EFFECTS OF NPK FERTILIZER AND FUNGICIDE APPLICATION RATES ON THE PERFOMANCE AND MANAGEMENT OF LATE BLIGHT (*Phytophthora infestans*) IN IRISH POTATOES (*Solanum tuberosum* L)

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EGERTON UNIVERSITY

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DECLARATION AND RECOMMENDATION

DECLARATION

This thesis is original work and has not been previously presented in this University or any other institution for the award of any degree.

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RECOMMENDATION

This thesis has been submitted with our approval as supervisors according to Egerton University regulations.

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DEDICATION

This thesis is adedication to my mother, Hellen Moraa and father, Barnabas Rosana. A special dedication goes to Rose Kwamboka and Henry Maina Muma.

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ABSTRACT

Food insecurity has been an issue in developing nations worldwide including Kenya. This is as a result of soil related problems, climate change, crop pests and diseases among food crops. Late blight disease caused by *Phytophthora infestans* in Irish potato (*Solanum tuberosum* L) is a major challenge among the small-scale farmers in the highlands of Kenya. Yield losses as a result of late blight in Kenya are about 40 - 50%. The appropriate use of fungicides and fertilizers application rates is an option in the management of late blight. The objectives of this study were to determine effects of N:P:K 17:17:17 fertilizer and Acrobat MZ fungicide (Dimethomorph 90g/Kg + Mancozeb 600g/Kg) application rates on the incidence, severity of late blight and growth parameters of irish potato varieties. The experiments were carried out in a randomized complete block design both at Egerton University, field 7 and Tumaini farm, Molo. Inoculation of the crop with *P. infestans* was done at the vegetative stage. The treatments rates were fertilizer at 0, 90 and 135 $KgHa^{-1}$, fungicide at rates of 0, 2.5 and 3.5g/L and two potato varieties (*Kenya sherekea* and *Dutch robjin*). Fertilizer was applied during planting while fungicide started at 37 days after planting (DAP) and repeated after seven days interval up to 61 DAP. Data collection was done at 47, 54 and 61 DAP on the number of leaves, haulms, height, percentage disease severity index (PDSI) and disease incidence (PDI) while yield was recorded 120 DAP. Data was subjected to analysis of variance (ANOVA) and treatment means were separated using Least Significant Difference (LSD) test. There were significant ($P \leq 0.05$) differences among the varieties and sites for disease development on application of fertilizer and fungicides. Results indicated that fertilizer and fungicide application rates had interrelated effects on late blight development. Total tuber yields significantly ($P \leq 0.05$) increased in all fungicide treated plots. The correlation matrix showed that total yield had significant and positive correlation with the site (r = 0.61), plant height (r = 0.51), number of leaves (r = 0.40) fungicide (r = 0.49) and fertilizer (r = 0.39). Irish potato variety had significant ($P \leq 0.05$) effects on both yield and disease development at Egerton University and Molo sites.

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ABBREVIATIONS

ACCFP	African climate change fellowship programme
ADC	Agricultural Development Corporation
ANOVA	Analysis of Variance
CIP	International Potato Center
CM	Cisgenetic modification
DAP	Days after planting
DAI	Days after incubation
DO	Disease onset
DuRPh	Durable resistance against *Phytophthora*
DSI	Disease Severity Index
GM	Genetic modification
GTZ	Gesellschaftfür Internationale Zusammenarbeit
IPM	Integrated Pest Management
IDM	Integrated Disease Management
MoA	Ministry of Agriculture
NDP	Number of diseased plants
NPK	Nitrogen, Phosphorus, Potassium
PDI	Percent Disease Incidence
PDSI	Percentage Disease Severity Index
PSDA	Promotion of Private Sector in Agriculture
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
SDW	Sterile distilled water
TNPP	Total number of plants per plot
TYY	Total tuber yield

CHAPTER ONE
INTRODUCTION

1.1 Background information

Irish potato is an important tuber crop. In the world it is ranked fourth after wheat (*Triticum aestivum* L.), rice (*Oryza sativa* L.) and maize (*Zea mays* L.). This is because of its nutritional value, adaptability to diverse environments and high yield potential. It is therefore a preferred crop especially in a temperate, subtropical and tropical condition where production has been on the increase (FAO, 2010). The world leading producers of Irish potato include China (85.9 million tons), India (45 million tons) and the Russian Federation (29.5 million tons) (FAOSTAT, 2011). Potato production has been increasing, and it has even surpassed that of other staple food crops in Africa regarding the total production area (MoA, 2005). The overall production costs are low, and it grows in a wide variety of climates of altitude above 1000 meters above sea level (M a. s. l.) (Hijmans, 2001).

In Kenya, Irish potato is used as a food and cash crop. It is therefore considered as the second most important crop after maize (MOA/GTZ-PSDA, 2009). The crop significantly contributes to food security and is a primary source of income for small scale farmers in the high altitude areas (above 1800 M a. s. l). With more than 800,000 farmers who are growing the crop, it is considered to be playing a significant role in employing over 2.5 million people indirectly as market agents, transporters, and processors (MOA, 2005). The demand for potatoes has been increasing in the country because of population growth, urbanization, tourism and export of processed products (MOA, 2005). Kenya is classified as a potato growing country with a high potential of production (Ogola *et al*., 2011). Based on geographic location, production practices, and preference of potato variety, the growing areas are divided into the following regions. They include: Mt. Kenya, mainly Meru Central, parts of Nyeri and Laikipia; Aberdares and Eastern Rift Valley, Kiambu, Nakuru, Nyandarua, Mau, Bomet, Narok, Mt. Elgon, Keiyo and Marakwet; and Taita Taveta (Kaguongo *et al*., 2008). Despite the increase in demand for potatoes, there are factors that limit the potential of increased potato production below 10 T/ha in developing countries like Kenya. These factors include: lack of improved varieties, poor seed quality of most traditional varieties and limited availability of certified seed from the few released varieties and diseases of which the most important being late blight (MOA/GTZ-PSDA, 2009).

Late blight occurs on potato worldwide, and it is considered the world's most costly disease on Irish potato crops (Haverkort *et al*., 2008). The wind normally spreads the spores of the pathogen to a nearby plant, where at the right condition (20 - 25°C, nutrients availability) germinate directly and cause infection. In the case of lower temperatures (10 - 15°C, in absence of nutrients) they release 3 - 8 bi-flagellate motile zoospores (zoosporogenesis) (Grenville-Briggs *et al.*, 2005). The current management tool of late blight in Kenya has been through the development of potato varieties with resistance to late blight (MOA, 2005). Resistance genes from wild *Solanum* species were introduced into potatoes by classical breeding (Umaeus & Umaeus, 1994) but due to selection pressure, *P. infestans* have rapidly evolved into new virulent forms (Fry, 2008). Yield losses due to late blight in Kenya range between 40 - 50% (Olanya *et al.*, 2001). Regarding the varieties and prevailing weather conditions the losses range between 20 – 80% (Lung'aho *et al.*, 2008).

Potato production in Kenya is highly dependent on fungicides of which both contact and systemic fungicides are used in the management of late blight in potatoes. Varieties with durable resistance significantly reduce the number of fungicide sprays reducing the production costs hence environmentally friendly way of growing potatoes in particular by the small-scale farmers in tropical regions (Nakitandwe *et al.*, 2005). This study was undertaken to determine the effects of fertilizer and fungicide application rates on the incidence and severity of late blight and potato growth parameters.

1.2. Statement of the problem

Worldwide food insecurity has been increasing as a result of crop diseases. Irish potato is an important food crop globally being the fourth after wheat, rice, and maize. The production has been declining due to diseases like late blight. In Kenya, it is a common disease in Irish potato production areas. The management of the disease would make Kenya more food secure. The production of quality and quantity potatoes would divert the attention from over dependence on maize as a staple food crop in Kenya. The low productivity of potatoes experienced in Kenya is as a result of low quality seed, inappropriate diseases management, and poor soil fertility management practices. Late blight is among the diseases that cause major economic losses in potato farming. The disease attacks all parts of the plant, but of vital importance is its effect on the foliage that results in deterioration in quality and quantity of potato production. The disease has led to low quality yield, in particular among the smallholder farmers. Farmers prefer to plant potatoes applying a high amount of mineral fertilizers to increase yield and boost plant vigor, which predisposes the crop to late blight infection. The management of late blight, therefore, becomes difficult due to predisposing effects of fertilizer, thus causing enormous economic losses. Currently, late blight control system is primarily based on use of fungicides. It is a practice that has increased in recent decades due to the emergence of new strains of the pathogen due to indiscrimate use of fungicides and mineral fertilizers. Comparing both intensive and integrated crop production systems, the knowledge of the relationship of plant nutrition and disease development will be a key consideration in deciding the fate of disease management in the crop production system. The proper use of fungicides and fertilizers application rates is an option in the management of late blight. This study, therefore contributes to the search for an alternative and affordable approach that is environmentally friendly and appropriate for use by the consumer to control the pathogen. The management of late blight in potato production provides an option that can contribute to enhanced food security and improved livelihoods among smallholder farmers in Kenya.

1.3 Objectives

1.3.1 Broad objective

To contribute to improved food security and livelihoods among the smallholder farmers through the use of fertilizers and fungicides in the management of late blight in potatoes.

1.3.2 Specific objectives

The specific objectives of this study were to determine the effects of N:P:K 17:17:17 fertilizer and Acrobat fungicide (Dimethomorph 90g/Kg + Mancozeb 600g/Kg) application rates on the:

1. Incidence and severity of late blight on Irish potatoes varieties
2. Growth parameters of Irish potatoes varieties

1.4 Hypotheses

The hypotheses of this study were:

1. Fertilizer and fungicide application rates have no effects the incidence and severity of late blight of Irish potatoes varieties
2. Fertilizer and fungicide application rates have no effects on growth parameters Irish potatoes varieties

1.5 Justification of the study

Potato (*Solanum tuberosum* L.) is an important crop that is used worldwide as human food and as well as animal feed. In many parts of Kenya, Irish potato is an important food and cash crop, thus increase in its production can enormously contribute to the national objective of food diversification and food security. Potato is also an important nutrient source in human nutrition. Increasing potato yield is required to meet the needs of an increasing human population. More emphases should be put in the management of late blight which is the most devastating disease of Irish potatoes. The disease is a serious threat to food security as it affects both potato foliage in the field and tuber in the storage which can destroy the whole crop leading to total crop loss. The global losses related to late blight exceed $5 billion annually therefore the pathogen is regarded as a threat to global food security. Yield losses as a result of late blight in Kenya are about 40 - 50%. The disease is enhanced as a result of indiscriminate application of excess fertilizers by small scale farmers. This enhances the development of plant canopy, a microclimate that is conducive to the progress of the late blight disease and infection. The epidemic of the disease is rapid as the pathogen has a high reproductive potential. Farmers therefore incur high costs in managing the disease through the use fungicides. The efficacy of fungicide in controlling late blight has been low leading to farmers adopting different and high rates of application. Although fungicides offer protection against late blight, the cost of most fungicides is prohibitive for most farmers who resource constrained in developing countries. Therefore, a combination of proper fertilizers and fungicides application rates should be employed to reduce losses in the field.

CHAPTER TWO

LITERATURE REVIEW

2.1 Irish potato production and economic importance

Irish potato (*Solanum tuberosum* L.) is ranked as the world's fourth major food crop after wheat, rice and maize with world production record of 320 million tons in 2007 (FAO, 2012). It is the world's most important non-grain food commodity with its production increasing each year whereby Asia and Europe producing about 80 % (FAO, 2012). Considering the number of hectares harvested and metric tons produced, potato is considered one of the fastest growing food crops in the subtropics and tropics (FAOSTAT, 2011). It is regarded as high - potential food security crop because of its ability to provide a high yield of high - quality product per unit input with a shorter crop cycle (mostly < 120 days) than major cereal crops such as maize (Adane *et al.*, 2010). As a result production in developing countries has almost doubled since 1991, with a corresponding increase in consumption (Hoffler *et al.*, 2008).

