniform germination. This corresponds to a plant population of 44,400 tubers per hectare (18,000 plants per acre). This spacing makes it easy to carry out cultural activities including disease and insect sprouting, spraying, rouging, and harvesting. To allow for tuber growth and simple harvesting, potatoes should be sown in ridges at a height of 25 cm.

Inorganic fertilizer may boost overall output while reducing the number of giant potato tubers produced. The ability to protect a high yield is heavily reliant on maintaining the optimal number of plants per unit area and their spatial arrangement in the field (Gebremedhin et al., 2008).

The plant height for potato is high if the plants are grown close to each other due to population density and competition for recourse like sun light, nutrient and water (Lamessa and Zewdu, 2016).

Seedlings emerge at a faster rate in a wider spacing than in a space with a higher density of plants per plot (Akassa, Belew, and Debele, 2014). According to (Zamil et al., 2010), the largest spacing promotes plant development and height, which is in contrast to narrow spacing.

The distance between ridges and plants for the growth of ware and seed potato tubers was one of the most significant difficulties contributing to the low output of potatoes, especially in Ethiopia's western areas (Allen and Warr, 1992). Seed cost, plant development, output, and crop quality are all affected by plant spacing.

When the space between the potatoes is narrow, the number of potatoes produced is higher (Lamessa, and Zewdu 2016). Wider spacing resulted in fewer tubers since fewer stems resulted in a high number of tubers, close spacing improve output quality and large potato tubers (Burton, 1989).

2.6.3 Climatic Conditions/Temperatures

The Irish potatoes (*Solanum tuberosum L*), the fourth largest world food crop after rice, wheat, and maize, have been harmed by weather fluctuation. Potato yields in northern Europe grow as a result of weather variability, whereas yields in the rest of Europe decline or remain steady, according to crop models (Wolf, et al., 2000).

Potato yields are generally determined by temperature, incoming solar radiation, water, and nutrient availability. Biological systems rely on incoming radiation since photosynthesis is their primary source of energy. Drought and intra-seasonal dry spells are common as a result of irregular rainfall patterns, resulting in poor crop yields and, in some cases, crop failure (Kinoti et al., 2010).

The European agriculture sector was predicted to have lost thirteen billion euros as a result of the 2003 heat wave, which saw temperatures up to 6°C above long-term norms and precipitation shortages of up to 300 mm (Ciais, 2005).

Potatoes respond nonlinearly to changes in their growing conditions and have threshold responses. As a result, weather variability and extreme events have a far greater impact on production, yield stability, and quality (Porter and Semenov, 2005).

Due to physiological and biochemical changes in the plant, such as photosynthesis, respiration, and hydration status, high temperatures can reduce yield. The detrimental effects of excessive heat can be mitigated in part by uniformly distributed optimal precipitation. The ideal rainfall for early potatoes is between 250 and 350 millimeters higher than this optimum precipitation reduces yield by delaying germination and sprouting and increasing disease incidence (Rymuza et al., 2015).

Potatoes can be cultivated in a variety of temperatures, although they thrive in temperate climes (Haverkort, 2012). Tuberization slows down at temperatures above 25°C (Stol, Haverkot, Kooman, Keulen, and Penning, 1991).

The impact of global warming on potato output has been studied using simulation models by a number of writers. Because of a longer growing season, higher temperatures are expected to boost potato yields in England and Wales (Davies *et al*., 1996), Scotland (Peiris et al., 1996), and Finland (Carter et al., 1996). The United States, on the other hand, is expected to see a reduction in overall yields (Rosenzweig et al., 1996).

High temperatures of air and soil have a negative impact on the growth and development of potato. At high temperatures above $25\,^{0}C$ shortens the growing period of potatoes and reduces tuber yield. High soil temperatures stimulate formation and branching of stolons, which directly adversely affects the yield. The physiological processes in plants significantly slow down at the soil temperature higher than $25\,^{0}C$, while at the temperature higher than 29 ^{0}C formation and bulking of tubers is slow. Long-term effects of high temperatures from 30 to 40 ^{0}C during the formation of tubers cause degeneration of potatoes, particularly in the early varieties (Zoran, 2016)

2.6.4 Rainfall/water

To generate 1 kg of tuber dry matter, potatoes require 0.35 to 0.80 m^3 of water. Under field settings, this amounts to a water need of 350 to 650 mm during the growing season, depending on climate and cultivar (Sood and Singh, 2003).

Changes in precipitation patterns have a significant impact on agriculture because water is required for plant growth. Forecasts of future precipitation change have a considerable impact on the quantity and direction of climatic impact on crop production because rain-fed agriculture accounts for more than 80% of global agriculture (Olesen and Bindi, 2002).

Tropical developed countries with rural economies depend on rain-fed agriculture account for around 95 percent of current world population increase, while tropical developing countries account for the remaining 5% (Rockstrom, 2001).

The dominant source of food production has been rain-fed agriculture in Sub-Saharan Africa. It is likely to remain so for the near future, as rain-fed agriculture accounts for over 95% of agricultural land (Parr et at., 1990; Rosengrant et al., 2000).

Dry land potato production led in 1991, according to a research (Kabanda, 2011) of potato production patterns in South Africa from 1991 to 2003. Dry land farming, on the other hand, had reduced by roughly 22% by 2002/03, while irrigation had increased by 78 percent. Because of the high production costs, farmers were forced to adopt irrigation technologies to control the significant risks and price fluctuations associated with dry land potato growing.

Potato agriculture is well-known in the East African highlands, which takes importance of the two rainy seasons. The lowlands, on the other hand, feature erratic rainfall patterns and fragile soils. Roots and tubers thrive in the humid and sub-humid zones of Central Africa, where drought is a problem (Maharjan et al., 2011). As a result of unpredictable rainfall patterns, drought and intra-seasonal dry spells are prevalent; resulting in low crop output and, in some cases, crop failure (Kinoti et al., 2010).

2.6.5 Soil fertility/soil texture/soil pH

The concentration of hydrogen ions (H+) in the soil determines its pH. On a scale of 0 to 14, it represents the acidity and alkalinity of the soil solution. The pH of acidic solutions is less than 7, whereas the pH of basic or alkaline solutions is more than 7. On the pH scale, each unit is 10 times more acidic than the one above it (Ann, Jones, and Rutz, 2017).

Soil pH 6.5 to 8 makes Nitrogen, Potassium, Calcium, Magnesium, and Sulfur more accessible, whereas pH 5 to 7 makes Boron, Copper, Iron, Manganese, Nickel, and Zinc more available. High quantities of H+, aluminum, and manganese in soil solutions can approach hazardous levels at pH less than 5.5, limiting crop yield (3, 4). Phosphorus is most readily accessible in soils with a pH range of 5.5 to 7.5 (Ann, Jones, and Rutz, 2017). Potatoes thrive well on soil with a pH of 6.5, but the potato scab organism does as well. Scab is significantly decreased at pH levels lower than 5.2, which potatoes survive, although additional fertilization is required to compensate for the reduced nutrient availability at such low pH levels.

2.7 Farming Techniques

2.7.1 Land preparation

Both primary and secondary tillage should be carried out to produce fine tilth which is required for the growth of homogenous, wide, and smooth potato tubers (PPM, 2013). The land should be prepared before onset of rainfall. Farmers are supposed to plough the land 20 cm deep by breaking the clods to obtain fine, firm and weed-free surface.

2.7.2 Seeds

Certified potato seeds should be obtained from a leading farmer identified by an agricultural extension officer. The seeds must be a variety adapting that area and also uncut tubers. Red Shangi potato tuber seeds are disease and pest free and are suitable for growing in most Agro-ecological Zones (PPM, 2013). Additionally, the variety is popular with farmers since it is high yielding.

2.7.3 Planting

Planting should be timed to coincide with the start of the rain season to maximize water use efficiency (PPM, 2013). The tubers should be place with sprouts facing up when positioned inside the furrows for first germination.

2.7.4 Weed control and Ridging

Weeding should be done three weeks after planting. Weeds should be typically eradicated to avoid competition with the potato crop for moisture, light, nutrients, and space, which would lower the production. (PPM, 2013) Weeds should be controlled manually using a hoe. Ridging should be done when plants starts flowering during the second weeding to prevent exposed tubers from turning green. The length of the ridge should be approximately 25 cm.

2.7.5 Dehaulming

When the potatoes crop reaches 80-90 days, dehaulming should done by removing the haulms, or aerial sections of the potato plants, with a sickle. When the aerial components turn yellow, this is usually the time to remove the haulms. Dehaulming of the potato tuber helps to harden and increase their firmness (GOK, 2013).

2.7.6 Harvesting

Harvesting should be done 14 days after destruction of haulm. This should be done when the soil is dry for easing working on it. A hand tool (hoe) should used to expose the potatoes (GOK, 2013).

CHAPTER THREE

RESEARCH METHODOLOGY

3.0 Introduction

The materials and sources used in the experiment, as well as the labour involved, are covered in this section. The experiment's structure, procedures, techniques (RSM), multiple answers, optimization, objectives and data analysis are all discussed.

3.1 Farm Inputs and Tools

The requisite farm inputs and farm tools used during planting of potatoes were as follows: Clean seeds of potato, Fertilizers (TSP and Urea), Chemicals and machinery spraying, Land, Water or Rainfall, Books, pens, calculators, Methods for weight calculation, Tape measurement and Questionnaires.

3.2 Treatment Structure and Design Layout

The potatoes were sown during the 2020 rainy season in April in a farmer's field at Kabiemit in Nandi County. A Randomized Complete Block Design (RCBD) with three replications in a factorial arrangement was employed for the study. Two levels of inorganic fertilizers were as follows.

1. 155 Kg P_2O_5 ha^{-1} of triple superphosphate (TSP) and 80 Kg N ha^{-1} of urea
2. 77 Kg P_2O_5 ha^{-1} of triple superphosphate (TSP) and 40 Kg N ha^{-1} of urea

And two levels of combined inter and intra-row spacing;

1. A spacing of 75cm between row and 30 cm between plants (S_1).
2. A spacing of 65 cm between rows and 20 cm between plants and finally $\left(S_2\right)$

The distance between blocks and plots was 1 m and 0.5 m respectively. The plot size 4.0 m by 4.0 m = 16.0 m^2 was applied for all treatments. All fertilizers were applied during planting, with nitrogen supplied as urea (46 percent N) at two rates (40 and 80 kg ha^{-1} N). Phosphorus was also provided as triple super phosphate (46%) at two rates, 77 and 155 kg P_2O_5 ha^{-1}, respectively, during planting time (Koech et al., 2017). All fertilizers were applied at planting and were done per crop point using estimates from international fertilizer manual (IFA, 1992; Koech et al., 2017). The control of bacterial wilt and potato blight was done by using BM Enrich® and Ridomil® respectively. The factorial design layout is as given in table 3.1.