Potato is an important crop due to its inherent potential for tonnage production, remunerative income and good nutritional values in developing countries (FAO, 2008). Irish potato production can grow quickly due to its high response to fertilizer and if farmers already have enough knowledge of fertilizer use and improved crop husbandry (Mellor, 2001). Potato's high energy content, short maturity period and ease of production have also made it an important component of urban Agriculture that provides jobs and food security to some 800 million people globally (Hoffler *et al*., 2008). As the population of people continues to increase in the developing countries, hundreds of millions of people in such countries including Kenya are facing food crises as the cost of their staple foods continues to rise. Potato production in Kenya is normally concentrated in the highlands (1500 – 3000 m. a. s. l) of Central, Eastern and Rift valley provinces (Kaguongo *et al*., 2008).

Potatoes are grown and eaten locally, with little significant international trade compared to cereals and are particularly valuable as food in developing countries. Potatoes are rich in minerals like K, P and Mg as well as vitamins B1, B3, B6 and vitamin C (Camire *et al.*, 2009). They also contain toxic glucoalkaloids like solanine and chaconine that often occurs just beneath the skin. Storage of potatoes in dark and cool place is important in keeping the levels of glucoalkaloids low (Prokop & Albert, 2008).

Kenya is the fifth largest potato producer in Sub-Saharan Africa, with an output of 790,000 tons (FAO, 2008). Annual crop value is about Kshs.5 Billion at farm gate and more than 10 Billion at consumer prices. The industry employs about 2.5 million People. The crop is the second most important staple food crop after maize (MoA, 2005) and plays a major role in national food and nutritional security in Kenya (MoA, 2005). Furthermore, potatoes are an important food and cash crop (Kiiya *et al*., 2006).

The total area under potato production in Kenya has been increasing steadily in recent years and the consumption is expanding significantly with the population especially in urban areas. The high demand is in fried potato chips consumption and this takes about 12% of the produced volume. The growth in fried potato crisps is slow and takes only 0.8% of the total production volume (MOA, 2009). Because of its relatively short growing season, two potato crops are possible in a year compared to one crop of maize at these altitudes. This makes potato very attractive to small-scale farmers. Although the area under potato production has been increasing, yields (estimated to be 4 – 10 tons/ha) are below the potential productivity per hectare (Haverkort, 1990). In high and medium rainfall areas, they are grown by about 500,000 farmers cultivating 108,000 hectares, with an annual production of over 1 million tons in two growing seasons (MoA, 2005).

2.2 The taxonomy and origin of potato

Potato belongs to the family of *Solanaceae* like Vegetables such as tomato (*Solanum lycopersicum* L.), pepper (*Capsicum annum* L.), eggplant (*Solanum melongena* L.) and ornamental plants such as Petunia (*Petunia xhybrida* L.) and Nicotiana (*Nicotiana tabacum* L.). Potato is an annual plant that produces starchy tubers, which are highly nutritious (Buckenhusker, 2005). The central highlands of Mexico are considered a center of genetic diversity for both the potato late blight pathogen (Flier *et al*., 2003) and for germplasm of tuber - bearing *Solanum sp*. (Spooner *et al*., 2001). Up to date, there still exists a wide variety of wild relatives of the species with a great diversity in this region. It grows up to 90 - 100 cm tall producing white and pink or purple flowers with yellow stamens 3 - 4 weeks after sprouting. Being herbaceous annual plant that grows up to 100 cm tall and it has weak stems that are angular and may be solid or hollow due to the disintegration of pith cells and produces a tuber that is commonly known as potato which is rich in starch (Spooner *et al.*, 2005).

2.3 Nutrition of potatoes

Balanced fertilization has proved to be a king pin in agricultural production under different farming situations and contributed to nearly 50 percent in overall increase in agricultural production (Singh *et al*., 2008). In Kenya, the recommended fertilizer rate is 90 kg N/ha and 230 kg P_2O_5/ha for potato production (Kanguongo *et al.,* 2008). Other recommendation for fertilizing potato with DAP fertilizer are at the rate of 80 kg N/ha and 90 kg P/ha (Fischer *et al*., 2004). Potatoes also produce more dry matter in a short cycle (Singh & Trehan, 1998). In a field experiment that was set up to investigate the effects of different sources of nitrogen on potato at Tigoni area in Kenya, it was found that N. P. K (20:20:20) at the rate of (90 kg N/ha) gave the highest yields of 86 and 62 t/ha for varieties Tigoni and Asante (Muthoni & Kabira, 2011). Together with the recommended amounts, timing of fertilizer application is also crucial. This is because the N uptake by the potato crop is low before plant emergence and only starts to become intensive about 15 days after emergence (Olivier *et al*., 2006).

The potato crop requires balanced dose of N, P and K for optimum production (Singh & Trehan, 1998). Potassium application as compared to Nitrogen has been neglected by farmers resulting in continual depletion of soil K (Lal *et al.,* 2007). In the normal range of nutrient solution, increasing amount of a balanced fertilizer increases susceptibility to late blight. Excess nitrogen tends to stimulate lush foliage or it encourages rapid vine growth which leads to increased proportion of foliage unprotected by non-systemic fungicides in the latter part of spray cycle (Beukema *et al*., 1990). Nitrogen fertilizer increases the nitrogen uptake and this increase has a positive effect on chlorophyll concentration, plant height, photosynthetic rate, total number of leaves and dry matter accumulation (Isreal *et al*., 2012 & Yassen *et al*., 2011.). An average plant height of 88.4 cm, 22 leaves per plant as well as 13 shoots have been achieved in research (Yassen *et al*., 2011). Nitrogen in the presence of adequate phosphorus and potassium stimulates canopy growth, leaves and branches. This is through production of extra leaves and branches, extension of leaf area duration and expansion of leaf area (Muthoni & Kabira, 2011). Avoiding excess nitrogen and use of moderate nitrogen fertilization is often recommended as a cultural practice to delay the development of late blight. Increased application of nitrogen can lead to increase in disease severity and use of more and more fungicides. Higher dose of phosphorus and potassium has been found to give a higher yield in a late blight year (Roy *et al*., 2001)

2.2 Constraints to potato production

The national average potato yields for Kenya is about 7.7 tons per hectare, but this figure has fluctuated considerably over recent years, from over 9.5 ton/ha to around 7.5 ton/ha (FAO, 2008). The major constraints of potato production are late blight, bacterial wilt (*Pseudomonas solanacearum*), lack of clean seeds, lack of proper pest and disease management, marketing System and lack of clear policies on packaging (Riungu, 2011). Potato prices have remained stable despite all these (Hoffler *et al*., 2008). Research is mainly concentrated on development of tolerant and high yielding varieties with good culinary qualities (Kabira, 1994).

2.4.1 Potato seed

Increased shortage of clean planting materials has led to low yields, poor quality produce, and spread of pests and diseases (GIZ - PSDA Kenya, 2011). The prices of seeds vary with varieties and from one area to another, with prices of most improved varieties having higher mean prices compared to the local varieties (Kaguongo *et al*., 2008). Seed costs contribute a significant 42% of the total production costs (Kirumba *et al*., 2004). Kenya produces less than 1% of the national certified seeds. Because of this shortage of clean planting materials, farmers are forced to plant seeds from informal sources such as farm - saved (self - supply) and local markets. The informal system leads to the use of poor quality seeds and often accelerates the spread of seed - borne diseases such as bacterial wilt (Ng'ang'a *et al*., 2003) which affects 77% of potato farms in Kenya (Kaguongo *et al*., 2010). Due to the high prevalence of this disease, a strict rotation programme is required in the production of potato though few farmers can afford to maintain the recommended one and a half years rotational programme due to scarcity of land (Riungu, 2011). Important seed borne diseases include bacterial wilt and virus diseases caused by potato virus Y (PVY) and potato leaf roll virus (PLRV). High quality seed can increase yields by 1.8–3.8 (average 2.8) times compared to farmers' seed and that every further field multiplication generation significantly reduced this yield gain (Schulte-Geldermann *et al*., 2010)

2.4.2 Potato diseases

The low yields have been attributed to potato diseases especially bacterial wilt, late blight, viruses and insect pests (Nganga *et al*., 2002). Among the diseases limiting the potential of increased potato production in developing countries is late blight that occurs on potato worldwide hence considered the world's most costly disease on food crops (Haverkort *et al*., 2008). Late blight is caused by oomycete *Phytophthora infestans* (Mont.) de Bary has historically been an important disease of potatoes and tomatoes worldwide. The disease caused widespread crop failures throughout Northern Europe including Ireland where it was responsible for the Irish famine (Elansky *et al*., 2001). Since then, it has spread far and wide and now occurs wherever potatoes are grown (Haverkort *et al*., 2009) *Phytophthora infestans,* can cause annual global losses estimated to be between US$ 3 and 5 billion (Judelson & Blanco, 2005). In most parts of the developing world, the most widely grown potato genotypes are susceptible to late blight therefore fungicides are a necessity for crop production (Oyarzún *et al.*, 2005).

A survey carried out to estimate the impact of late blight on potato yield and fungicide use in the United States revealed that use of the fungicides alone cost $77.1 million at an average cost of around $507 per ha which does not include non-fungicide control practices (Guenthner *et al*., 2001). Region wise economic importance of late blight shows that the disease takes highest toll of potato in Sub-Saharan Africa (44% crop losses) followed by Latin America (36%), Caribbean (36%), South-East Asia (35%), South-West Asia (19%) and Middle East and North Africa (9%) (CIP, 1997). In Kenya farmers suffer from a tremendous breakout of the disease at germination and first leaf formation (Schulte-Geldermann *et al.*, 2010). Late blight belongs to the class Oomycetes, which occur in a group, called the Stramenopiles, clustering together with others in a super group, the Chromalveolata (Adl *et al*., 2005). Oomycetes have an evolutionary history that may have involved the enslavement of a photosynthetic organism by another non-photosynthetic primitive eukaryote, with the plastid being lost secondarily in oomycetes (Cavalier - Smith, 2000).

2.4.3 Soil fertility

Low soil fertility is another constraint to potato production in the cool highlands of Kenya. The rapid decline in soil fertility is occasioned by continuous cultivation without adequate replenishment of mined nutrients (Kiiya *et al*., 2006). Soil phosphorus in major potato growing parts of Kenya is deficient by 2.9 ppm while total nitrogen is lower than 0.15% (Recke, 1997). The situation is exacerbated by the inherently high soil acidity with pH values of 4 to 5 (Kiiya *et al*., 2006). As a result of small land sizes, farmers continuously plant crops on the same land, practicing intensive cropping systems that mainly involve double and relay cropping of different crops without a fallow period (Kaguongo *et al.*, 2008). Fertilizer application is mostly below the recommended rate of 90 KgN/ha + 230 P_2O_5/ha (Kaguongo *et al*., 2008).

The high cost of inputs especially seeds; fungicides and fertilizers greatly limit the production of potatoes in Kenya (Kaguongo *et al*., 2008)**.** This has led to under application of fungicides and fertilizers and coupled with poor quality seeds. As a result, the net returns to the farmer are minimal. The high cost of inputs is largely a reflection of poor producer prices (Ng'ang'a *et al*., 2003). Fertilizer application for potato among the small - scale farmers has been low with only 10 - 15% of farmers using the recommended rates, which may be due to the high cost of inorganic fertilizer (Ogola *et al*., 2011).

2.5 History and origin of *Phytophthora infestans*

The global population structure of *P. infestans* began to change in the latter part of the 20th century. This was due to migrations from central highlands of Mexico that is considered a center of genetic diversity for the potato late blight pathogen. It spread to Europe and then secondary migrations from Europe to other locations worldwide (Grunwald *et al*, 2001). *P. infestans* infects a range of species from the genus *Solanum*, with the most economically important being the potato, (*Solanum tuberosum* L.*)* but other species such as the tomato, (*Solanum lycopersicum* L.) are also threatened economically. Non - crop host plants, for example nightshade species, could aid in the spread of *P. infestans* (Deahl *et al*., 2006). Subsequent appearances of A2 mating type strains in Europe indicate that the pathogen has been changing (Fry *et al*., 1991). Up to date it is known that the route of migration was via a large (25 000 metric tons) shipment of potatoes for fresh consumption imported to Europe from Mexico in the winter of 1976/77 (Niederhauser, 1991).

Pathogenic potential of *P. infestans* is often divided into race-specific and race-nonspecific resistance. Attempts have been made to breed for late-blight resistance in potato, with major resistance genes (*R* - genes), derived from the *Solanum demissum* deployed (Tan *et al.*, 2010). These major genes for resistance gave complete or very high levels of control, but turned out to be race-specific and rapidly became ineffective as the virulent isolates increased in the emerged of *P. infestans* (Fry, 2008). Single *R*-genes have no stable effect in the present *P infestans* race situation in as noticed in Norway and other European countries (Hermansen *et al.,* 2000)

Farmers over a long period have been relying on fungicide as the only alternative to manage Late blight. Evidence over the past 20 years indicates a major change in the population of *P. infestans* worldwide with emergence of more virulent and resistant strains (Fry *et al*., 1997). These new strains are metalaxyl resistant, the most effective fungicide that farmers have been using for controlling the disease (Goodwin *et al*., 1996), and they are more aggressive than the old strains which is seen as a major threat in the potato sector (Miller *et al*., 1998. Metalaxyl resistance has been observed in Cameroon (Fontem *et al*., 2005) and elsewhere (Mukalazi *et al*., 2001).

Isolates collected from potato and tomato in Kenya in 1995 were all shown to belong to old strains (Vega - Sanchez *et al*., 2000). However, 86% of isolates collected from potato fields in 1997 – 1998 had a high level of metalaxyl resistance and 20% were shown to produce low numbers of oospores (Hohl, 2000). The aggressive nature of these fungicide resistant strains and limited capability of resource constrained farmers to deal with the pathogen, control and management in tropics difficult. This is likely to be achieved only through the development and implementation of integrated disease management, however there is poor adoption of IDM technologies by resource-constrained farmers in developing countries (Trutman *et al.*, 1996).

2.6 Epidemiology of late blight

The magnitude of disease progress depends on an interaction between biotic factors such as cultivar, age, nutrition, the amount of inoculum present on the host and the abiotic factors such distribution and duration of saturated or near-saturated air within a favourable temperature in the crop canopy (Harrison, 1992). An understanding of pathogen survival can help in developing the disease management strategies. Infected seed tubers serve as overwintering and the primary source of inoculum (Kirk, 2003). *P. infestans* is a heterothallic Oomycete, and it is a near-obligate hemibiotrophic pathogen under natural and agricultural conditions. The asexual cycle enables dramatically rapid population growth in susceptible host tissue (Fry, 2008). Sporangia are produced on sporangiophores that grow from infected tissue. The sporangia are readily dehiscent, particularly to changes in relative humidity, and can be aerially dispersed to other plant tissues (Aylor *et al*., 2001).

Sporangia in free water germinate either via a germ tube at higher temperatures (optimum around 20 – 25 °C), or by releasing wall-less zoospores at lower temperatures (optimum between 10 and 15 °C) (Grenville - Briggs *et al.*, 2005). The germ tube penetrates directly or enters through stomata, and the mycelium grows profusely between the cells, sending long, curled haustoria into the cells. The older infected cells die while the mycelium continues to spread into fresh tissue. As the disease develops, established lesions enlarge and new ones develop, often killing the foliage and reducing potato tuber yields (Agrios, 2005); asexual life cycle of *P. infestans* can be completed rapidly with the production of massive numbers of sporangia that are readily dispersed. This is the reason why whole fields can transform from slightly diseased to almost complete destruction within a few days. Fertilization leads to Oospores that serves both as a survival structure and as a source of variation via sexual recombination. As survival structures, oospores have been demonstrated to persist for several years in soil (Turkensteen *et al*., 2000). They survive very low temperatures well, but not at higher temperatures, being unable to survive two hours at 46 °C or 12 h at 40 °C (Fay & Fry, 1997).

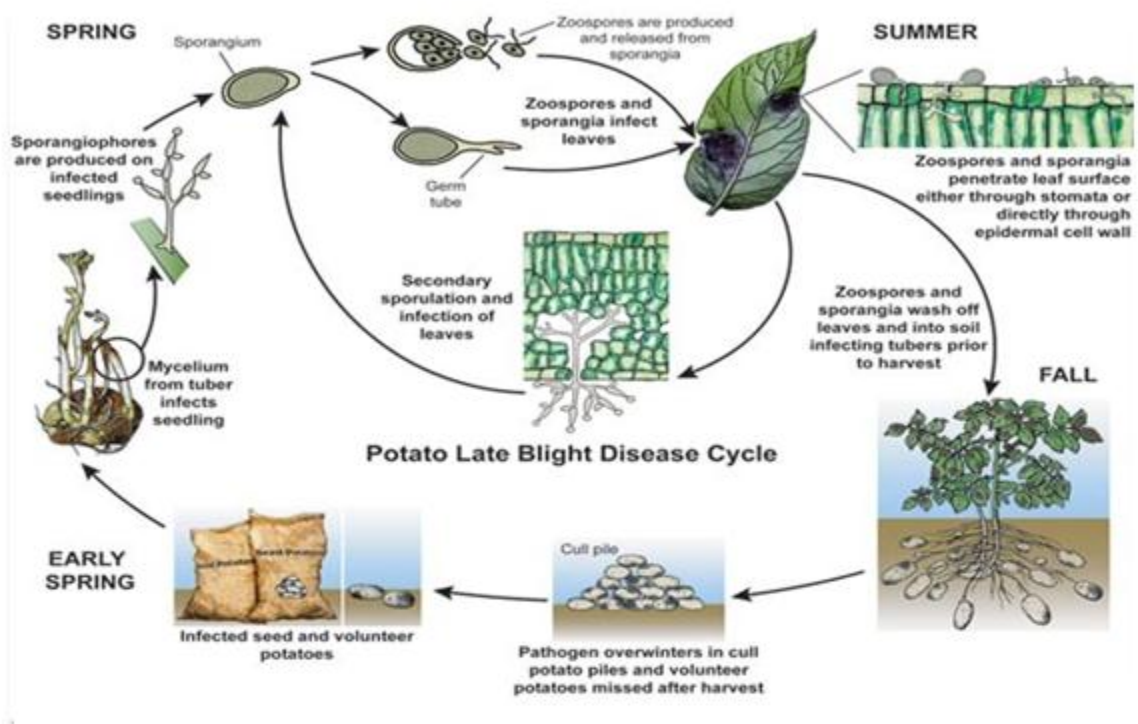

Figure 2.1: Life cycle of the late blight pathogen *Phythophtora infestans* (Wharton, 2005).

Disease symptoms start as water soaked, pale green irregular leaf lesions, which enlarge, turn brown, shrivel and dry out. Under conditions of moist weather, the underside of the lesions may be covered with a fine white moldy growth composed of sporangiophores and sporangia. On petioles stems, lesions appear at any point as oily, brown areas later turning into black and the whole plant may die. On fruits the disease appears as dark green to brown, greasy, irregular blotches, and fruit becomes shriveled at later stages. Cool, rainy weather, high relative humidity and heavy dew formation favor the infection, disease progress and sporangia production (Stevenson, 1997) which can destroy the unprotected crop within 10 to 14 days (Rubin & Cohen, 2004.; Govers, 2005).

2.7 Management of late blight disease in potatoes

Reduction of the primary sources of inoculums is the first step in the management of late blight. Control of contaminated sources such as waste heaps, infected tubers, volunteer plants, disease in neighbouring fields and re-growth after haulms destruction can help in management of the disease (Turkensteen & Mulder, 1999).

A combination of methods, like crop rotation, resistance breeding, chemical treatments, top-killing of the foliage prior to harvest and the use of high quality seed potato, are needed to keep late blight under control. There are also forecast systems, which aim at predicting when the weather is suitable for the pathogen and thus recommend when to spray the fields with fungicides (Haverkort *et al.*, 2008). It is estimated that the economic costs associated with late blight to be somewhere around $ 3 – 5 billion per year (Haldar *et al*., 2006). Cost of late blight is high in developing countries with lowest yields and eastern bloc countries which suffer over €10 billion per annum at least, whereas growers in developed countries with high yields (7.5% of global potato production) suffer damage of the order of €1 billion per year (Haverkort *et al.*, 2009). Region wise economic importance of late blight shows that the disease takes highest toll of potato in Sub-Saharan Africa (44% crop losses) followed by Latin America (36%), Caribbean (36%), South-East Asia (35%), South-West Asia (19%) and Middle East and North Africa (9%) (CIP, 1997).

2.7.1 Resistance breeding

Demand for late blight resistant varieties is always at top priority of the farmers to manage the disease (Rana *et al*., 2011; 2013). Breeders have tried to obtain resistance that is more durable by pyramiding (combining several R - genes) from wild *Solanum* relatives recently (Tan *et al.*, 2010). Race – non-specific resistance has shown signs of durability due to polygenic nature. A plant with quantitative resistance will not be immune but confer equal protection against all races and result in lower selection pressure to the pathogen. Despite all these breeding work, undesirable traits like lateness in maturity emerged (Visker *et al*., 2005). This is because of *P. infestans* has rapidly evolved into new virulent races in response to selection pressure therefore overcoming all of the 11

R - genes introduced from *S. demissum* (Fry, 2008). Stacking of several R - genes could be facilitated with genetic engineering by introduction of transgenes, e.g. genes from non-crossable species, or cisgenes from the species itself or from a crossable species (Jacobsen & Schouten, 2009). This has led to success in commercial use of the GM starch potato, named Amflora and use of transgenic modification developed a variety, named Fortuna, which harbor two resistance genes (Van der Vossen *et al.*, 2005). Breeders are now hoping that the use of cisgenetic modifications (CM), without the use of selection markers such as antibiotic resistance genes, will prove acceptance by the public and facilitate the legalization of CM varieties (Holme *et al.*, 2013). In 2006, a research program called Durable Resistance against *Phytophthora* in potato (DuRPh), continuing over 10 years, was started at Wageningen University and use of selection markers relying on CM approach (Haverkort *et al.*, 2009).

Development, maintenance and utilization of disease resistant varieties are considered a sustainable long-term solution to yield reductions resulting from such disease infections (Khurana, 2000). Potato improvement in Kenya has been focused to the development of potato varieties with increased resistance to late blight, high tuber yields, early maturity, good storability and improved processing qualities into value added products (MoA, 2005). In collaboration with the International Potato Center (CIP), several high yielding varieties were released, including Tigoni and Asante in 1998 followed by *Kenya Sifa, Kenya Sherkea, Kenya Karibu, Kenya Faulu* and *Kenya Mavuno* which were released in 2002 (Lungaho *et al.*, 2006)). Utilization of host resistance to late blight has a lot of significance in integrated late blight management due to its long-term economic benefits for small-scale farmers. It also minimizes changes in the population structure of *P. infestans* hence decreasing the likelihood of resistance to fungicide (Mukalazi *et al*., 2001). In addition to the benefits of reducing yield losses due to epidemics of late blight, planting resistant varieties can also contribute to reduce the health risks associated with fungicide applications. A number of studies have demonstrated the high human health risk associated with pesticide application in developing countries, where protective clothing is routinely not used (Yanggen *et al*., 2004).