Table 3.1: Design matrix of factorial experimental layout of the experiment

	Treatments		
Design points	**Urea (N)**	**TSP (P)**	**Plant spacing factor (S)**
1	**-1**	**-1**	**-1**
2	**1**	**-1**	**-1**
3	**-1**	**1**	**-1**
4	**1**	**1**	**-1**
5	**-1**	**-1**	**1**
6	**1**	**-1**	**1**
7	**-1**	**1**	**1**
8	**1**	**1**	**1**
9	**0**	**0**	**0**
10	**0**	**0**	**0**

Where;

-1 represent low levels, 1 represent high levels and 0 is the middle of high and low levels of independent variables X_1, X_2, and X_3

Table 3.2: Field Experimental Layout

Plot	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Rep 1	B	C	ABC	A	0	0	BC	AC	(I)	AB

Rep 2	(I)	BC	0	AC	AB	B	0	A	ABC	C
Rep 3	0	(I)	AC	AB	BC	ABC	A	B	C	0

The treatment was applied in a farmers land as shown in Table 3.2 where A, B, and C represent $X_1, \mathrm{X}_2,$ and X_3 respectively.

3.3 Response Surface Methodology (RSM)

The production of potato tube can be optimize by regulating the quantity of inorganic fertilizer (N and P), and S. The fundamental method consists of four steps:

1. Procedure of moving into optimal region.
2. The response surface behavior in the optimum region.
3. Optimum condition estimation.
4. Verification.

If p = 3 factors, X_1, X_2 *and* X_3. Then we have the response variable *y*, and a function *f*, such that

$$E(y) = f(x_1, x_2, x_3) + \varepsilon \quad \text{(3.1)}$$

3.4 Types of RSM

The first-order, second-order, third-order, and fourth-order models are the four fundamental types of RSM however, the current study only looked at the first-order model.

3.5 First-order model

In first order model the response function is defined by a linear function of independent variables.

The first-order model with three explanatory variables is written as follows:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \varepsilon \quad \text{……………..……………………………….. (3.2)}$$

where β_0 is the intercept and the regression coefficient for the independent variable X_1, X_2 and X_3 are β_1, β_2 and β_3 respectively and ε is the error. Because it only incorporates the major effects of the independent variables, the first-order model is also known as the main effects model. The following is the form of a fitted first-order linear model with k factors:

$$y = \beta_0 + \sum_{i}^{k} (\beta_i x_i) + \varepsilon \quad \text{…...….……….………………...……………. (3.3)}$$

In a regression problem, first-order models are written in matrix notation as.

$$y = x\beta + \varepsilon \quad \text{……………………...…………………………..………… (3.4)}$$

where

$$Y = \begin{bmatrix} y_1 \\ y_2 \\ . \\ . \\ y_n \end{bmatrix}, \qquad \beta = \begin{bmatrix} \beta_0 \\ \beta_1 \\ . \\ . \\ \beta_p \end{bmatrix}, \qquad \varepsilon = \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ . \\ . \\ \varepsilon_n \end{bmatrix}$$

The design matrix $$X = \begin{bmatrix} 1 & x_{11} & x_{12} & \cdot & \cdot & \cdot & x_{1p} \\ 1 & x_{21} & x_{22} & & & & x_{2p} \\ \cdot & & & \cdot & & & \cdot \\ \cdot & & & & \cdot & & \cdot \\ \cdot & & & & & \cdot & \cdot \\ 1 & x_{n1} & x_{n2} & \cdot & \cdot & \cdot & x_{np} \end{bmatrix}.$$

The data was coded to center it at 0 and utilized ± 1. The designs used with first-order response surface models are the factorial design p^q.

The three factors (p = 3) N, P and S were centered as follows in the experiment:

$x_1 = 60\,\text{kg}$ $\quad$ $x_2 = 116\,\text{kg}$

$x_3 = 70\,\text{cm by } 25\,\text{cm}$

where $X_1, X_2,$ and X_3 are the independent variables N, P, and S.

The next stage is to determine how far out from the center the design should be expanded from the centre. Make them far apart enough to observe the influence of the factor, but not so far apart that the surface looks to be bending.

The lower and higher levels can be obtained by.

$X_1 = \pm 20\,\text{kg of Urea}$ $\quad$ $X_2 = \pm 39\,\text{kg of TSP}$

$X_3 = \pm (5\,\text{cm by } 5\,\text{cm})$

This gives

$X_1 = 60\,\text{k}g \pm 20\,\text{kg of Urea}$ $\quad$ $X_2 = 116\,\text{kg} \pm 39\,\text{kg of TSP}$

$X_3 = 70\,\text{cm by } 25\,\text{cm} \pm (5\,\text{cm by } 5\,\text{cm})$

$X_1 = 40kg$ and $80\,\text{kg}$ of Urea $\qquad$ $\text{X}_2 = 77\,\text{kg}$ and $155\,\text{kg}$ of TSP
$\text{X}_3 = 65\,\text{cm by } 20\,\text{cm}$ and $75\,\text{cm by } 30\,\text{cm}$

The lower level of nitrogen 40 kg ha^{-1} of Urea, phosphorus 77 kg ha^{-1} of TSP and crop spacing of 65 cm by 20 cm was coded to -1 while the higher level of nitrogen 80 kg ha^{-1} of Urea, phosphorus 155 kg ha^{-1} of TSP and crop spacing of 75 by 30 cm was coded +1.

The design matrix X will be:

$$X = \begin{bmatrix} x_0 & x_1 & x_2 & x_3 \\ +1 & -1 & -1 & -1 \\ +1 & +1 & -1 & -1 \\ +1 & -1 & +1 & -1 \\ +1 & +1 & +1 & -1 \\ +1 & -1 & -1 & +1 \\ +1 & +1 & -1 & +1 \\ +1 & -1 & +1 & +1 \\ +1 & +1 & +1 & +1 \end{bmatrix}$$

$$\hat{\beta} = (X'X)^{-1} X'y$$
$$\text{cov}\left(\hat{\beta}\right) = \sigma^2 (X'X)^{-1} \quad \text{..} \quad (3.5)$$

From above design matrix X

$$(X'X) = \begin{bmatrix} +1 & +1 & +1 & +1 & +1 & +1 & +1 & +1 \\ -1 & +1 & -1 & +1 & -1 & +1 & -1 & +1 \\ -1 & -1 & +1 & +1 & -1 & -1 & +1 & +1 \\ -1 & -1 & -1 & -1 & +1 & +1 & +1 & +1 \end{bmatrix} \begin{bmatrix} +1 & -1 & -1 & -1 \\ +1 & +1 & -1 & -1 \\ +1 & -1 & +1 & -1 \\ +1 & +1 & +1 & -1 \\ +1 & -1 & -1 & +1 \\ +1 & +1 & -1 & +1 \\ +1 & -1 & +1 & +1 \\ +1 & +1 & +1 & +1 \end{bmatrix}$$

$$(X'X)^{-1} = \begin{bmatrix} 1/8 & 0 & 0 & 0 \\ 0 & 1/8 & 0 & 0 \\ 0 & 0 & 1/8 & 0 \\ 0 & 0 & 0 & 1/8 \end{bmatrix}$$

Since this is a diagonal matrix, the regression coefficient estimations are independent.

Then

$$\hat{\beta}_0 = \bar{y} \qquad \hat{\beta}_i = \frac{effect\ \mathrm{i}}{2} \quad \mathrm{i} = 1, 2, 3$$

$$Var(\hat{\beta}_i) = \frac{\sigma^2}{8} \quad \mathrm{i} = 0,1,2,3$$

……...………. (3.6)

where $effect\mathrm{i}$ are independent variables $X_1, X_2, and\ X_3$.

The interactions are orthogonal to the main effects. The quadratic form, x_i^2, will give a column matrix of $1's$, that will be confounded with $\hat{\beta}_0$.

Earlier method did not support the measurement of experimental error, and hence did not support a model fit test. When the first order model is used in the design, the following results are obtained:

Source	**DF**
Total	7
Linear	3
Residual	4

The residual is made up of the experiment's errors as well as the lack of fit. Center points can be added to 2^{p} or $2^{p\text{-}q}$ design to provide an estimate of experimental error. The design matrix will be:

x_0	x_1	x_2	x_3	x_1x_2	x_1x_3	x_2x_3	$x_1x_2x_3$	x_1^2	x_2^2	x_3^2
$+1$	-1	-1	-1	$+1$	$+1$	$+1$	-1	$+1$	$+1$	$+1$
$+1$	$+1$	-1	-1	-1	-1	$+1$	$+1$	$+1$	$+1$	$+1$
$+1$	-1	$+1$	-1	-1	$+1$	-1	$+1$	$+1$	$+1$	$+1$
$+1$	$+1$	$+1$	-1	$+1$	-1	-1	-1	$+1$	$+1$	$+1$
$+1$	-1	-1	$+1$	$+1$	-1	-1	$+1$	$+1$	$+1$	$+1$
$+1$	$+1$	-1	$+1$	-1	$+1$	-1	-1	$+1$	$+1$	$+1$
$+1$	-1	$+1$	$+1$	-1	-1	$+1$	-1	$+1$	$+1$	$+1$
$+1$	$+1$	$+1$	$+1$	$+$	$+1$	$+1$	$+1$	$+1$	$+1$	$+1$
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0

In the interaction of interest, the signs in the interaction columns are the signs that come from multiplying the primary effect columns X_1, X_2, and X_3. All of the columns are orthogonal to one another.

Each estimated effect for a 2^3 design with n replicates is the difference between two means:

a) The first mean is the average of all data in an effect column that corresponds to the + rows.

b) The second mean is the average of all data in an effect column that corresponds to the - rows.

Factor A's average effect, indicated A, is

$$A=\frac{(a+ab+ac+abc)}{4n}-\frac{((I)+b+c+bc)}{4n}=\frac{1}{4n}[a+ab+ac+abc-(I)-b-c-bc]$$

Factor B's average effect, indicated B, is

$$B=\frac{(b+ab+bc+abc)}{4n}-\frac{((I)+a+c+ac)}{4n}=\frac{1}{4n}[b+ab+bc+abc-(I)-a-c-ac]$$

Factor C's average effect, indicated C, is

$$C=\frac{(c+ac+bc+abc)}{4n}-\frac{((I)+a+b+ab)}{4n}=\frac{1}{4n}[c+ac+bc+abc-(I)-a-b-ab]$$

Two-factor interaction effect between Factors A and B, is

$$AB=\frac{(abc+ab+c+(I))}{4n}-\frac{(a+b+ac+bc)}{4n}=\frac{1}{4n}[abc+ab+c+(I)-a-b-ac-bc]$$

The two-factor interaction effect within Factors A and C, is

$$AC=\frac{(abc+ac+b+(I))}{4n}-\frac{(a+c+ab+bc)}{4n}=\frac{1}{4n}[abc+ac+b+(I)-a-c-ab-bc]$$

Two-factor interaction effect between Factors B and C, is

$$BC=\frac{(abc+bc+a+(I))}{4n}-\frac{(b+c+ab+ac)}{4n}=\frac{1}{4n}[abc+bc+a+(I)-b-c-ab-ac]$$

Three-factor interaction effect between Factors A, B and C, is

$$ABC=\frac{(abc+a+b+c)}{4n}-\frac{(ac+ac+bc+(I))}{4n}=\frac{1}{4n}[abc+a+b+c-ab-ac-bc-(I)]$$

It's important to note that the quadratic terms were approximated separately from intercept but not together. We've also run multiple center points in order to calculate the experimental error. The ANOVA is used in this experiment is.

Source	**DF**		**Source**	**DF**

Total	11		Total	11
X_1	1		Linear	3
X_2	1		Lack of fit	5
X_3	1		Exp. Error	3
X_1X_2	1	Or		
X_1X_3	1			
X_2X_3	1			
$X_1X_2X_3$	1			
$X_1^2X_2^2X_3^2$	1			
Exp. Error	**3**			

3.6 Blocking in Response Surface Design

It is the grouping of variable which are homogenizes in one group or replicate.

3.6.1 Confounding 2^k factorial designs in two blocks

We use linear combination $L = \alpha_1 x_1 + \alpha_2 x_2 + \ldots + \alpha_k x_k$ referred to as the defining constraints.

where x_i is the level of the i^{th} factor appearing in a particular treatment combination.

α_i is the exponent appearing in the i^{th} factor in the effect to be confounded. For 2^k factorial design we have;

$x_i = 0$ for low level,

$x_i = 1$ for high level and

$\alpha_i = 0 \text{ or } 1$

For 2^3, the defining contract corresponding to ABC is

$L = x_1 + x_2 + x_3$ ………………………………………………………………….. (3.7)

	I	A	B	C	AB	AC	BC	ABC
I	$+1$	-1	-1	-1	$+1$	$+1$	$+1$	-1
a	$+1$	$+1$	-1	-1	-1	-1	$+1$	$+1$
b	$+1$	-1	$+1$	-1	-1	$+1$	-1	$+1$
c	$+1$	$+1$	$+1$	-1	$+1$	-1	-1	$+1$
ab	$+1$	-1	-1	$+1$	$+1$	-1	-1	-1
ac	$+1$	$+1$	-1	$+1$	-1	$+1$	-1	-1
bc	$+1$	-1	$+1$	$+1$	-1	-1	$+1$	-1
abc	$+1$	$+1$	$+1$	$+1$	$+1$	$+1$	$+1$	$+1$

Using equation 3.7, two fractions will be obtained as follow.

$I = (0,0,0) = 1(0) + 1(0) + 1(0) = 0 = 0(\text{mod}\,2)$

$a = (1,0,0) = 1(1) + 1(0) + 1(0) = 1 = 1(\text{mod}\,2)$

$b = (0,1,0) = 1(0) + 1(1) + 1(0) = 1 = 1(\text{mod}\,2)$

$ab = (1,1,0) = 1(1) + 1(1) + 1(0) = 0 = 0(\text{mod}\,2)$

$c = (0,0,1) = 1(0) + 1(0) + 1(1) = 1 = 1(\text{mod}\,2)$

$ac = (1,0,1) = 1(1) + 1(0) + 1(1) = 0 = 0(\text{mod}\,2)$

$bc = (0,1,1) = 1(0) + 1(1) + 1(1) = 0 = 0(\text{mod}\,2)$

$abc = (1,1,1) = 1(1) + 1(1) + 1(1) = 1 = 1(\text{mod}\,2)$

Treatments (I, AB, AC, BC) are found in first fractional factorial design, while treatments (A, B, C, ABC), are found in second fractional factorial design.

The two-level designs can be divided into fractions. Consider $2^{3\text{-}1}$ design in which $X_3 = X_1 X_2$. The following is the design matrix:

$$X = \begin{bmatrix} 1 & +1 & -1 & -1 \\ 1 & -1 & +1 & -1 \\ 1 & -1 & -1 & +1 \\ 1 & +1 & +1 & +1 \end{bmatrix}$$

The main effects are confounded with interaction effects in quadratic model as shown below;

x_0	x_1	x_2	x_3	x_1x_2	x_1x_3	x_2x_3	$x_1x_2x_3$
$+1$	$+1$	-1	-1	-01	$+01$	$+01$	$+01$
$+1$	-1	$+1$	-1	-01	-01	-01	$+01$
$+1$	-1	-1	$+1$	$+01$	-01	-01	$+01$
$+1$	$+1$	$+1$	$+1$	$+01$	$+01$	$+01$	$+01$

The signs in the interaction columns are the signs that come from multiplying the main effect columns $X_1, X_2, and\ X_3$. The quadratic columns are obtained by squaring the main effects columns $X_1, X_2, and\ X_3$.

Then:

The estimates of the main effects of independent variables $X_1, X_2, and\ X_3$ respectively will be confounded with the estimates of interaction of the same independent variables.

X_1 is confounded with $X_2 X_3$

X_2 is confounded with X_1X_3

X_3 is confounded with X_1X_2

X_0 is confounded with $X_1X_2X_3$

3.7 Data Collection

The data was collected by considering the following measurements:

1) The total weight in kg of potato tubers harvested from each plot under the different treatment was determined
2) A sample of 20 potato tubers was randomly selected and used in determining the average length of the potato tubers.

3.8 Data Analysis

The collected data was summarized using descriptive statistics. The summaries included the averages, use of frequency distribution tables, bar graphs. Also One Way ANOVA was utilized. To model the significance of the three factors (N, P and S), a first order factorial design model was fitted to assess the relevance of the components with the target response variable. The R statistical software was used to analyze the data, with a significance level of $p < 0.05$.

CHAPTER FOUR

DATA ANALYSIS AND RESULTS

4.0 Introduction

The outcomes and explanations of each of the specific objectives specified in Chapter Three are presented in this chapter.

4.1 Determining the Optimal Yield and Size of Potato Tuber with the Factors Crop Spacing and Inorganic Fertilizer using A Two-Level Factorial Design

A three-factor, two-level matrix of first order design was utilized to investigate the effect of inorganic fertilizer and intra and inter-row spacing on potato tubers output and size with three replicates.

Table 4.1: Average Size of potato tubers under different treatment

Observed size value (cm)

Plot number	X_1	X_2	X_3	Rep 1	Rep 2	Rep 3	Total	Average
1	-1	-1	-1	8.05	8.88	9.30	26.23	8.74
2	1	-1	-1	8.67	9.50	9.10	27.27	9.09
3	-1	1	-1	9.65	10.25	9.66	29.56	9.85
4	1	1	-1	8.83	10.40	11.18	30.41	10.14
5	-1	-1	1	9.63	10.20	9.86	29.69	9.90
6	1	-1	1	10.13	10.33	11.03	31.48	10.49
7	-1	1	1	12.88	12.80	10.88	36.55	12.18
8	1	1	1	11.78	10.75	10.75	33.28	11.09
9	0	0	0	10.87	10.67	10.65	32.19	10.73
10	0	0	0	10.88	10.68	10.70	32.25	10.75

Where the values +1= 80 kg, 155 kg and 75 cm by 30 cm are the highest levels of X_1 = N, X_2 = P and X_3 = S between potato respectively, while 0 = 60 kg, 116 kg and 70 cm by 25 cm are the middle levels of $X_1, X_2, and\ X_3$ respectively and -1 = 40 kg, 77 kg and 65 cm by 20 cm are the lowest levels of $X_1, X_2, and\ X_3$ respectively.

The largest average length of the potato tuber per replicate was 12.88, 12.80, and 11.18 cm when the mixture of N and P components was 40 and 155 kg ha^{-1} and S of 75 by 30 cm for the first two replicates, and 80 and 155 kg ha^{-1} and S of 65 by 20 cm for the third replicate, as shown in Table 4.1. The smallest average potato tuber length per replicate was 8.05, 8.88, and 9.10 cm when the N and P component combinations were 40 and 77 kg ha^{-1} for the first two replicates and 80 kg and 77 kg ha^{-1} for the third replication respectively, with S of 65 by 20 cm in all the replicates. On average, when the N and P factors were 40 and 155 kg ha^{-1}, respectively, and the S was 75 by 30 cm, the largest average size of 12.18 cm was attained. The smallest average length was 8.74 cm, which was achieved when the mixture components were 40 and 77 kg ha^{-1}, N and P respectively, with 65 by 20 cm S Table 4.1.

Table 4.2: Average Yield of Potato Tubers in tons ha^{-1} under different treatments

Plot Number	X_1	X_2	X_3	Observed value Rep 1	Rep 2	Rep 3	Total	Average
1	-1	-1	-1	12.75	13.42	13.09	39.26	13.09
2	1	-1	-1	14.19	13.42	14.76	42.38	14.13
3	-1	1	-1	17.08	16.11	18.12	51.30	17.10
4	1	1	-1	18.64	17.45	19.83	55.92	18.64
5	-1	-1	1	12.19	11.16	13.02	36.36	12.12
6	1	-1	1	15.10	14.25	16.11	46.36	15.37
7	-1	1	1	15.50	16.11	15.49	47.11	15.70
8	1	1	1	15.49	14.87	15.59	45.96	15.32
9	0	0	0	15.55	12.17	14.88	42.60	14.20
10	0	0	0	14.88	16.23	14.20	45.31	15.10

Where; +1 = 80 kg, 155 kg and 75 cm by 30 cm are the highest levels of X_1 = N, X_2 = P and X_3 = S between potato respectively, 0 = 60 kg, 116 kg and 70 cm by 25 cm are the middle levels of $X_1, X_2, and\ X_3$ respectively -1 and = 40 kg, 77 kg and 65 cm by 20cm are the lowest levels of $X_1, X_2, and\ X_3$ respectively.