2.7.2 Application of fungicides

Attempts to control late blight are almost entirely through use of fungicides on cultivars with low to moderate levels of resistance (Haverkort, 1990). Since most of the potato cultivars grown in the world are susceptible to late blight the use of fungicides is therefore essential as potato crops can receive up to 15 or more applications of fungicides depending on the weather (Cooke *et al.*, 2011). Fungicides are usually more effective when its application is done before infestation occurs, this does not always happen because other factors such as rain, wind, lack of equipment and a precarious financial situation may preclude application or rapid canopy growth. In Kenya, most farmers only apply fungicides after seeing symptoms (Nyakanga *et al*.,2004). Many fungicides, contact and systemic are available to manage the disease. The use contact fungicides are meant to protect the crop locally and cannot be taken up by the plant, such as Shirlan. In case of infected soil or seed potato, the recommendations are to use systemic or translaminar fungicides such as Acrobat, Epok, Ridomil Gold and Tattoo. S ystemic fungicides are absorbed by the leaf and transported through the xylem vessels, either short or long distances, within the plant. Use of systemic fungicides early in the season is an effective strategy to manage late blight if source of primary infection is infected seed (Hermansen & Naerstad, 2009).

Fungicides mixtures which have been used in the world to manage late blight include Tattoo C (31% Propmocarb hydrochloride + 31% Chlorothalonil), Curzate M8 (8% Cymoxanil + 64% Mancozeb), Acrobat MZ (9% Dimethomorph + 60% Mancozeb), Seredo (10% Fenamidone +50% Mancozeb) and (Fenamidone + Mancozeb) (Mayton *et al*., 2001). However, the efficacy of these compounds has been shown to be affected by temperature and to vary from region to region (Mayton *et al*., 2001). The higher cost of these mixtures and the nature of systemic fungicides require some investigation into application rates and their fit into existing spray regimes. A reported case from South Western Uganda on fungicide application strategy for late blight management based on host resistance and spray scheduling has been investigated and shown to be effective (Kankwatsa *et al*., 2003). There has been a tendency of development of resistant fungal races against use of systemic fungicides (Singh, 1996). The drawback to reliance on such fungicides is the risk of selection of fungicide resistant strains of *P. infestans*, as occurred with the phenylamides (Cooke & Little, 2010). Metalaxyl is an acylalanine phenylamide that is very effective against oomycetes. It was first used commercially in 1978 to control *P. infestans* (Cooke *et al*., 1991).

2.7.3. Cultural control

There are different methods of cultural practices applicable for late blight management. Cultural practices provide the first line of defense against late blight (Kirk *et al*., 2013). Applications of cultural practices help to reduce the pathogen population by; reducing its survival, reproduction, dispersal and penetration of the pathogen. Survival of *P. infestans* to initiate epidemic can be reduced through avoidance of introducing late blight into a field by planting only disease-free seed tubers, preferably certified seed, destroying all cull and volunteer potatoes, avoid frequent or night-time overhead irrigation and good soil coverage (Draper *et al*., 1994). Late blight is controlled by eliminating cull piles and volunteer potatoes, using proper harvesting and storage practices, and applying fungicides when necessary (Davis *et al*., 2009). The most effective strategy for managing late blight is to avoid sources of inoculum. The initial sources of inoculum are infected potatoes in cull piles, infected volunteer potato plants that have survived the winter, and infected seed tubers. Therefore, it is important to keep a clean operation by destroying all cull and volunteer potatoes (Agrios, 2005). Seed sources should be selected carefully to avoid bringing in late blight on seed, especially new strains of the pathogen (Kirk, 2009). When partially blighted leaves and stems are surviving at harvest time, it is necessary to remove the aboveground parts of potato plants or destroy them by chemical sprays (herbicides) or mechanical means to prevent the tubers from becoming infected (Agrios, 2005).

2.7.4. Integrated disease management (IDM)

Integrated disease management has helped farmers drastically reduce the need for chemical controls while increasing production (FAO, 2008). Effective control of late blight requires employing an integrated disease management approach (Kirk *et al*., 2013). The integration of different management options, including cultural practices (good crop husbandry), resistant varieties and fungicides is required to control late blight. Late blight of potatoes can be managed successfully by using a combination of sanitary measures, resistant varieties, and well-timed or scheduled chemical sprays (Agrios, 2005). In integrated management of disease the host resistance contributes to reducing the number of sprays required to keep late blight below an economic threshold level (Jones, 1998). The integration of late blight management has often been thought as one of the better disease management options in tropical regions where fungal inocula are abundant throughout the year (Olanya *et al*., 2004). These include: variation of frequency of application of fungicides based on host resistance of potato varieties (reduced fungicide use), early planting and improved variety (early and mid-maturity, tolerant variety (Kankwatsa *et al*., 2002).

CHAPTER THREE
MATERIALS AND METHODS

3.1 Site description

The experiments were conducted at the agronomy demonstration field Egerton University in Njoro Sub County and Tumaini farm in Molo Sub County, Kenya in July – October, 2014. Egerton University site lies at latitude 0° 23´ S, longitude 35° 35´ E, and at an altitude of 2238 meters above sea level. The annual mean precipitation is 1000 mm, and the annual mean temperature is 15.9 °C. The site is situated in the agro-ecological zone III and has mollic andosols loam soils (Jaetzold *et al*., 2007). The site has relatively high altitude as well as high annual rainfall which are suitable for potato production and late blight development and spread. Molo site lies at latitude 0°12´S, Longitude 35°41´E and at altitude of 2200 m above sea level. The mean annual rainfall of Molo is 1200 mm and mean temperatures of 13.75°C (Jaetzold *et al*., 2007). The site has two cropping seasons and the main crops grown are pyrethrum, potatoes, barley and maize (Jaetzold *et al*., 2006). The soils of Molo are acidic, well drained, deep, dark reddish brown with a mollic A horizon, and classified as mollic Andosols (FAO – UNESCO, 1990). The two site have got similar cropping systems with the main crops being potatoes, barley, wheat and maize (Jaetzold *et al*., 2006). The sites were chosen because of their different temperature and precipitation conditions and because differences were observed in late blight pressure among other locations.

3.2 Effect of fertilizer and fungicide application rates on the incidence and severity of late blight on Irish potatoes

3.2.1 Preparation and Isolation of (*P. infestans*)

Diseased leaves were obtained and cleaned with tap water. A small piece was cut at the margin of a lesion and placed on the tuber slices pieces with side length of 5 – 7 mm in moist petri - dish, then incubated at 15 – 18 º C. After seven days, the pathogen colony was formed on tubers slices.

Hundred milliter of V8 juice (Campbell Soup Co., Camden, NJ) was mixed with 2.5g of $CaCo_3$ then stirred. The 150 ml of clarified V8 medium was first centrifuged for 5 min at maximum speed (6000 rpm) and then 100 ml of the supernatant was obtained. A 900 ml distilled water, $CaCO_3$ (2g) and agar (15 g/L) was added to the supernatant (CIP, 1997). The mixture was diluted

(100:900V/V) with distilled sterile water and then autoclaved. A V8 agar was prepared by adding 15g of DifcoBacto Agar (Difco Laboratories, Detroit, Michigan) to 1L V8 media and autoclaved again. The medium was amended with antibiotics (rifampicin 20mg. mL^{-1}, ampicillin 200 mg.mL^{-1}, benlate 100 mg. mL^{-1}). The mixture was then poured into sterilized petri - dish. The white colony of late blight pathogen was removed from tuber slices then inoculated on a V8 agar plate medium cultured 7 – 10 days at 15 – 18 º C. The pure colony of *Phytophthora infestans* was transferred into slant medium and then incubated at 15 – 18 º C in darkness until full growth.

3.2.2 Experimental procedure

After land preparation the experiment was laid out in a split – split plot arrangement of randomized complete block design (RCBD) with three replicates. The treatments were 3 levels of fertilizer, 3 levels of fungicides and 2 potato varieties. The plot size measuring 3×1.2 m with a spacing of 75 cm × 30 cm (75 cm between the rows and 30 cm between the plants) resulting in 4 rows per plot. A clean certified potato seed of medium size (50g) of varieties *Kenya Sherekea* (Tolerant variety) and *Dutch Robjin* (Susceptible variety) sourced from Agricultural Development Cooperation (ADC), Molo were sown per hole. Insect pests were controlled by spraying the plots when 50% emergence had been attained and when the pest population had reached economic threshold using Actara (250 g/Kg Thiamethoxam). Cultural practices such as weeding were carried out regularly when weeds appeared. The three rates of N: P: K 17:17:17 fertilizer (0, 90, 135 $KgHa^{-1}$) were applied at planting and Acrobat MZ fungicide (Dimethomorph 90g/Kg + Mancozeb 600g/Kg) at rates of (0, 2.5, 3.5g/l) 7 days after inoculation. Fungicide application were started at the time of appearance of late blight symptoms on potato plants in experimental plots using a Neptune knapsack sprayer with a hollow cone nozzle.

3.2.3 Field inoculation

The *Phytophthora infestans* isolate that was used in all trials for inoculation was isolated from infected potato leaves and tubers obtained from the field as described by (Fontem *et al*., 2004), and identified in the laboratory. The cultures were washed twice with sterilized distilled water and released in 10 mL sterile distilled water (SDW) followed by placing it at 4^oC for 0.5 h followed by incubation at 25℃ for about 1h. The release of zoospores was monitored and counted using haemocytometer and adjusted to 2×10^4 sporangia/Ml in readiness for inoculation.

Plants were inoculated at 37 days after emergence (DAE) with spore suspension (2.0×10^4 spore/ml) of the pathogen after sprinkle irrigation to enhance disease development. Fertilizer (N. P. K) treatment application was done during planting using 3 levels of fertilizer which was sufficient for crop growth. Fungicide application started 10 days after inoculation and repeated in intervals of seven days up to 61DAP.

3.2.4 Data collection

Disease onset (DO) in each cultivar was recorded in days after planting. Starting with the appearance of the first late blight symptoms, each plant within two middle rows in each plot was visually evaluated for percent foliar infection at seven-day intervals starting at 47 days after inoculation. Evaluations continued until untreated plots of the susceptible variety no longer increased in disease development at 61 days. Disease incidence and severity per plot were converted to percentages according to (Shutong *et al*., 2007) as shown in the Equations below.

$$\mathrm{PDI}(\%) = \frac{\mathrm{NDP}}{\mathrm{TNPP}} \times 100$$

Where; PDI = Percent disease index per plot, NDP = number of diseased plants, TNPP = Total number of plants per plot

Disease severity per plot in both experiments was visually assessed on a scale of 0 – 9 as shown 0: No disease; 1: Small lesion on the inoculated point with the lesion area less than 10% of the whole leaflet; 3: Lesion area between 10 and 20% of whole leaflet;5: Lesion area between 20 and 30% of whole leaflet, the waterish area less than 50% of the whole leaflet; 7: Lesion area between 30 and 60%; 9: Lesion area over 60% of the whole leaflet . Where 0 means (immune) no disease was observed and 9 mean all leaves and stems drying and dead due to disease (highly susceptible). The disease severity was converted to disease severity index using the formula below (Shutong *et al*., 2007)

$$DSI\ (\%) = \sum \frac{DSL \times NLSL}{TNL \times HSR} \times 100$$

Where; DSI = Percent disease severity index, NLSL = No of leaflets with the same level TNL = Total number of leaflets HSR = Highest severity rating.

Total tuber yield (TTY) of each experimental unit (plot) was determined by harvesting the two inner rows of each plot. Tubers were sorted as unmarketable (blighted, rotten and deformed) and marketable from the total tuber yields and the components were measured. All measures were given in T/ha, which was derived by extrapolation from the yield per plot.