As indicated in Table 4.2, the greatest average yields of potato tubers per replicate was 18.64, 17.45, and 19.83 t ha^{-1} when the N and P components were 80 and 155 kg ha^{-1}, respectively, and S was 65 by 20 cm for all repetitions. The lowest average potato tuber yields per replicate was 12.19, 11.16, and 13.02 t ha^{-1} with S of 75 by 30 cm and N and P component combinations of 40 and 77 kg ha^{-1} for all replicates. When the N and P components were 80 and 155 kg ha^{-1}, respectively, and the S was 65 cm by 20 cm, the highest average yield of potato tuber was 18.64 tons per hectare and the lowest average yield was at 12.12 tons per hectare, which was attained when the components of N, and P was at 40 and 77 kg per hectare, respectively, and 75 cm by 30 cm S.

4.2 Estimating the effects of the factors for crop spacing, and inorganic fertilizers on the output and size of potatoes tubers using the first-order factorial design

First-order model was used to estimate the parameter values (regression coefficients) in this section, with data on the yield, and size of potato tubers as the response variable of interest.

4.2.1 The Yield of Potato Tuber

Table 4.3: Estimated first-order regression model between responses variables (yield of potato tuber) and independent variables $\left(X_1, X_2, and\ X_3\right)$

Coefficients:	Estimates	Std. Error	t values	Pr(>|t|)
Intercept	15.1934	0.25307	60.0364	< 1.9e-16 ***
X_1	0.6916	0.25307	2.7328	0.01282 .
X_2	1.4973	0.25307	5.9165	8.7e-06 ***
X_3	-0.54442	0.25307	-2.1513	0.04387 .

Significant if codes: 0 '*' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1**

Residual standard error: 1.2398 on 20 degrees of freedom, Multiple R-squared: 0.7019, Adjusted R-squared: 0.6572 and F-statistic: 15.7006 on 3 and 20 DF, p-value: 1.748e-05

The output of the analysis for the first-order model for potato tuber yield with all parameter estimations is given in Table 4.3. The results of the regression model for potato tuber yield revealed that N = (β_1 = 0.6916 p = 0.01282.) and P = (β_2 = 1.4973, p = 0.0000087) had positive linear significant effects, whereas the S = (β_3 = -0.54442, p = 0.04387.) had a negative linear significant influence. This implies increasing the inorganic fertilizer levels for N and P, increased the potato tuber yield output, whereas increasing crop spacing contrary decreased potato tuber yield Table 4.3. The Multiple and Adjusted R-squared are greater than 0.6 thus first order response surface model is significant and the independent variables N, P and S have linear regression on the yield of potato tuber.

The yield of potato tuber can now be represented by the first-order regression equation by using the estimates values of table 4.3 corresponding to independent variables $X_1, X_2, and\ X_3$ as shown below

$$Yield = 15.1934 + 0.6916x_1 + 1.4973x_2 - 0.54442x_3 \quad \text{………………..……..... (4.2)}$$

Table 4.4: Analysis of Variance for first-order model with yield as response variable of interest

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Linear	3	72.400	24.133	15.7006	1.74e-05 ***
Lack of fit	4	20.277	5.0693	3.2979	0.04152 .
Pure error	16	10.465	0.654		
Residuals	20	30.742	1.5371	-	-

Significant if codes: 0 '*' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' '**

From Table 4.4, Linear (p = 0.0000174) is less than significant error (p = 0.05) thus the first order response surface methodology for the yield of potato tuber is significant.

4.2.2 The Size of Potato Tuber

Table 4.5: Estimated first-order regression model between responses variables (Size of potato tuber) and the independent variables $(X_1, X_2, and\ X_3)$

Coefficients:	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	10.1859	0.15089	67.505	<2e-16 ***
X_1	0.0169	0.15089	0.112	0.9119
X_2	0.6302	0.15089	4.177	0.000461 ***
X_3	0.7309	0.15089	4.8439	9.85e-05 ***

Significant if codes: 0 '*' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1**

Residual standard error: 0.7392 on 20 degrees of freedom, Multiple R-squared: 0.6717, Adjusted R-squared: 0.6225 and F-statistic: 13.6399 on 3 and 20 DF, p-value: 0.0000451

Table 4.5 shows the regression output for the size of potato tubers. Results for the length of potato tuber, demonstrates that only P and S had a significant positive effect. N had non-significant positive effect with size of potato tubers as response variable of interest. Therefore, the parameter values were S = (β_3 = 0.7309, p = 0.0000985), N = (β_1 = 0.0169, p = 0.9119), and P = (β_2 = 0.6302, p = 0.000461). The Multiple and Adjusted R-squared are greater than 0.6, thus first order response surface model is significant and the independent variables N, P and S have linear regression on the size of potato tuber.

The regression equation for estimating the size of potato tuber using the first order model is obtain by using the estimates values of table 4.5 corresponding to independent variables $X_1, X_2, and\ X_3$ as shown below:

$$Size = 10.1859 + 0.0169x_1 + 0.6302x_2 + 0.7309x_3 \quad \text{.......................................} \quad (4.3)$$

Table 4.6: Analysis of Variance for first-order model with size as response variable of interest

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Linear	3	22.3590	7.4530	13.63994	4.507e-05***
Lack of fit	4	2.8123	0.7031	1.2867	0.3085
Pure Error	16	8.1159	0.5072		
Residuals	20	10.9282	0.54641	.	.

Significant if codes: 0 '*' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1**

From Table 4.6, Linear ($p = 0.00004507$) is significant at $p < 0.05$ thus the first order response surface methodology for the size of potato tuber is significant.

4.3 Estimating the regression parameters for first-order model with interaction effects and two center points by method of least squares

First-order model with interaction and two center points was used to estimate the parameter values (regression coefficients) in this section, with data on the yield, and size of potato tubers as the response variable of interest.

4.3.1 The Yield of Potato Tuber

Table 4.7: Estimated First order factorial model with interaction terms for the responses variables (Yield of potato tubers) and the independent variables, $(X_1, X_2, and\ X_3)$ with two center points.

Coefficients:	Estimates	Std. Error	t values	Pr(>|t|)
Intercept	15.01256	0.18885	79.493	< 2e-16 ***
X_1	0.6916	0.20031	3.4526	0.002384 *
X_2	1.4973	0.20031	7.475	2.4e-07 ***
X_3	-0.54442	0.20031	-2.718	0.01289 *
X_1X_2	-0.4022	0.20031	-2.008	0.05771
X_1X_3	0.04692	0.20031	0.234	0.81708
X_2X_3	-0.635	0.20031	-3.170	0.00461 **
$X_1X_2X_3$	-0.527	0.20031	-2.631	0.01562 **

Significant if codes: 0 '*' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1**

Residual standard error: 0.9813 on 21 degrees of freedom, Multiple R-squared: 0.8231, Adjusted R-squared: 0.7557 and F-statistic: 12.21 on 8 and 21 DF, p-value: 2.407e-06

The interaction of P and S had the largest negative linear effect on the yield of potato tuber P and S = (β_{23} = -0.635 p = 0.00461) followed by the interaction between N, P and S = (β_{123} = -0.527, p = 0.01562) and finally N and P = (β_{12} = -0.4022 p = 0.05771), with interaction of P and S, or N, P and S having significant effects at $p < 0.05$. As shown in Table 4.7, the yield of potato tubers increases as the application of interaction between P and N, P and S, or N, P and S is reduced but reduce more with interaction of P and S since it has the largest negative than the others. The interaction between N and S = (β_{13} = 0.04692, p = 0.81708), the yield of potato tubers indicates positive linear significant influence, but it remained statistically insignificant at p > 0.05. Since the Multiple and Adjusted R-squared are greater than 0.6, the first order response surface model with interaction effects is significant and thus the independent variables N, P and S have linear regression on the yield of potato tuber.

The regression equation for estimating the yield of potato tuber using the first order model with interaction effects is obtain by using the estimates values of table 4.7 corresponding to independent variables $X_1, X_2, and\ X_3$ is:

$$\begin{aligned} Yield &= 15.0126 + 0.6916x_1 + 1.4973x_2 - 0.54442x_3 - 0.4022x_1x_2 \\ &+ 0.04692x_1x_3 - 0.635x_2x_3 - 0.527x_1x_2x_3 \end{aligned} \quad \text{...............} \ (4.4)$$

Table 4.8: Analysis of Variance for first-order model with yield as response variable of interest

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Linear	3	72.4	24.1333	25.0605	3.9e-07 ***
Interaction	4	20.277	5.06925	5.2640	0.004261 **
Lack of fit	5	21.690	4.338	4.5047	0.00603 **
Residual	21	20.222	0.9630	.	.

Significant if codes: 0 ‘*’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1**

From Table 4.8, the Linear (p = 0.00000039) is significant also the interaction effects (p= 0.004261) and lack of fit (p = 0.00603) are significant effects thus the interaction model for the yield of potato tuber is significant at $p < 0.05$.

4.3.2 The Size of Potato Tuber

Table 4.9: Estimated First order factorial model with interaction terms for the responses variables (Size of potato tuber) and the independent variables $(X_1, X_2, and\ X_3)$ with two center points

Coefficients:	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	10.37042	0.12004	86.391	< 2e-16 ***
X_1	0.0169	0.12732	0.1327	0.8957
X_2	0.6302	0.12732	4.9500	6.75e-05 ***
X_3	0.7309	0.12732	5.7400	1.07e-05 ***
X_1X_2	-0.2191	0.12732	-1.7221	0.0999
X_1X_3	-0.1406	0.12732	-1.1040	0.2819
X_2X_3	0.09054	0.12732	0.7110	0.4848
$X_1X_2X_3$	-0.20296	0.12732	1.5940	0.1259

Significant if codes: 0 '*' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1**

Residual standard error: 0.6237 on 21 degrees of freedom, Multiple R-squared: 0.7653, Adjusted R-squared: 0.6759 and F-statistic: 8.56 on 8 and 21 DF, p-value: 3.86 e-05

The interaction between N and P = (β_{12} = -0.2191, p = 0.0999) had the highest negative linear effect, followed by the interaction of N, P and S = (β_{123} = -0.20296, p = 0.1259) and finally the interaction between N and S = (β_{12} = -0.1406, p = 0.2819) for potato tuber size where all had non-significant effect. This means that as the interaction between N and S, P and N, and similarly N, P and S increase the size of potato tuber decreases, the size of the potato tuber decrease with interaction of N and P increasing more as compared with the others. For the interaction between P and S = (β_{23} = 0.09054, p = 0.4848), the size of the potato tuber displays a positive linear impact, implying that the size of the potato tubers increases as the interaction between P and S increases Table 4.9 though it is not significant giving the highest average size of 12.18 cm. Since the Multiple and Adjusted R-squared are greater than 0.6, the first order response surface model with interaction effects is significant and thus the independent variables N, P and S have linear regression on the size of potato tuber.

The regression equation for estimating the size of potato tuber using the first order model with interaction effects is obtain by using the estimates values of table 4.9 corresponding to independent variables $X_1, X_2, and\ X_3$ is:

$$Size = 10.37042 + 0.0169x_1 + 0.6302x_2 + 0.7309x_3 - \\ 0.2191x_1x_2 - 0.1406x_1x_3 + 0.09054x_2x_3 - 0.20296x_1x_2x_3 \cdots\cdots \text{(4.5)}$$

Table 4.10: Analysis of Variance for first-order model with size as response variable of interest

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Linear	3	22.3570	7.4530	19.1545	3.2e-06 ***
Interaction	4	2.8123	0.703075	1.8069	0.1652
Lack of fit	5	4.2835	0.8567	2.2017	0.0926
Residuals	21	8.1703	0.3891	.	.

Significant if codes: 0 '*' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1**

From Table 4.10, the Linear ($p = 0.0000032$) is significant. The interaction effects ($p = 0.1652$) and lack of fit ($p = 0.0926$) are non-significant effects thus the interaction model for the size of potato tuber is not necessary since it is non-significant at $p < 0.05$.

4.4 Estimating regression parameters for first-order model for fractional factorial by method of least squares

The first-order model was used to estimate the parameters (regression coefficients), with data on potato tuber yield and size as the response variables of interest for fractional factorial design.

4.4.1 The Yield of Potato Tuber

Table 4.11: Estimated first-order regression model for fractional factorial design between responses variables (Yield of potato tubers) and the independent variables $\left(X_1, X_2, and\ X_3\right)$

Coefficients:	**Estimate**	**Std. Error**	**t values**	**Pr(>|t|)**
(Intercept)	14.6664	0.2276	64.44	3.74e-12 ***
X_1	0.0566	0.2276	0.249	0.80992
X_2	1.5443	0.2276	6.785	0.00014 ***
X_3	-0.94658	0.2276	-4.159	0.00317 **

Significant if codes are: 0 '*' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1**

Residual standard error: 0.7884 on 8 degrees of freedom, Multiple R-squared: 0.8879, Adjusted R-squared: 0.8459 and F-statistic: 21.13 on 3 and 8 DF, p-value: 0.0003701

The statistical output for the first-order model for potato tuber yield with a fraction of the parameter estimations is presented in Table 4.11. The results of the regression analysis for potato tuber yield revealed that N = (β_1 = 0.0566, p = 0.80992.) and P = (β_2 = 1.5443, p = 0.00014 ***) have a positive linear effect, while S = (β_3 = -0.94658, p = 0.00317 **) has a negative linear effect, with P and S having a significant effect at $p < 0.05$. Since the Multiple and Adjusted R-squared are greater than 0.6, the first order response surface model is significant and thus the independent variables N, P and S have linear regression on the yield of potato tuber.

The regression equation for estimating the yield of potato tuber using first order response model for fractional factorial is obtain by using the estimates values of table 4.11 corresponding to independent variables $X_1, X_2, and\ X_3$ is:

$$Yield = 14.6664 + 0.0566x_1 + 1.5443x_2 - 0.94658x_3 \text{ .... } (4.6)$$

Table 4.12: Analysis of Variance for first-order model with Yield as response variable of interest

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
X_1	1	0.0384	0.0384	0.0618	0.80993
X_2	1	28.6165	28.6165	46.0361	0.000140 ***
X_3	1	10.7522	10.7522	17.2974	0.003169 **
Residuals	8	4.9729	0.6216	.	.

Significant if codes: 0 '*' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1**

From Table 4.12, the effects of main effects P = (p = 0.000140) and S = (p = 003169) were significant whereas the main of N = (p = 80993) is non-significant at $p < 0.05$.

4.4.2 The Size of Potato Tuber

Table 4.13: Estimated first-order regression model for fractional factorial design between responses variables (Size of potato tubers) and the independent variables (X_1, X_2 and X_3)

Coefficients:	Estimate	Std. Error	t values	Pr(>|t|)
Intercept	9.9829	0.1227	81.327	5.83e-13 ***
X_1	0.1074	0.1227	0.875	0.40703
X_2	0.4896	0.1227	3.988	0.00401 **
X_3	0.5117	0.1227	4.169	0.00313 **

Significant if codes are: 0 '*' 0.001 '**' 0.01 ='*' 0.05 '.' 0.1 ' ' 1**

Residual standard error: 0.4252 on 8 degrees of freedom, Multiple R-squared: 0.8098, Adjusted R-squared: 0.7384 and F-statistic: 11.35 on 3 and 8 DF, p-value: 0.002967

Result for the analyzed first-order model for potato tuber size with all parameter estimations can be found Table 4.13. The results for the regression analysis for the size of the potato tuber revealed that all of the effects are positive linear. N = (β_1 = 0.1074, p = 0.40703), P = (β_2 = 0.4896, p = 0.00401 **), and S = (β_3 = 0.5117, p = 0.00313 **). The main effects of P and S show significant effect and the main effect of N was non-significant effect at p < 5%. Since the Multiple and Adjusted R-squared are greater than 0.6, the first order response surface model is significant and thus the independent variables N, P and S have linear regression on the size of potato tuber.

The regression equation for estimating the size of potato tuber using first order response model for fractional factorial is obtain by using the estimates values of table 4.13 corresponding to independent variables $X_1, X_2, and\ X_3$ is:

$$Size = 9.9829 + 0.1074x_1 + 0.4896x_2 + 0.5117x_3 \quad \text{.................... (4.7)}$$

Table 4.14: Analysis of Variance for first-order model with size as response variable of interest

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
X_1	1	0.13846	0.13846	0.7658	0.40703
X_2	1	2.8763	2.8763	15.9078	0.004014 **
X_3	1	3.14266	3.14266	17.381	0.003126 **
Residuals	8	1.44648	0.18081		

Significant if codes: 0 '*' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' '**

From Table 4.14, the effects of main effects P = (p = 0.004014) and S = (p = 0.003126) were significant whereas the main of N = (p = 0.40703) was non-significant at $p < 0.05$.

CHAPTER FIVE

DISCUSSION

5.0 Introduction

The effect of inorganic fertilizer, as well as combinations of the three factors nitrogen, phosphorus, and inter and intra-row spacing factors on the yield and size of the potato tuber, is explained in this chapter using two-level factorial design and fractional factorial design.

5.1 Determining the optimal yield of potato tuber and size using a two-level factorial design

The amount of inorganic fertilizer given to plants has a considerable impact on the yield and size of potato tubers for satisfactory potato production. The most essential goal of this research was to determine the maximum yields and size of potato tubers that can be obtained by using the right crop spacing and the inorganic fertilizer levels.

The application of inorganic fertilizer can boost the output and size of potato tubers in the study area, according to this study. The highest overall tuber yield was 18.64 t ha^{-1} when the treatment factors considered was nitrogen, phosphorous and crop spacing respectively. The results are similar to findings from other researchers which showed that the average global production of potatoes is at 17.4 t ha^{-1} (Tunio et al., 2019). Also, research by (Israel, Ali, and Solomon, 2016) is in agreement with the current findings where it has been reported that the maximum commercial yield is obtained when P and N are fixed at high levels.

Furthermore, the current findings are contrary to the study that was carried out in Ethiopia, which shows the average yield for potato tuber per hectare to be 9.0 tons in

2013/14 (Central Statistical Agency (CSA, 2013). On the other hand, the optimal potato tuber size achieved in the current study was 12.83 cm. These results differ from those investigated by (Koech et al., 2017), where the three components (nitrogen, phosphorus, and potassium) were used and obtained an optimal size of potato tubers to be 17.62 cm.

The number of production constraint that accounts for low yield for the potato crop have been identified in many developing countries to include use of local cultivars instead of using modern approved seeds because of cost implications, and this causes high susceptibility to late blight which leads to yield losses (Dagne et al., 2018).

5.2 The impact of inter and intra row spacing on the yield, and size of potato tubers

Plant spacing is an efficient agricultural method for increasing the yield of potatoes tubers for consumption and trade potato production. The importance of crop planting density in the study region per unit area boosted potato tuber yield and size, according to this study.

According to research, the majority of potato producers pay less attention to the optimal plant population. The ability to get a high yield is contingent on careful analysis of the ideal total plants number per unit area (Dagne et al., 2018). Therefore, researchers elsewhere have indicated the need of reducing the crop spacing to improve the yield of potato tubers per hectare. Therefore, the expected highest yield of potato tuber is obtained when cultivars were planted in narrow spacing as opposed to wider spacing (Dagne et al., 2018).

Similarly, 75 cm by 30 cm plant spacing produced the largest tuber size of 12.18 cm, whereas when the crop spacing was reduced to 65 cm by 20 cm, then the size of the tuber dropped to 8.74 cm respectively. This is in line with (Gebremendhin, 2008), who stated that closer spacing produces a higher yield but smaller tubers, and (Lamessa and Zewdu 2016) who stated that tubers are more plentiful when spacing is narrow. (Burton, 1989) disagrees with this study, claiming that closer spacing boosted quality and largest potato tubers. These results also differ from research done (Koech et al., 2017), who obtained the optimal potato tuber size of 17.62 cm when the three inorganic fertilizer, nitrogen, phosphorus, and potassium were used.