3.3 Effect of Fungicide and N: P: K fertilizer application on potato (*Solunum tuberosum* L.) growth parameters

3.3.1 Experimental design and treatment application

The trial was laid out in a randomized complete bock design (RCBD) with three replicates. Each of the three replicates had eighteen treatments which were randomly allocated. Before planting the plot was ploughed using traditional hoes to a depth of 30 cm after which rectangular ridges were made. On each experimental unit 16 potato tubers of the varieties *Kenya Sherekea* (tolerant) and *Dutch robjin* (Susceptible) varieties were planted at a distance of 30 cm by 75 cm. Three levels of fertilizer (0, 90,135 KgHa $^{-1}$) was applied during planting while late blight was controlled by use of three levels of Acrobat fungicide (0, 2.5, 3.5 g/l) using a knapsack sprayer after the appearance of the first symptoms.

3.3.2 Data collection

Plant morphological features that were measured at different stages of plant growth to assess response to the treatments included the followings: plant height, the number of haulms and leaves at 47, 54 and 61 DAP. At 120 DAP harvesting was done, yield was measured by quantifying tuber numbers from each plot and expressed in tons per hectare (t/ha) for subsequent analysis.

3.3.3 Statistical analysis

The data collected on late blight severity, incidence potato growth parameters and yield were subjected to analysis of variance (ANOVA) using Statistical Analysis System (SAS Institute, 2001) software. Correlation ($P \leq 0.05$) among variables and parameters measured were analyzed using the correlations analysis. The strength of the linear relationship among various parameters measured was also assessed. Treatment means were separated using Least Significant Difference (LSD) at ($P \leq 0.05$ whenever ANOVA showed significant treatment effects.

CHAPTER FOUR

RESULTS AND DISCUSION

4.1 Effects of potato variety on incidence and severity of Late blight (*Phytophthora infestans*) on potatoes under field conditions.

The results of disease severity and incidence are presented in Tables 4.1 and 4.2 below. The two potato varieties, *Kenya sherekea* and *Dutch robjin* exhibited a significant (P≤0.05) differences in the incidence and severity to the development of late blight disease.

Table 4.1: Effects of potato variety on severity of late blight (*P. infestans*) at Molo and Egerton sites

Percentage disease severity index (DSI)						
	Egerton			Molo		
Variety	47 DAP	54 DAP	61 DAP	47 DAP	54 DAP	61 DAP
Dutch robjin	13.65ᵃ	18.96ᵃ	31.96ᵃ	15.87ᵃ	25.63ᵃ	37.75ᵃ
Kenya sherekea	8.86ᵇ	16.35ᵇ	17.39ᵇ	8.90ᵇ	18.95ᵇ	27.12ᵇ

Means followed by the same letter in each column are not significantly different at (P≤0.05) probability level. DAP= Days after planting

Table 4.2 Effects of potato variety on the percentage disease incidence of late blight (*P. infestans*) at Molo and Egerton sites

Percentage disease incidence (PDI)						
	Egerton			Molo		
Variety/DAI	**47 DAP**	**54 DAP**	**61 DAP**	**47 DAP**	**54 DAP**	**61 DAP**
Kenya sherekea	24.07ᵃ	37.50ᵃ	51.85ᵃ	33.33ᵃ	45.01ᵃ	52.11ᵃ
Dutch robjin	46.30ᵇ	60.65ᵇ	66.6ᵃ	57.27ᵇ	58.33ᵇ	75.0ᵇ

Means followed by the same letter in each column are not significantly different at (P≤0.05). DAP= Days after planting

Comparing the two varieties *Dutch robjin* recorded highest severity index of 31.96 and 37.75 at Egerton and Molo respectively compared to *Kenya sherekea* with 17.39 and 27.12 at Egerton and Molo respectively which was significantly (*P*≤0.05) different. Disease incidence among the two varieties was significant (*P*≤0.05) with *Dutch robjin* variety exhibiting unstable resistance to *P.*

infestans as compared to *Kenya sherekea* in the field conditions Table 4.2). The two varieties showed significant ($P \leq 0.05$) differences for disease incidence at Molo site. The percentage disease incidence increased progressively after inoculation due to high inoculum load. *Kenya sherekea* variety proved to be tolerant to late blight disease with mean values of 24.07 to 51.85 as compared to *Dutch robjin* variety 46.30 to 75 on disease incidence Table 4.2. *Dutch robjin* variety was more affected at both sites but epidemic was high at Molo site as compared to *Kenya sherekea*. Comparison of the two varieties therefore indicated the *Kenya sherekea* variety was more tolerant to late blight as compared to *Dutch robjin* which was susceptible to late blight. This indicates that resistance can be exploited to minimize on application of fungicides and other inputs for increased yield in potato production.

4.2 Effect of site on late blight (*P. infestans)* severity on potatoes

The results on effect of site, Egerton and Molo on late blight severity and incidence are given in Table 4 3 and 4.4 below. The precipitation during the cropping season was fairly high and relative humidity was also sufficient for late blight infection which favoured the development of the disease.

Table 4.3 Effects of site on (*P. infestans*) severity on potatoes at Molo and Egerton University sites

	Percentage disease severity index (DSI)		
Site	**47 DAP**	**54 DAP**	**61 DAP**
Egerton	10.51^{a}	16.35^{a}	18.95^{a}
Molo	12.01^{b}	18.96^{b}	30.40^{b}

Means followed by the same letter in each column are not significantly different at ($P \leq 0.05$)

DAP= Days after planting

Table 4.4 Effects of site on (*P. infestans*) incidence on irish potatoes in Molo and Egerton University sites

	Percentage disease incidence (DI)		
Site	**47 DAP**	**54 DAP**	**61 DAP**
Egerton	41.20^{a}	43.98^{a}	44.91^{a}
Molo	49.53^{b}	54.17^{a}	53.24^{b}

Means followed by the same letter in each column are not significantly different at (P≤0.05)

DAP= Days after planting.

There was a significant (*P*≤0.05) difference in the rate of disease development with time between the two experimental sites. The disease incidence was significantly (*P*≤0.05) higher in Molo than Egerton site days after planting. Disease incidence provided somewhat different view at 54 DAP which was not significant Table 4.4. The disease incidence was high at Molo site (54.17%) as compared to Egerton University site (44.91%). Overall disease severity was high in Molo site (30.40%) compared to Egerton University (18.95%).

Disease development at Molo was high than Egerton University due to favorable weather conditions which favored high inoculum load. Potato debris in the surrounding farms also served as a source of inoculum in addition to the artificially inoculated pathogen load. On the contrary, the experiment plot at Egerton University was at an isolated area where only cereals (sorghum and maize) had been planted prior to the experiment. The inoculum load was, therefore low with limited possibility of external pathogen transfer to the field apart from the artificially inoculated load.

Late blight occurrence was detected at both sites during the cropping season due presence of inoculum and favourable conditions. Environmental conditions at both sites of the experiments might have contributed to late blight occurrence and development. This was in agreement with research findings by (Olanya *et al*., 2001) on environmental conditions in East Africa highlands of Uganda and Kenya favourable for late blight occurrence and development throughout the year. The study was also in agreement to what (Kromann *et al*., 2009) reported that in areas of high disease pressure, such as the highland tropics, susceptible varieties require frequent fungicide applications and the disease is difficult to manage without the use of expensive systemic or trans - laminar fungicides.

4.3 Interaction effects of fertilizer and fungicide application rates on late blight (*P. infestans*) severity on potatoes under field conditions

The interaction effects of fertilizer and fungicide application rates on *P. infestans* severity on irish potatoes at Egerton University and Molo sites are presented in Table 4.5.

Table 4.5 Interaction effects of fertilizer and fungicide application rates on *P. infestans* severity on potatoes at Egerton University and Molo sites

	Disease severity index (DSI)						
		Egerton			Molo		
	Fertilizer ($KgHa^{-1}$)	0	90	135	0	90	135
	Fungicide (g/l)						
47 DAP	0	11.85[a]	12.44[a]	12.38[a]	15.87[a]	16.42[a]	16.01[a]
	2.5	11.01[a]	10.96[a]	11.55[a]	14.31[a]	12.9[a]	13.96[a]
	3.5	7.26[b]	11.78[a]	12.10[a]	11.89[b]	14.65[a]	15.79[a]
54 DAP	0	17.60[a]	19.36[a]	18.23[a]	25.63[a]	26.43[a]	25.61[a]
	2.5	16.82[a]	17.04[a]	18.57[a]	24.51[a]	22.83[a]	23.99[a]
	3.5	14.08[b]	18.23[a]	19[a]	21.89[b]	24.94[a]	25.78[a]
61 DAP	0	26.5[a]	26.41[a]	26.94[a]	37.75[a]	36.42[a]	35.6[a]
	2.5	23.74[a]	24.93[a]	26.53[a]	33.03[a]	31.35[a]	33.58[a]
	3.5	15.74[b]	24.92[a]	26.25[a]	30.08[b]	35.14[a]	33.98[a]

Means followed by the same letter in each column for each day after planting are not significantly different at ($P \leq 0.05$). DAP= Days after planting

Effects of fertilizer and fungicides interactions between Egerton and Molo sites indicated that severity was slightly high in Molo at 37.75 at 0 $KgHa^{-1}$ N-P-K fertilizer as compared to Egerton at 26.94 at 135 $KgHa^{-1}$ N-P-K fertilizer at 61 DAP for 0 g/l of fungicide. In general, late blight severity and incidence varied with mineral fertilizer schemes but the effect depended on disease pressure and fungicide rates. Table 4.5 presents the mean late blight severity differences under various treatments of mineral fertilizers and fungicide in which none of the mean disease severity differences were significant ($P \leq 0.05$) apart from two which were attributed to the effect of disease pressure and stages of growth. Untreated plots had recorded high severity indexes as shown in Table 4.5. High rates of fungicide seemed to be effective for management of late blight at both sites but it depended on the levels of fertilizers applied. Disease pressure was low at 47 DAP and it kept on increasing slightly up to 61DAP where high indexes was recorded. High disease severity at Molo can be attributed to alternating low and high humidity conditions which seem to favour disease development which was similar to the findings of (Vander- Walls *et al*., 2001) reported. This may be attributed to a balanced dose of fertilizers and fungicides. Host developmental stage has got some effects on late blight development with older plants recording increased severity rates as shown in Table 4.5 which is in agreement with findings of (Agrios, 2005)

Table 4.6 Interaction effects of fertilizer and fungicide application rates on late blight (*P. infestans*) incidence on potatoes at Egerton University and Molo sites days after planting

Percentage disease incidence (PDI)							
		Egerton			**Molo**		
	Fertilizer (KgHa)	**0**	**90**	**135**	**0**	**90**	**135**
Days After Planting	**Fungicide (g/l)**						
	0	54.17^{a}	50.0^{a}	50.0^{a}	75^{a}	69.02^{a}	58.33^{a}
47	**2.5**	37.30^{b}	54.17^{a}	52.08^{a}	66.67^{b}	60.66^{b}	52.08^{b}
	3.5	20.83^{c}	41.67^{b}	47.92^{b}	33.33^{c}	50^{c}	69.02^{c}
	0	43.75^{a}	58.33^{a}	47.92^{a}	58.33^{a}	66.67^{a}	75.5^{a}
54	**2.5**	52.08^{a}	47.92^{ab}	50.0^{a}	52.02^{b}	50^{b}	66^{ab}
	3.5	41.67^{a}	50.0^{b}	50.0^{a}	50^{b}	41.67^{c}	51^{c}
	0	64.58^{a}	56.25^{a}	58.33^{a}	68.33^{a}	66.67^{a}	58.33^{a}
61	**2.5**	31.25^{b}	47.92^{bc}	56.25^{a}	50^{b}	66.7^{a}	75^{b}
	3.5	33.33^{bc}	45.83^{c}	47.92^{b}	50^{b}	41.57^{b}	58.33^{c}

Means followed by the same letter in each column are not significantly different at ($P \leq 0.05$) for each day after planting. DAP= Days after planting

At 54 DAP, Molo site had significant ($P \leq 0.05$) difference for disease incidence on fertilizer and fungicides application rates combination as compared to Egerton site which was not significant Table 4.6. There was enhanced significant disease control obtained with fungicide mixtures under moderate to severe late blight conditions. The disease severity and incidence were high in the negative control plot at 61 DAP where neither fertilizer nor fungicide was applied. The highest rate of increase of late blight severity was recorded between 54 and 61DAP and the progress declines when the fungicide rates are increased (Table 4.5). The incidence was lower at 0 $KgHa^{-1}$ of fertilizer than 90 $KgHa^{-1}$ and $KgHa^{-1}$ which corresponds to reduction at 2.5g/l and 3.5g/l of fungicide (Table 4.6). At 54 DAP there was no significant change that was observed on the disease incidence when different rates of fertilizers and fungicides were combined Table 4.6.