5.3 Determining the significant effects of crop spacing, and inorganic fertilizers on the output and size of potato tubers using a first order modeling

The potato crop has been shown to require high levels of phosphorus (P) fertilizer than other inorganic fertilizer for its growth (FAO, 2019; & Hopkins and Hansen, 2019). Researchers elsewhere have demonstrated the inorganic fertilizer nitrogen to have strong positive effects on the output of potato tubers. The results obtained recorded that increasing nitrogen fertilizer increased the average tuber yield until a certain level when yield tend to remain constant (Fayera, 2017). Similar findings were also obtained by (Alemayehu et al., 2018) who recorded that both the smaller and larger tubers yield were significantly increased with increases in the application of nitrogen fertilizer up to 110 kg ha^{-1}. The current findings are in line with the study conducted by (Koech et al., 2017) and other researchers elsewhere in Western Kenya which showed the effect of N and P to have a strong correlation with increased yield and size of potato tuber.

Furthermore, research indicates phosphorous continues to remain critical in the growth of plants and also on the plant health (Workat, 2019). Therefore, the growth of potato plant has been shown to depend on several factors which include environ-mental conditions and genotype-environment interaction factors (Workat, 2019). Additionally, use of Nitrogen fertilizer is the factor known for essential crop protein synthesis, respiration, and growth of tubers (Kavvadias et al., 2012). However, too much use of N rates in the soils has been shown by researchers to reduce potato tuber production (Ruza et al., 2013).

However, the obtained results were contrary to the findings of the study conducted in Southern Ethiopia which recorded that increasing the rates of nitrogen fertilizer application decreased the output of potato tuber considerably (Desalegn et al., 2016).

5.4 Comparing the Model for Full and Fractional Factorial Designs by Utilizing the factors crop Spacing and Inorganic Fertilizers on the Yield and Size of Potato Tuber

Full factorial designs have continued to be frequently used in experimental designs. This approach has been utilizing factors known to be measured at both low and high levels respectively. Therefore, the question of interest has been on the estimation of response of interest with the effect of the selected covariates. The challenge among many farmers has been to save on cost.

Thus, the current study used both full and fractional factorial designs in estimating output and size distribution of potato tubers. In fitting both the full and the fractional factorial design on the yield and size of potato tuber, it was clear that both the models fitted well to the observed data, with an adjusted R^2 of at least 60%. This shows that both the fitted models could explain more than 60% of the variation in the mean response. However, use of fractional factorial design had better model fit when compared to the full factorial design

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.0 Introduction

This chapter gives the conclusions and recommendations on the impact of inorganic fertilizer and crop spacing and the combination of effects of nitrogen, phosphorus, and inter and intra-row spacing factors on the output and size of the potatoes tubers using first order response surface methodology.

6.1 Conclusions

a) The optimal yield of potato tuber was attain when nitrogen and phosphorus was applied at higher rates and narrow crop spacing whereas the optimal size of potato tuber was attain when nitrogen was applied at lower rate and phosphorus at higher with wider spacing.

b) The best level of crop spacing was at 65 cm by 20 cm to attain high yield of potato tuber and 75 cm by 30 cm to attain longest size of potato tuber when using a two-level full and fractional factorial design.

c) The best levels of inorganic fertilizer were 80 kg ha^{-1} and 155 kg ha^{-1} of nitrogen and phosphorus respectively to attain high yield of potato tuber and 40 kg ha^{-1} and 155 kg ha^{-1} of nitrogen and phosphorus respectively to attain longest size of potato tuber when using a two-level full and fractional factorial design.

d) The effects of inter and intra-row spacing gave a negative linear significant effect for the yield of potato tuber and positive linear significant effect for the size of potato tuber by using a first order response surface model.

e) The first order response surface model for full and fractional factorial design shows that the effects nitrogen and phosphorus fertilizer gave a positive linear effect on the yield and size of potato tubers.

f) In using both the full and fractional factorial designs, the coefficient of determination $\left(R^2\right)$for all ANOVA models was found to be greater than 0.6, showing that both the adopted designs are best for modeling the effects of the given factors deemed to have the strong effects on the yield and size of potato tubers.

6.2 Recommendations

a) Farmers should adjust to a wider crop spacing of 75 by 30 cm with application of high rate of phosphorus and low rate of nitrogen in order to harvest large tubers.

b) Farmers are encouraged to use both the inorganic fertilizers nitrogen and phosphorous, as they will tend to have better improved yields.

c) The recommended level for crop spacing for farmers in this study demonstrated that a plant spacing of 75 x 30 cm resulted in the production of huge potato tubers as opposed to a closer spacing of 65 x 20 cm.

d) To save time and money, experimenters are supposed to perform a fraction of the total required experimental runs as it tends to give the same results and it's cost effective.

6.3 Propose research projects in the future

a) Researchers to repeat the same experiment in other agricultural zones, and use higher order response surface methodology designs.

b) Researchers to repeat the same experiment with four factors: nitrogen, phosphorus, potassium and crop spacing using first order or second order response surface methodology.

REFERENCES

Akassa, B., Belew D., & Debela A., (2014). *Effect of Inter and Intra Row Spacing on Potato (Solanum tuberosum L.) Seed and Ware Tuber Seedling Emergence and Establishment.* Bako. Journal of Agronomy, 13(3): 127-130 DOI:10.3923/ja.2014.127.130

Alemayehu, M., & Jemberie, M. (2018). *Optimum rates of NPS fertilizer application for economically profitable production of potato varieties at Koga Irrigation Scheme, Northwestern Ethiopia.* Fatih Yildiz Reviewing Editor Article: 1439663 Received https://doi.org/10.1080/23311932.2018.1439663

Allen E.J., & Warr D.C.E., (1992). *Plant Density. In: The Potato Crop*, Harris, P. (Ed.). 2nd Ed., Chapman and Hall, London, pp: 292-330.

Alumira, J. D., & Obara C.M. (2008). *Post-Harvest systems of Potato and Sweet Potato in Kenya: Post-Harvest Consumption Analysis of Sweet Potato in Kenya.* FAO Corporate Document Repository. http://www.fao.org.

Ann (2009). *Kenya to give renewed attention to potato cultivation* [Online], http://www.africanagricultureblog.com

Ann, M., Jones, C., & Rutz, K.O. (2017). *Soil pH and Organic Matter Soil Scientist*. Nutrient Management Module No. 8 Montana State University.

Ayieko, M., & Tschirley, D. (2006). *Enhancing access and utilization of improved seed for food security in Kenya*. Tegemeo Institute of agricultural policy and development. Egerton University. Working paper No. 27/ 2006

Ballestrem, C.G. & Holler H.J. (1977). *Potato Production in Kenya.* Experiences and recommendation for improvement, Germany Agency for technical Cooperation.

German Agency for Technical Cooperation ISBN-10 3880850267 ISBN-13 978-3880850262

Bationo, A., Fairhurst, T., Giller, K., Kelly, V., Lunduka, R., Mando, A., & Shamie, Z. (2012). *Handbook for Integrated Soil Fertility* Management. Africa Soil Health Consortium Fairhurst., CAB International 2012.

Belachew, B. (2016). *Effect of nitrogen and phosphorus rates on growth, yield, yield components and quality of potato (solanum tuberosum l.) at Dedo Ethiopia.*

Bingham, D.R., & Sitter, R.R. (2001). *Design issues in fractional factorial split-plot experiments*. Journal of Quality Technology 33, 215.

Birch, J.A., Devine, J.R., Holmes, M.R.J. & Whitear J.D. (1967). *Field experiments on the fertilizer requirements of main crop potatoes.* J. Agric.Sci. (Camb.) 1967 (69) No. 1:13 24.

Bisgaard, S. (1994). *Blocking Generators for small* 2^{k-p} *designs*. *Journal of Quality Technology* **26**, 288-296.

Box G.B.P., & Wilson K.B. (1951). *On experimental attainment of optimum conditions*. Journal of the Royal Statistical Society 13: 1-45

Burton, W.G. (1989). *The Potato.* 3rd Ed. Longman Publisher Ltd., African Crop Science Conference Proceedings, 8:1207-1210..

Carter, T.R., Saarikko, R.A., & Niemi, K.J. (1996). *Assessing the risks and uncertainties of regional crop potential under a changing climate in Finland.* Agricture Food Science Finland 5329350.

Central Statistical Agency (CSA) (2013). "*Agricultural sample survey of area and production of crops of 2012/2013 (2005 E.C.) in Ethiopia.* September to December 2012. Volume III. Report on area production. Private peasant holdings-Meher season. Addis Ababa, Ethiopia." p.251.

Chen, H., & Cheng, C. S. (1999). *Theory of optimal blocking of 2^{n-m} designs.* The Annals of Statistics **27**, 1948-1973.

Cheng, C.S., & Li, C.C. (1993). *Constructing orthogonal fractional factorial designs when some factor-level combinations are debarred.* Technometrics 35, 277{283.

Cheng, S.W., & Wu, C.F.J. (2002). *Choice of optimal blocking schemes in two-level and three-level designs.* Technometrics **44,** 269-277.

Ciais, P. (2005). *Europe-wide reduction in primary productivity caused by the heat and drought*. Nature journal 437, 529–533.

CIP Annual Report (2019). *Discovery to Impact: Science-based solutions for global challenges*. Lima, Peru. International Potato Center. 37 p.

Dagne, Z., Dechassaand, N., & Mohammed, W. (2018). "*Influence of Plant Spacing and Seed Tuber Size on Yield and Quality of Potato (Solanum tuberosum L.) in Central Ethiopia."* Adv Crop Science Tech **6**(6): 406. doi:10.4172/2329-8863.1000406.

Davies, A., Jenkins, T., Pike, A., Shaq, J., Carson, I., Pollock, C.J., & Parry M.I. (1996). *Modeling the predicted geographic and economic response of UK cropping systems to climate change scenarios: the case of potatoes.* Aspects Appl Biol456B-69.

Dechassa, N. (2003). *Phosphorus efficiency of cabbage (*Brassica oleraceae *L. var.* capitata*) carrot (*Daucus carota *L.), and potato (*Solanum tuberosum *L.). Plant and Soil*, Amsterdam, v. 250, n. 2, p. 215-224.