Disease incidence results indicate a significant difference on days after planting between the two sites. Combination of fertilizer and fungicides application rates, both had significant effects on severity. Application of fertilizer at 135 $KgHa^{-1}$ lead to slightly high infection rates as compared to other rates of fertilizer application. The disease was more severe at 61DAI in all rates of fertilizer and fungicide application. Application of fertilizer at 0 $KgHa^{-1}$ and fungicide at 3.5g/l produced significant effects at 47 DAP and 61 DAP. The disease incidence showed significant ($P \leq 0.05$) differences at the three growth stages Table 4.6. The incidence increased as fertilizer rates increased and decreased as the level of fungicide rates as shown in (Table 4.6). This was an indication that fungicides mixtures can provide effective late blight management in established epidemics compared with the use of a protectant or systemic fungicide (Mayton *et al.*, 2001). Late blight severity and incidence results from Table 4.5 and 4.6 shows that the disease can occur at any time during the growing season which was in agreement to the findings of (Bevacqua, 2000).

4.4 Effect of different potato growth stages on severity and incidence of late blight under field conditions.

The results of growth stages of potatoes on disease severity and incidence are presented in Tables 4.7.

Table 4.7: Interaction effects of variety and fungicide application on late blight (*P. infestans*) severity on potatoes at different growth stages at Egerton University and Molo.

Percentage disease severity index (DSI)					
		Egerton		**Molo**	
	Variety	**Kenya sherekea**	**Dutch robjin**	**Kenya sherekea**	**Dutch robjin**
	Fungicide(g/l)				
47 DAP (Growth stage 1)	**0**	9.51^{a}	14.93^{a}	10.01^{a}	13.93^{a}
	2.5	9.55^{a}	12.80^{b}	11.51^{a}	14.8^{b}
	3.5	7.5^{b}	13.23^{ab}	9.0^{b}	13.47^{ab}
54 DAP (Growth stage 2)	**0**	17.22^{c}	19.57^{a}	19.21^{a}	20.22^{a}
	2.5	15.07^{a}	19.89^{a}	16.07^{a}	19.21^{a}
	3.5	16.79^{ab}	17.43^{a}	15.07^{b}	18.4^{b}
61 DAP (Growth stage 3)	**0**	19.27^{a}	33.98^{a}	20.27^{a}	32.54^{a}
	2.5	18.99^{bc}	31.14^{a}	20.9^{ab}	32.02^{a}
	35	13.92^{c}	30.75^{b}	15.05^{c}	33.75^{a}

Means followed by the same letter in each column for each growth stage are not significantly different at (P≤0.05)

DAP= Days after planting

Table 4.8: Interaction effects of variety and fungicide application on (P. infestans) incidence on Potatoes at different growth stages at Egerton University and Molo

Percentage disease incidence (PDI)					
		Egerton		Molo	
	Varieties	Kenya Sherekea	Dutch robjin	Kenya sherekea	Dutch robjin
	Fungicide (g/l)				
47 DAP (Growth stage 1)	0	31.94^{a}	70.83^{a}	50.01^{a}	80.93^{a}
	2.5	23.61^{b}	72.22^{a}	30.94^{b}	75.21^{b}
	3.5	16.67^{c}	56.94^{b}	17.08^{c}	58.97^{c}
54 DAP (Growth stage 2)	0	55.56^{a}	44.44^{a}	55.5^{a}	60.21^{a}
	2.5	48.61^{b}	51.39^{b}	49.09^{b}	50.22^{b}
	3.5	51.39^{bc}	43.06^{a}	49.01^{b}	53.52^{b}
61 DAP (Growth stage 3)	0	54.17^{a}	65.28^{a}	51.01^{a}	42.17^{a}
	2.5	26.39^{bc}	63.89^{a}	48^{b}	52.97^{a}
	3.5	31.94^{c}	52.78^{b}	29.94^{c}	58.78^{a}

Means followed by the same letter in each column for each growth stage are not significantly different at ($P \leq 0.05$)

DAP= Days after planting

Analysis of variance showed significant ($P \leq 0.05$) differences among the varieties and fungicide application rates at different growth stages Table 4.7. In general, the results of combined analysis showed that the interaction of varieties and fungicides was significant ($P \leq 0.05$) for disease severity at 47, 54 DAP and 61 DAP Table 4.7. Further analysis showed significant ($P \leq 0.05$) differences between *Kenya sherekea* and *Dutch robjin* varieties for late blight severity and incidence. Application of fungicides at 3.5 g/l was effective at both sites for *Kenya sherekea* variety across all the growth stage. *Dutch robjin* variety recorded the highest disease incidence (72.22%) and (80.93%) in control plots (no fungicide sprays) compared to *Kenya sherekea* variety (55.56%) Table 4.8.

Application of fungicides was effective in reducing development and progress of late blight disease on tolerant variety *Kenya sherekea* compared to susceptible variety *Dutch robjin*. Fertilizer treatment and variety interaction showed that there were significant ($P \leq 0.05$) differences on disease severity and incidences at different growth stages. Disease resistance in potato varieties together with the use of fungicides can slow down the development of late blight. A variety with field resistance to late blight in tubers and a medium to high resistance in the foliage can help in reducing the use of fungicides Table 4.7 and 4.8. Young plants are slightly susceptible to blight while plants of intermediate age are more resistant than the young or old plants depending on the levels of fungicide used Table 4.7 and 4.8. Use of host density as a tool for management of late blight has been used for control of late blight. Growth and development stage of host plants influence development of late blight.

The results of the study therefore indicate that fungicide use alone or host resistance alone cannot control potato late blight fully which requires use of the integrated approaches. This is therefore in agreement with the research conducted in sub-tropical environments which documented that optimum management of late blight requires an integrated approach (Fry & Shtienberg, 1990).

The results in Table 4.9 indicate that fertilizer application had significant effects on the severity of late blight for the two sites and cultivars. The recorded increase in severity from 41 DAP to 61 DAP was observed at both sites and for the two varieties. The Kenya sherekea variety recorded lower severity indexes than Dutch robjin at the two sites Table 4.9.

Table 4.9: Interaction effects of variety and fertilizer application on late blight (*P. infestans*) severity on Potatoes at different growth stages.

Percentage disease severity index (DSI)					
		Egerton		**Molo**	
	Varieties	**Kenya sherekea**	**Dutch robjin**	**Kenya sherekea**	**Dutch robjin**
	Fertilizer (KgHa^{-1})				
41 DAP (Growth stage 1)	**0**	6.99^{a}	13.09^{a}	12.99^{a}	17.01^{a}
	90	9.69^{ab}	13.77^{a}	14.09^{b}	17.28^{ab}
	135	9.91^{c}	14.11^{a}	15.27^{c}	30.06^{c}
54 DAP (Growth stage 2)	**0**	15.16^{a}	17.16^{a}	17.16^{a}	30.11^{a}
	90	16.91^{a}	19.91^{a}	19.01^{b}	23.09^{b}
	135	17.39^{a}	19.80^{a}	20.12^{bc}	38.11^{c}
61 DAP (Growth stage 3)	**0**	13.23^{a}	30.84^{a}	21.23^{a}	28.2^{a}
	90	18.92^{b}	31.92^{a}	24.07^{bc}	29.41^{ab}
	135	20.03^{c}	33.12^{ab}	24.29^{c}	30.97^{a}

Means followed by the same letter in each column for each growth stage are not significantly different at ($P \leq 0.05$). DAP= Days after planting

Table 4.10: Interaction effects of variety and fertilizer application on late blight (*P. infestans*) incidence on Potatoes at different growth stages.

Percentage disease incidence (PDI)					
		Egerton		Molo	
	Varieties	Kenya sherekea	Dutch robjin	Kenya sherekea	Dutch robjin
	Fertilizer ($KgHa^{-1}$)				
47 DAP (Growth stage 1)	0	16.67[a]	58.33[a]	27.09[a]	68.27[a]
	90	25.0[ab]	72.22[bc]	28[a]	70.11[a]
	135	30.56[c]	69.44[c]	38.76[b]	75[b]
54 DAP (Growth stage 2)	0	40.08[a]	47.22[a]	40.02[a]	69.09[a]
	90	44.44[a]	63.87[b]	42[ab]	70[a]
	135	47.22[b]	51.37[a]	50.22[c]	79.09c
61 DAP (Growth stage 3)	0	30.56[a]	55.56[ab]	40.05[a]	72[ab]
	90	43.06[bc]	69.44[ab]	42.09[bc]	75[ab]
	135	38.89[c]	56.94[a]	45.1[c]	89[c]

Means followed by the same letter in each column for each growth stage are not significantly different at ($P \leq 0.05$)

DAP= Days after planting

Data on disease incidence revealed that there was significant ($P \leq 0.05$) differences for the fertilizers and varieties at different stages of growth apart from 54 DAP Table 4.9 and 4.10. Evaluation of the cultivars on their response to inorganic fertilizer amendment showed that there was a general increase in late blight severity with increase in fertilizer rate. The increase in late blight severity was higher for Dutch robjin than Kenya sherekea Table 4.9 and 4.10. Varieties exhibited different levels of severity and incidence. Dutch robjin variety recorded highest percentages for both severity and incidence at both sites compared to Kenya sherekea Table 4.9 and 4.10.

Results indicated that fertilizing potatoes at 135 KgHa $^{-1}$ increased its susceptibility to late blight across sites. Just like disease severity, increased fertilization leads to increased disease incidence Table 4.9. Increasing fertilizer rates to 135 KgHa $^{-1}$ had effects on disease development for the tolerant variety *Kenya sherekea* across the sites Table 4.9 and 4.10. Lack of consistency in disease levels that was recorded across the sites could be attributed to environmental variations among the sites (Olanya *et al*., 2004) In some cases, the occurrence of the disease before initiation of spray program resulted from inadequate disease control confounding effects on treatment. This could require adjustment of fungicide to higher application rates to reduce destruction of susceptible varieties.

When the cultivars were evaluated for their response to inorganic fertilizer amendments, there was a general increase in late blight disease severity and incidence with an increase in fertilizer rates among the varieties.

This could be due to the effects of mineral fertilizer which encouraged rapid growth and development of new tissues that leads to favourable microenvironment for disease development (Tarla *et al*., 2011). The increase in late blight severity and incidence was higher for in Dutch robjin variety as compared to Kenya sherekea variety. Results further indicated that application of fertilizers at high rates increased its susceptibility to late blight which also required increased rates of fungicide application. Therefore the findings did not agree to earlier findings of (Marscher, 1997) that plants with optimum nutrition have maximum disease resistance. Small scale farmers should exercise caution in fertilizer application rates based on the host resistance to late blight. *Dutch robjin* proved to be more susceptible to late blight hence may require higher rates of fungicide depending on disease pressure than *Kenya sherekea*. This research demonstrated consistency to other findings that susceptible varieties require more fungicides than resistant varieties (Naerstad *et al*, 2007). The results showed that unsprayed plots resulted in high disease development and progress rate than the sprayed plots which could result in losses. This results confirmed (Neiderhauser, 1999) that fungicides must be used in control of late blight and (Hakiza, 1999) that fungicides application is an integral part of potato late blight management.