Desalegn, R., Wakene, T., Dawit, M., & Tolessa, T. (2016). *Effects of nitrogen and phosphorus fertilizer levels on yield and yield components of Irish potato*

(Solanum Tuberosum) at Bule Hora District, Eastern Guji Zone, Southern Ethiopia. International Journal of Agricultural Economics, 1, 71–77.

Dette, H., & Yuri. G. (2014). E- *Optimal designs for second – order response surface models.*

Dubetz, J., & Bole, J.B. (1975). *Effect of Nitrogen, Phosphorus and Potassium on yield components and specific gravity of potatoes.* Smerisa Potato Journal Vol. 52 No. 12.

Elphinstone J.G., Cahill G., Davey T., Harper G., Humphriss S., Saddlers G.S., Toth I.K. & Wales (2018). *Effects of storage conditions on bacterial loading of seed potato tubers.* Ref:1112030, 8-9

FAO (2009). *International Year of the Potato: Sustainable potato production Guideline for Developing Countries,*

FAO (2013). *A policymakers' guide to crop diversification*, The case of the potato in Kenya. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAOSTAT (2016). *Agriculture Organization of the United Nations Statistics Division. Economic and Social Development Department*, FAO, Rome, Italy. Available at http://faostat3. fao.org/home/E.

FAO. 2017. *The future of food and agriculture – Trends and challenges.* Rome.

FAO (2019). FAOSTAT, *Statistical Databases*. Food and Agriculture Organization. Available online: http://www.fao.org/faostat/en/#data (accessed on 12th August, 2021).

Fayera, W.N. (2017). *Yield and yield components of potato (Solanum Tuberosum L.) as influenced by planting density and rate of nitrogen application at Holeta, West Oromia Region of Ethiopia*. African Journal of Agricultural Research, 12, 2242–2254. doi:10.5897/AJAR

Fernandes, A. M., Soratto, R.P., & Silva, L. S. (2011). *Nutrition, dry matter accumulation and partitioning and phosphorus use efficiency of potato grown at different phosphorus levels in nutrient solution*. R. ev. Bras. Ciênc. Solo 36, 1528–1537.

Fernandes, A. M., & Soratto, R. P. (2016). *Phosphorus fertilizer rate for fresh market potato cultivars* grown in tropical soil with low phosphorus availability. American Journal of Potato Research, Orono, v. 93, n. 4, p. 404-414,

Firew, G., Nigussie, D., & Wassu, M. (2016). *Response of potato (Solanum Tuberosum L.) to the application of mineral nitrogen and phosphorus fertilizers under irrigation* in Dire Dawa. Journal of Natural Sciences Research, 6. 19–37.

Franklin, M.F., & Bailey, R.A. (1977). *Selection of defining contrasts and confounded effects in two-level experiments. Applied Statistics* 26, 321{326.

Gebremedhin W., Gebre E., & Lemaga, B. (2008). *Potato Variety Development. In: Root and Tuber Crops:* The Untapped Resources, Ethiopian Institute of Agricultural Research, Addis Ababa, page: 51-84

George E.P., Box, J., Stuart, S., & William G. (2005). *Hunter Statistics for Experimenters Design*, Innovation, and Discovery 2nd Ed Wiley~ Inter-Science a John Wiley & Sons~ inc. ~ publication Copyright e 2005 by John Wiley & Sons, Jnc. All rights reserved Published by John Wiley & Sons, (nc., Hoh<.1ken, New Jersey. J > published simultaneously in Canada.

Gitau, R., Kimenju S., Kibaara B., Nyoro J., Bruntrup M., & Zimmermann R. (2009). *Agricultural policy-making in sub-saharan Africa, Kenya's Past Policies*. Tegemeo Institute of Agricultural Policy and Development, Nairobi.

GOK (2007). *Kenya Vision 2030*, Ministry of Planning and National Development and, the National Economic and Social Council, Government of the republic of Kenya, Office of the President, Kenya.

Hallstrom A, & Davis, K. (1988). *Imbalance in treatment assignments in stratified blocked randomization*. Control Clin Trials 9(4):375–382

Hanley, F., Jarvis R.H., & Ridgman W.J. (1965). *The effects of fertilizers on the bulking of Majestic Potatoes*. J. Agric. sci. (Camb,). 65: 159-169.

Haverkort, A. J.,Koesveld, M.J., van Scheper, H., & Wijnands, J.H.M. (2012). *Potato prospects for Ethiopia: On the road to value addition* (PPO publication; No. 528). PPO AGV. https://edepot.wur.nl/244969.

Hopkins, B.G., Horneck, D.A., & Mac Guidwin, A.E., (2010). *Improving phosphorus use efficiency through potato rhizosphere modification and extension.* Am. J. Potato Res. 91, 161–174.

Hopkins, B.G., & Hansen, N.C. (2019). *Phosphorus Management in High-Yield Systems*. J. Environ. Qual.48, 1265–1280.

IFA (1992). *World Fertilizer Use Manual. Design*: Rolf-D. Wuthe, D-6940 Weinheim.

Ionas, V.A. (1975). *Effect of mineral fertilizers on increases in tuber yields of potatoes and accumulation of dry matter, starch and protein.* Potato Abstract. 1976 Vol. 1 Nos. 1-3.

Israel, Z., Ali, M., & Solomon, T. T. (2016). *Potato (Solanum Tuberosum L.) growth and tuber quality, soil nitrogen and phosphorus content as affected by different rates of nitrogen and phosphorus* at Masha. International Journal of Agricultural Research, 11, 95–104. doi:10.3923/ijar.2016.95.104

Kabanda, T. (2011). *Impacts of Climate Change on Agriculture*: Collapsing of Dry Land Potato Farming in North East South Africa, North West University.

Kavvadias, V., C. Paschalidis, G. Akrivos, & D. Petropoulos. (2012). *Nitrogen and potassium fertilization responses of potato (Solanum tuberosum) cv. Spunta*. Com. Soil Sci. Plant Anal. 43(1-2), 176-189. Doi: 10.1080/00103624.2012.634711

Kinoti j., Zhongbo S., Woldai., & Kiteme B., (2010). *Integrating socioeconomic aspects in spatial multi-criteria evaluation process for selecting Rainwater harvesting sites as a mitigation measure to climate change* in Sub Sahara Africa. Centre for Training and integrated Research in ASAL Development (CETRAD) Nanyuki, Kenya.

Kinyua, Z.M., Smith, J.J., Lung'aho, C., Olanya, M., & Priou, S. (2001). *On-farm success and challenges of producing bacterial wilt free tubers in seed plots* in Kenya. African Crop Science Journal, 9, 279-285. http://dx.doi.org/10.4314/acsj.v9i1.27649

Koech, J.K, Mutiso, M.J, & Koskei, JK., (2017). *Response Surface Methodology Approach to the Optimization of Potato (Solanum tuberosum) Tuber Yield Using Second-Order Rotatable Design.* J Biom Biostat 8: 351. doi: 10.4172/2155-6180.1000351.

Kutubi, H. S., (2021) *On Randomized Complete Block Design* Basic and Applied Research (IJSBAR) ISSN 2307-4531 (Print & Online) http://gssrr.org/index.php?journal

Lachin. J.M. (1988a). *Properties of simple randomization in clinical trials*. Control Clin Trials 9:312–326

Lamessa, K., & Zewdu, A. (2016). *Effect of spacing and fertilizer dose on growth and yield of potato (Solanum tuberosum L) Gudane variety at West Hararghe.*

IJHOP vol. 2(1), pp. 011-018, May, 2016. © www.premierpublishers.org, ISSN: 2141-502X

Maharjan, K. L., Piya, L., & Joshi, N.P. (2011). *Effect of climate variables on yield of major food-crops* in Nepal -A time-series analysis Published in: Journal of Contemporary India Studies: Space and Society, Vol. 1, (March 2011): pp. 19-26.

Mariga, I.K., Ngugi, D.N., & Mugambi, J.R.K. (1980). *The effects of spacing, fertilizer rate and method of fertilizer placement on the yield and yield component of two potato (Solanum tuberosum L) varieties: annett and B53*

Mengui, K. C., Oh, S., & Lee, S. H. (2019). *The Technical Efficiency of Smallholder Irish Potato Producers in Santa Subdivision, Cameroon.* Agriculture **9**: 259; DOI: 10.3390/agriculture9120259

MoA (2008). *National policy on potato industry, Policy reforms to revitalize the potato industry*, Ministry of Agriculture, Nairobi, Kenya.

Muriithi K.D. (2011). *Application of response surface methodology for optimization of potato tuber yield.* America Journal of Theoretical and Applied Statistics. Vol 4, No. 4, 2015, pp. 300-304. Doi: 10.11648/j.ajtas.20150404.20

Muthoni, M.J., Shimelis, H., & Melis, R. (2014). *Development of high yielding potato (Solanum tuberosum L.) genotypes with resistance to bacterial wilt (Ralstonia solanacearum)* for the Kenyan highlands.

Myers, H.R., Douglas C.M., Anderson & Cook, C.M. (2009). *Response surface methodology, process and product optimization using designed experiments*. 3rd Ed. John Wiley & Sons, New Jersey: pp.219-264.

Nand, K.F., Baligar, V.C., & Jones, C.A. (2011). *Growth and Mineral Nutrition of Field Crops*, 3rd Ed, Taylor and Francis Group, LLC.

Oehlert, G.W. (2010). *A First Course in Design and Analysis of Experiments* University of Minnenosata p. cm. Includes bibligraphical references and index. ISBN 0-7167-3510-5 1. Experimental Design I. Title QA279.O34 2000 519.5—dc21 99-059934.

Okalebo, J. R. (2009). *Recognizing the constraints of soil fertility depletion and technologies to reverse it in Kenyan Agriculture*. Moi University inaugural lecture series No.1, Moi University press, Eldoret, Kenya.

Olesen, J.E., & Bindi M. (2002). *Consequences of climate change for European agricultural productivity, land use and policy*. Eur. J. Agron. 16, 239–262

Ostle, B., & Malone, L. (2000) *Statistics in research: basic concepts and techniques for research workers.* Iowa State University Press, Wiley-Blackwe

Painter, C.G., Ohms, R.E., & Walz A. (1977). *The effect of planting date seed spacing, nitrogen rate and harvest date on yield and quality of potatoes* in South-western Idaho. Potato Abstracts Vol. 3 No. 5.