Higher benefits of tolerant cultivar *Kenya sherekea* sprayed only thrice on different rates of fungicide demonstrated the importance of cultivar host resistance on fungicide application rates and frequency of spraying in the management of late blight. Whereas susceptible cultivar like *Dutch robjin* results in using increased rates of fungicides which results in high production costs. Resistant cultivars therefore provide an opportunity for reduced amounts of fungicide to control potato late blight which in agreement with the findings of (Clayton & Shattock, 1995). Low levels of disease in *Kenya sherekea* could be due to relatively high levels of horizontal resistance compared to *Dutch robjin*. This could be a very important aspect in integrated disease management in potatoes by farmers in an attempt to minimize fungicide usage in production. This was consistent with (Denitsa & Naidenova, 2005) reported on potato genotypes with low levels of resistance to late blight that it was possible to reduce the amount of fungicide required for adequate control by introducing varieties with increased levels of durable resistance.

The results are consistent to the documented research results for low input farming systems of the tropical highlands of Africa that have shown that high frequency of fungicide use and associated costs have resulted in enormous economic losses to small scale farmers (Nyakanga *et al*., 2003). Integration of host resistance in late blight management system could help small scale farmers reduce high rates of fungicide application hence significant economic benefits for resource constrained farmers in Kenya. Although this study shows that fungicides have the potential for increased growth and development, it depends on host resistance and application rates. This study suggests that if susceptible potato variety such as Dutch robjin has to be used, fungicide application rates have to be increased to effectively manage late blight.

4.5 Effect of fertilizer and fungicide application on Irish potato growth variables

Application of N:P:K 17:17:17 fertilizer treatments were found to have effects on potato growth variables but the level depended on the application of fungicide. At both sites in Molo and Egerton, application of N:P:K 17:17:17 fertilizer and Acrobat fungicide on Irish potatoes resulted to a significant change in height. Application of both fertilizer and fungicides was significantly ($P \leq 0.05$) effective on increase of potato height. Table 4. 11.

Table 4.11: Effects of N:P:K 17:17:17 fertilizer and Acrobat fungicide on height of potatoes at Molo and Egerton University.

Height (cm)							
		Egerton			Molo		
	Fertilizer KgHa $^{-1}$	0	90	135	0	90	135
	Fungicide g/l						
	0	20.11^{a}	22.76^{a}	25.7^{a}	22.11^{a}	23.76^{a}	26.70^{a}
47 DAE	2.5	22.64^{b}	25.60^{bc}	25.80^{ab}	25.14^{ab}	28.60^{ab}	28.30^{bc}
	3.5	22.77^{b}	23.88^{c}	24.95^{b}	26.27^{b}	27.28^{b}	28.05^{c}
	0	37.50^{a}	42.22^{a}	43.37^{a}	39.5^{a}	44.20^{a}	45.37^{a}
54 DAE	2.5	36.45^{a}	40.60^{ab}	42.80^{bc}	38.95^{ab}	42.60^{bc}	45.30^{a}
	3.5	38.20^{b}	39.33^{b}	41.31^{c}	41.7^{c}	42.8^{c}	44.80^{a}
	0	44.86^{a}	47.25^{a}	47.65^{a}	46.86^{a}	49.20^{a}	49.70^{a}
61DAE	2.5	43.28^{a}	44.99^{bc}	46.77^{b}	45.78^{ab}	47.09^{a}	49.27^{a}
	3.5	47.97^{b}	45.67^{c}	48.80^{a}	50.47^{c}	48.17^{a}	50.0^{a}

Means followed by the same letter in each column days after emergence are not significantly different at ($P \leq 0.05$)

DAE= Days after emergence

At both sites, timing was highly significant at ($P<0.05$) at 47,54 and 61 days after emergence. The interaction between fungicide rates and fertilizer rates of application was all the time not significant ($P>0.05$) but stem height increased with the time. At both sites, the treatment which received 135 KgHa $^{-1}$ of the total fertilizer rate at planting time and 3.5g/l of fungicides was the tallest while the treatment which received 0 KgHa $^{-1}$ of the total fertilizer rate and 0g/l of fungicide rate the shortest. The differences between sites in terms of means and grand means of stem height resulted from cool temperatures and high differences between day and night temperatures. Both factors delay crop growth and development, thereby lengthen Irish potato growth and bulking period. The results are in agreement with the findings of (Jones & Jacobsen, 2009) who emphasized the positive effect, on fertilizer use efficiency in general and Irish potato crop growth and yield in particular.

Table 4.12: The number of haulms as influenced by the interaction of N:P:K 17:17:17 fertilizer and Acrobat fungicide rates at Molo and Egerton University

Haulms (no)							
		Egerton			Molo		
	Fertilizer ($KgHa^{-1}$)	0	90	135	0	90	135
	Fungicide Rates						
47 DAE	0	3.25^{a}	5.08^{a}	5.8^{c}	4.6^{a}	6.07^{a}	6.85^{a}
	2.5	3.75a	5.25^{ab}	6.25^{ab}	4.65^{a}	6.30^{a}	7.0^{ab}
	3.5	3.58a	6^{b}	6.4^{a}	4.58^{a}	7.0^{b}	7.20^{b}
54 DAE	0	3.4^{a}	6.88^{a}	6.58^{a}	4.4^{a}	7.81^{a}	7.68^{ab}
	2.5	5.58^{b}	6.58^{ab}	7.5^{a}	7.20^{b}	8.58^{ab}	9.59^{a}
	3.5	5.08^{bc}	6.75^{b}	7.25^{b}	7.08^{bc}	8.65^{b}	9.30^{ab}
61 DAE	0	3.8^{a}	6.25^{a}	7.41^{ab}	5.50^{a}	8.30^{a}	9.50^{ab}
	2.5	7.5^{b}	7.66^{b}	8.25^{a}	6.50^{b}	9.90^{ab}	10.50^{a}
	3.5	5.75^{b}	7.33^{bc}	7.83^{ab}	7.75^{c}	9.20^{ab}	9.80^{ab}

Means followed by the same letter in each column days after emergence are not significantly different at ($P \leq 0.05$)

DAE= Days after emergence

Application of N:P:K 17:17:17 fertilizer and fungicide treatments resulted in a significant ($P \leq 0.05$) change in the number of haulms in potatoes in the two sites Table 4.12. Effects of fertilizer and fungicide combinations were effective at 47 DAE for 90 $KgHa^{-1}$ and 3.5g/l. Further effects were witnessed at 54DAE and 61 DAE when fertilizer and fungicide were combined. The highest number of haulms (10.5) were recorded at Molo for 2.5g/l of fungicide and 135kg/ha of fertilizer Table 4.12. The lowest number of haulms were recorded at application rates of 0kg/ha for fertilizer and 0g/l fungicide across all the days Table 4.12.

The results found were consistent with the findings of (Roy *et al.,* 2006) which recognized the role of N in branching- tillering phenomenon. The role of N availability as a factor influencing tillering has also been discussed by (Assuero & Tognetti, 2010). These authors suggested that N plays a strong mediatory role in tiller production through cytokinin production by roots, since production of this hormone is mediated by N concentration in the roots which, in turn, is a function of N absorption from the soil and seasonal reallocation of tissue N. In general, application of mineral fertilizer and fungicide had better values on plant physical growth as the rates of application of the treatments increased. The results confirm results obtained by (Moyin - jesu, 2007) who found out that mineral fertilizers are ready nutrients available for crops for development.

Table 4.13: Number of leaves as influenced by interaction of N:P:K fertilizer and fungicide rates at Molo and Egerton University

	Leaves (no)						
		Egerton			**Molo**		
	Fertilizer (KgHa $^{-1}$)	**0**	**90**	**135**	**0**	**90**	**135**
	Fungicide Rates						
	0	8.75^{a}	11.25^{a}	11.58^{ab}	9.50^{a}	12.0^{a}	12.56^{ab}
47 DAE	**2.5**	8.33^{a}	10.33^{b}	12.33^{a}	10.32^{b}	12.31^{bc}	14.32^{a}
	3.5	8.66^{a}	9.91^{c}	12.41^{a}	11.61^{c}	12.80^{c}	15.40^{a}
	0	10.41^{a}	12.33^{a}	12.50^{ab}	11.40^{a}	13.45^{a}	13.60^{a}
54 DAE	**2.5**	10.83^{b}	11.58^{ab}	13.58^{a}	13.70^{b}	14.56^{ab}	16.50^{b}
	3.5	10.66^{b}	11.66^{ab}	13.41^{a}	14.66^{c}	15.36^{c}	17.40^{c}
	0	11.83^{a}	13.75^{a}	14^{ab}	13.80^{a}	15.61^{a}	17.21^{a}
61DAE	**2.5**	12.58^{b}	13.25^{ab}	15^{a}	14.58^{bc}	15.30^{ab}	17.11^{a}
	3.5	12.25^{bc}	13.50^{ab}	15^{a}	14.21^{bc}	15.30^{ab}	17.40^{a}

Means followed by the same letter in each column days after emergence are not significantly different at (P≤0.05)

DAE= Days after emergence.

Interaction of fertilizer and fungicides rates had effects on leaves development across the sites with Molo site recording highest leaf number (17.40) Table 4.13. The latter was the highest mean number recorded at 135 KgHa $^{-1}$ of fertilizer and 3.5 g/l fungicide application rates.

Application of N:P:K fertilizer treatments was found to have effects on the number of leaves per plant but the level depended on the application of fungicide to control late blight to avoid defoliation of the leaves. The untreated plots recorded the lowest number of leaves per plant the two experimental sites at 8.75and 9.50 respectively Table 4.13. The timing of application of fertilizer (especially N) is an important factor which determines the rate of vegetative growth (leaves and branching) and canopy cover standing and structure. The key to plant growth and development depends on the establishment of vigorous and well developed root system, a strong and well-shaped branching achieved through adequate N:P: K and water supply in addition to solar radiation (Gathungu *et al*., 2000). Response to the treatments was evident in the experiment with Molo recording higher number of leaves per stem than Egerton due to climatic conditions and fertilizer nutrients. The results were in agreement to (White *et al*., 2007) who reported that nitrogen in the presence of adequate phosphorus and potassium stimulates canopy growth, leaves and branches.

Table 4.14 Effects of N:P:K 17:17:17 fertilizer and Acrobat fungicide interactions on the potato yield at Egeton University and Molo

Yield KgHa^{-1} at 120 DAP			
	Fungicide g/l		
Fertilizer(KgHa^{-1}) /	**0**	**2.5**	**3.5**
Egerton			
0	10.0a	16.8^{a}	19.3^{b}
90	9.1^{b}	13.1^{b}	19.7^{ab}
135	10.0^{ab}	20.5^{c}	23.3^{a}
Molo			
0	11.2^{a}	17.8^{a}	18.3^{a}
90	19.1^{b}	23.4^{b}	25.7^{b}
135	19.0^{c}	29.2^{c}	30.0^{c}

Means followed by the same letter in each column for each site are not significantly different at (P≤0.05)
DAP= Days after planting

Final tuber yield as tons per hectare as shown in Table 4.14 differed significantly($P \leq 0.05$) between fertilizer and fungicides-treated and untreated (control) since it ranged between 10.0 and 23.3 at Egerton University compared to 11.2 and 30.0 at Molo site. The highest yield was awarded to the treatment of fungicide and fertilizer rates of 3.5g/l and 135 KgHa $^{-1}$ respectively at both experimental sites. Although mineral fertilizer consistently proved to have a significant role on yield, it exposed the potatoes to late blight due to the effect on succulency of the whole plant. High tuber yield was obtained from plants that were treated with fungicide which had Dimethomorph 90g/Kg + Mancozeb 600g/Kg mixtures that were systemic and protective in nature. This suggests that compound mixtures are effective for blight control and can result in improved tuber yield under humid tropical conditions. This was in agreement to what (Namanda *et al*., 2004) reported that fungicides application considerably increased the yield of susceptible varieties and also, resistant varieties, but to a lesser degree. Generally, potato yields at Molo field were high compared to yield from Egerton University. This could be attributed partly to high soil fertility in the Molo field since green peas had been grown in the field prior to the study. This resulted in the luxurious growth of the crop and thus high yields, and relatively high blight incidence. It was therefore important to apply fungicide at different rates as the rates of fertilizer increased. The study's results are in agreement with the findings of (Waterer & Heard., 2003) who recommended split application of N, K (and even P if necessary) fertilizer and their closer placement to crop root system in order to optimize fertilizer use efficiency and maximize potato tuber yield.