Parr, J.F., Stewart, B.A., Horrnick, S.B., & Singh, R.P. (1990). *Improving the sustainability of dryland farming systems: a global perspective*. In Singh Advances in Soil Science, Vol.13, Dryland Agriculture Strategies for Sustainability. New York

Peiris D.R., Crawford J.W., Grashoff C., Jefferies R.A., Porter & Marshall B., (1996). *A simulation study of crop growth and development under climate change.* Agricuture For Meteorol 79:271-887.

Pervez, M. A., Ayyub, C. M., Shaheen, M. R., & Noor, M. A. (2013). *Determination of physio morphological characteristics of potato crop regulated by potassium management.* Pakistan Journal of Agricultural Sciences 50: 611–615.

Porter, J.R., & Semenov, M.A. (2005). *Crop responses to climatic variation*. Philos Trans R Soc B

Potato Production Manual (PPM), (2013). *A guide to potato production and postharvest management in Kenya*.

Raymundo, R., Asseng, S., Robertson, R., Petsakos, A., Hoogenboom, G., & Quiroz, R., (2018). *Climate change impact on global potato production.* Eur. J. Agron. 100, 87–98. doi: 10.1016/j.eja.2017.11.008

Rockstrom, J. (2001). *Green water security for the food makers of tomorrow: windows of opportunity in drought-prone savannahs.* Proceedings of the East Africa Integrated River Basin Management Conference Sokoine University of Agriculture, Morogoro. Water Science and Technology 43(4) 71 78.

Rosegrant, M.W., Cai, X., Cline, S. & Nakagawa, N. (2000). *The role of rain-fed agriculture in the future of global food production.* EPTD Discussion Paper No. 90, Environmental and Production Technology Division, International Food Policy Research Institute, Washington D.C.

Rosenberger, W., & Lachin, J.M. (2002). *Randomization in clinical trials*: theory and practice, Wiley, New York

Rosenzweig, C., Phillips J., Goldberg R., Carroll J., & Hodges T., (1996). *Potential impacts of climate change on citrus and potato production* in the US. Agriculture System 52(4): 455-479.

Ruza A., Skrabule, I., & Vaivode, A. (2013) *Influence of nitrogen on potato productivity and nutrient use efficiency.* Proc. Latvian Acad. Sci. Section B, Vol. 67 (2013), no.3 (684), pp. 247-253. DOI: 10.2478/prolas-2013-0043

Rymuza, K., Radzka, E., & Lenartowicz T. (2015).*The effect of weather conditions on early potato yields* in east-central Poland. Communications in Biometry and Crop Science 10, 65–72

Sandhu, A., Sharma, S., Bhutani, R., & Khurana, S. (2014). *Effects of planting date and fertilizer dose on plant growth attributes and nutrient uptake of potato (Solanum Tuberosum L.).* International Journal of Agricultural Sciences, 4, 196–202.

Simon, R. (1979). *Restricted randomization designs in clinical trials.* Biometrics 35:503–512

Sitter, R. R., Chen, J. & Feder, M. (1997). *Fractional resolution and minimum aberration in blocked* 2^{n-k} *Designs. Technometrics* **39,** 382-390.

Soltani, M., & Jaber S. (2016). *Determination of optimal combination of applied water and nitrogen for potato yield using response surface methodology (RSM) Department of Irrigation and Drainage Engineering*, Aburaihan Campus, University of Tehran, Tehran.

Sood, M.C. & Singh, N. (2003). *Water Management. In: Khurana, S.M.P., Minhas, J.S., Pandey, S.K., eds. The potato: Production and utilization in Sub-Tropics*. New Delhi, India, Mehta Publishers, pp. 111-120.

Sriom, S., Mishra, D. P., Rajbhar, P., Singh, D., Singh, R. K., & Mishra, S. K., (2017). *Effect of different levels of nitrogen on growth and yield in potato (Solanum Tuberosum L.)* International Journal of Current Microbiology and Applied Sciences 6: 1456–1460.

Stark, J., Westermann, D., & Hopkins, B. (2004). *Nutrient Management Guideline for Russet Burbank Potatoes.* Agric Experiment & UI Extension Publication: BUL 840 https://www.lib.uidaho.edu/digital/uiext/items/uiext25485.html

Steduto, P., Hsiao, C. T., Fereses, E., & Raes, D. (2012). *Crop yield response to water*. FAO and irrigation paper 66 ISBN 978-92-5107274-5 page 187

Stol, W., de Koning G.H., Haverkort A.J, Kooman P.L., Keulen H., & Penning F.W.T., (1991). *Agro-ecological characterization for potato production: a simulation study at the request of the International Potato Center (CIP)*, Lima, Peru. (Report/ Centre of Agrobiological Research; no: 155). CABO-DLO. https://edepot.wur.nl/331148

Sun, D. X., Wu, C. F. J., & Chen, Y. (1997). *Optimal blocking Schemes for 2^n and 2^{n-p} Designs.* Techno metrics **39,** 298-307.

Tang, B. & Deng, L.Y. (1999). *Minimum g2-aberration for non regular fractional factorial designs. The Annals of Statistics* 27, 1914{1926.

Tunio, M. H., Gao, J., Shaikh, S. A., Lakhiar, I. A., Qureshi, W. A., & Solangi, K. A. (2019). "*Potato production in aeroponics: An emerging food growing system in sustainable agriculture for food security*. Chilean Journal of Agricultural Research **80**(1): 118-132: Doi:10.4067/S0718-58392020000100118.

Turamyenjirijuru, A., Keter, J.A., Ndutu, J.M., Onwonga, R.W., & Ruganzu, V. (2013). *Effects of timing and methods of mineral fertilizer application on Irish potato (solanum tuberosum L.) Performance*: Musanze and Nyaruguru.

Winters, H.F., & Miskinen G.W. (1967). *Vegetable Gardening* in the Carribean Area. Aqric. Handbook No. 323 - U.S. Dept. Agric.

Wolf, J., Harrison, P.A., Butterfield R.E., & Lonsdale, K. G. (2000). '*Modeling climate change impacts at the site scale on potato', in downing, Climate change, climate variability and agriculture* in Europe: An integrated Assessment, research, report, environmental change unit, university of oxford, PP 239 – 261.

Workat. S. K. (2019). *Effects of nitrogen and phosphorus on potatoes production in Ethiopia:* A review, Cogent Food & Agriculture, 5:1, 1572985, DOI: 10.1080/23311932.2019.1572985

Wubengeda, A., Kassu, T., Tilahun, H., Yonase, D., & Dawit, H. (2016). *Determining of optimal irrigation regimes and Npk fertilizer rate for potato (Solanum Tuberosum L.)* at Kulumsa, Arsi Zone. Academia Journal of Agricultural Research, 4,326–332.

Zamil, M.F., Rahman, M.M., Robbani M.G., & Khatun, T. (2010). *Combined effect of nitrogen and plant spacing on the growth and yield of potato with economics performance.* Bangladesh Res. Publ. J., 3: 1062-1070.

Zoran, J. (2016) *Impact of climate change on potato production in Montenegro and options to mitigate the adverse effects.* Academia Journal of Environmental Science 4(3): 0047-054, March 2016 DOI: 10.15413/ajes.2016.0301ISSN: 2315-778X©2016

APPENDIX

Appendix I Plates of photographs

Figure 1 Displays of potatoes 53 days after planting when the potatoes stars to bloom

Figure 1 are display of potatoes plants 53 days after planting and one week after weeding and ridging.

Figure 2 Display of potatoes 89 days after planting when the tubers were ready to be harvested.

Figure 2 are display of potatoes plants 89 days after planting and two days after cutting the aerial part of the plant. The tubers are ready to be harvested.

Figure 3 Display of potatoes tubers during harvesting 99 days from planting date.

Figure 3 are display of potato tubers during harvesting two week after dehaulming.

Appendix II Study Area

Study area in Kabiemit Location

Figure 4 Display of Map for study area in Nandi County.

The research was carried out at the location of Kabiemit, which is situated in the division of Kipkaren in the northern part of Nandi County along the Uasin Gishu County boundary. It is situated in the Rift valley region of Kenya (0.50000 N, 35.07190 E). It is approximately 30 km along the Eldoret - Chepterwai road from Eldoret town. Kabiemit is situated in the western highlands of the Rift Valley, so most of the inhabitants are farmers. They are mixed farmers and they domesticate animals like cattle, sheep and goats. The major cash crop in the Kabiemit location is maize, followed by sugar cane, which was introduced seven years ago. Majority of the farmers are self-employed and they depend on the farm output to raise their families and to educate their children. The map of Nandi County is displayed in figure 4.

Appendix III Similarity Report

Turnitin Originality Report

MODELING THE EFFECTS OF CROP SPACING AND INORGANIC FERTILIZER ON THE POTATO TUBER YIELD AND SIZE USING FIRST ORDER TWO-LEVEL FACTORIAL DESIGN by Ronald Kaptich

turnitin

From Theses (Theses)

- Processed on 14-Nov-2022 11:29 EAT
- ID: 1953459293
- Word Count: 17556

37

Similarity Index
36%
Similarity by Source

Internet Sources:
34%
Publications:
15%
Student Papers:
7%

sources:

1 15% match (Internet from 01-Oct-2022)
http://article.sapub.org/10.5923.j.statistics.20211104.02.html

2 1% match (Internet from 13-Oct-2022)
http://erepository.uoeld.ac.ke/bitstream/handle/123456789/978/KIPRONO%20BEN%20KOECH.pdf?isAllowed=y&sequence=1

3 1% match (Internet from 07-Nov-2017)
http://ijastnet.com/journals/Vol_7_No_2_June_2017/7.pdf

4 1% match (student papers from 05-Apr-2022)
Submitted to University of Rwanda on 2022-04-05

5 1% match (Internet from 03-Apr-2021)
https://ir-library.ku.ac.ke/bitstream/handle/123456789/8983/Karanja%2C%20Amon%20Mwangi.pdf?sequence=1

6 < 1% match (Internet from 08-Nov-2022)
http://erepository.uoeld.ac.ke/bitstream/handle/123456789/785/WANGUI%20PATRICK%20MWANGI.pdf?isAllowed=y&sequence=1

7 < 1% match (Internet from 07-Nov-2022)
http://erepository.uoeld.ac.ke/bitstream/handle/123456789/1168/KERINA%20ARNOLD.pdf?isAllowed=y&sequence=1