Results on yield indicate that use of fertilizers increased yields as the rates of fertilizers increased between 0 and 135 KgHa $^{-1}$. This was dependent on better nutrient balance and varietal response to fertilizers hence in agreement with what (Sigh, 1997) research findings on organic manures and inorganic fertilizers on potato production. Yield gains per unit of fertilizer added were high from 0 to 135 KgHa $^{-1}$ of fertilizer provided that fungicides rates were also increased. This can be explained by the fact that on fungicide application, tuber sizes were improved, therefore reducing the proportion final yield. This was not a surprise because of these two fungicides rates, which gave the best control of the late blight disease. It was clear that increase in yield was correlated with decreasing in foliar late blight severity (Muhinyuza *et al*., 2008).

Table 4.15: Correlation analysis for the site, height, the number of leaves, the number of the haulms, fungicide, fertilizer and yield of irish potatoes in July – October, 2014.

	Site	Height	Number of leaves	Number of haulms	Fungicide	Fertilizer	Yield
Site	1						
Height	0.45**	1					
Number of leaves	-0.42	0.4	1				
Number of haulms	0.53**	0.31	0.24	1			
Fungicide	0.55**	-0.41	0.53*	-0.47	1		
Fertilizer	0.38	0.31*	-0.32	0.54**	- 0.47**	1	
Yield	0.61**	0.51**	0.40**	- 0.33	0.49**	0.39**	1

**, ** represent differences at 0.05 and 0.01 level of significance, respectively*

Results presented in Table 4.15 showed that total yield had significant (*P* = 0.01) and positive correlation with site (*r* = 0.61**), plant height (*r* =0.40**), fungicide (r = 0.49**) and fertilizer (*r* = 0.39**). These results indicate that total yield of potato depends on the site, the plant height, the number of leaves, fungicide and fertilizer. The positive relationship between number of leaves stem height and yield observed in this study stressed the importance of these parameters in the growth and the development of the crop as well as the degree of interdependence that exists between them. This relationship could be associated with the elevation of the amount of the fertilize applied signifying the importance of nutrients N, P and K for plant growth and development. According to (Babaji *et al.*, 2009), nutrients N, P and K have a major role in the increase in dry matter composition in plant and hence in leaf area. A similar study conducted by (Zamil *et al*., 2010) found that the tuber yield per hectare was significantly and positively correlated with plant height, foliage coverage, and number of stems per hill. sized tuber

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The two varieties were susceptible to late blight in favourable environments but the degree of susceptibility differed with the level of resistance, site and fertilizer rate. *Kenya shrekea* variety was tolerant to late blight than *Dutch robjin* under any rate of fungicide and fertilizer application. The N: P: K 17:17:17 fertilizers and Acrobat MZ fungicide application rates were effective in improving yields of potato when applied in combination.

Applications of fungicides had a significant deterrent effect on the development of late blight disease and a positive effect on growth characteristics and yield of the two potato varieties.

5.2 Recommendations

Fungicides and fertilizer application rates should be a key consideration on potato growing by farmers due to their significant effects on the yield at both Molo and Egerton sites.

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APPENDICES

Appendix 1: Thesis output - Publication

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Effects of Fertilizer and Fungicide Application Rates on the Incidence and Severity of Late Blight (*Phytophthora infestans*) on Irish Potatoes (*Solanum tuberosum* L)

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Abstract The effects of fertilizer and fungicide application rates have been demonstrated in the field on potato production. However, the fertilizer rates have not been tested fully to ascertain its effects on incidence and severity of late blight (*Phytophthora infestans*) on irish potatoes (*Solanum tuberosum* L). The objective of this study was to determine effects of N-P-K 17:17:17 fertilizer and Acrobat fungicide (Dimethomorph 90g/Kg + Mancozeb 600g/Kg) application rates on the incidence and severity of late blight on Irish potatoes. The experiment was conducted at Egerton University Field seven and Tumaini farm, in Molo Sub County. This was done in a randomized complete block design in a split split plot arrangement with Kenya sherekea and Dutch robjin potato varieties being used. The pathogen was isolated from infected leaves and tubers and identified in the laboratory. It was then used for in inoculation in the field. The treatments rates were N-P-K 17:17:17 fertilizer at 0, 90, 135Kg ha^{-1} and fungicide, Acrobat (Dimethomorph 90g/Kg + Mancozeb 600g/Kg) at rates of 0, 2.5, 3.5g/L. Each potato variety was sprayed with the fungicide three times in intervals of seven days at 47DAP, 54DAP and 61DAP. Fertilizer application was done at planting and 35 days later after emergence at equal splits. Data was collected on percent disease index (PDI) and disease severity index (DSI). Analysis of variance (ANOVA) was conducted and means separated using Tukey's test whenever ANOVA showed significant treatment differences. There was significant ($P \leq 0.05$) difference among the varieties, sites, fertilizer and fungicide levels for disease severity and incidence. The results showed that fertilizer and fungicide application rates had some effects on late blight development under field conditions depending on variety. Therefore fertilizers and fungicides should be used cautiously to reduce incidence and severity of potatoes to late blight.

Keywords: *fertilizer, phytophthora infestans, solanum tuberosum, fungicide*

Appendix 2: Mean squares for disease severity index (DSI) for treatments application 47, 54 and 61 days under field conditions

Source of variation	Df	DSI 1	DSI 2	DSI 3
Replicate	2	1.02	0.04	8.59
Site	1	61.01**	1586.00**	3544.01**
Variety	1	620.21**	183.80**	5727.18**
Site*Variety	1	6.11	2126.67**	1219.88**
Fungicide	2	30.85	15.91	169.67**
Site*Fungicide	2	0.24	59.38**	5.37
Variety*Fungicide	2	16.21**	39.39**	49.47**
Site*Variety*Fungicide	2	0.73	11.16	36.31
Fertilizer	2	40.81**	61.36**	200.29**
Site*Fertilizer	2	0.34	5.28	3.38
Variety*Fertilizer	2	11.62	4.63	62.54**
Site*Variety*Fertilizer	2	0.13	32.02**	19.1
Fertilizer *Fungicide	4	24.84**	21.45	104.70**
Site*Fertilizer*Fungicide	4	1.05	25.04**	6.07
Variety*Fertilizer*Fungicide	4	2.61	18.41	6.75
Site*Variety*Fertilizer*Fungicide	4	0.47	1.62	5.88
Error	70	3.73	9.95	15.25
CV		17.17	17.87	15.82

*, ** Significance at ($P \leq 0.05$) and ($P \leq 0.01$) respectively. DSI 1, DSI 2 and DSI 3 represent percent disease severity index at 47, 54 and 61 days after planting.

Appendix 3: Mean squares for experiment on percentage disease incidence (PDI) at 47, 54 and 61 days after treatment application and inoculation at Egerton University and Molo 2014.

Source of variation	Df	PDI 1	PDI 2	PDI 3
Replicate	2	5.84	4.95	6.41
Site	1	27.86	30.93	23.59
Variety	1	401.92**	14.09	147.27**
Site*Variety	1	15.35	177.18**	25.22
Fungicide	2	26.07**	1.05	33.45
Site*Fungicide	2	3.69	12.33	2.92
Variety*Fungicide	2	9.33	5.55	23.09
Site*Variety*Fungicide	2	3.43	15.81	3.15
Fertilizer	2	21.07**	4.37	21.15
Site*Fertilizer	2	0.21	8.401	11.47
Variety*Fertilizer	2	5.56	22.86	3.69
Site*Variety*Fertilizer	2	1.95	4.45	5.75
Fertilizer *Fungicide	4	10.44	3.81	8.85
Site*Fertilizer*Fungicide	4	3.14	4.45	13.55
Variety*Fertilizer*Fungicide	4	10.51**	8.6	5.28
Site*Variety*Fertilizer*Fungicide	4	0.48	18.65**	5.88
Error	70	3.77	6.01	5.6
CV		15.59	21.6	20.85

*, ** Significance at ($P\leq0.05$) and ($P\leq0.01$) respectively. PDI 1, PDI 2 and PDI 3 represent percent disease index at 47, 54 and 61days after inoculation

Appendix 4: Mean squares for potato height at 47, 54 and 61 days after treatment application and inoculation at Egerton University and Molo 2014.

Source	df	HGT 1	HGT 2	HGT 3
Replicate	2	9.17	0.03	1.72
Site	1	420.48**	25490.23**	15905.34**
Variety	1	6.12	72.03	246.73**
Site*Variety	1	2.58	30.72	31.41
Fungicide	2	16.08	19.67	18.53
Site*Fungicide	2	9.34	9.19	0.08
Variety*Fungicide	2	3.95	5.46	22.84
Site*Variety*Fungicide	2	1.23	4.43	1.09
Fertilizer	2	92.9	242.60**	173.68
Site*Fertilizer	2	26.33	147.7	234.48**
Variety*Fertilizer	2	3.37	6.57	11.39
Site*Variety*Fertilizer	2	1.02	6.03	13.73
Fertilizer *Fungicide	4	9	14.25	17.53
Site*Fertilizer*Fungicide	4	9.1	23.16	16.63
Variety*Fertilizer*Fungicide	4	1.94	23.35	12.39
Site*Variety*Fertilizer*Fungicide	4	3.14	15.94	4.92
Error	70	26.82	35.63	35.2
CV		2.06	14.85	12.99

*, ** Significant at ($P \leq 0.05$) and ($P \leq 0.01$) respectively.

Appendix 5: Mean squares for potato leaves at 47, 54 and 61 days after treatment application and inoculation at Egerton University and Molo 2014.

Source of variation	Df	LEAF1	LEAF 2	LEAF3
Replicate	2	6.56	5.78	2.23
Site	1	4.08	75**	243**
Variety	1	0.08	2.37	1.81
Site*Variety	1	1.12	1.81	0.33
Fungicide	2	0.45	0.58	1.95
Site*Fungicide	2	0.36	0.58	1.19
Variety*Fungicide	2	1.19	0.01	0.40
Site*Variety*Fungicide	2	0.18	1.56	2.68
Fertilizer	2	112.29**	57.52**	53.81**
Site*Fertilizer	2	33.08**	20.52**	7.11
Variety*Fertilizer	2	1.36	0.45	0.25
Site*Variety*Fertilizer	2	1.45	2.23	3.11
Fertilizer *Fungicide	4	4.12	3.03	2.24
Site*Fertilizer*Fungicide	4	3.28	1.52	0.76
Variety*Fertilizer*Fungicide	4	0.22	1.93	2.30
Site*Variety*Fertilizer*Fungicide	4	3.18	0.48	1.31
Error	70	2.59	2.82	2.64
CV		15.48	14.11	12.07

*, ** Significant at ($P \leq 0.05$) and ($P \leq 0.01$) respectively

Appendix 6: Mean squares for potato tillers at 47, 54 and 61 days after treatment application and inoculation at Egerton University and Molo 2014.

Source	Df	TIL 1	TIL 2	TIL 3
Replicate	2	21.67	17.06	19.51
Site	1	436.01**	225.33**	176.33**
Variety	1	12.68	17.92	17.93
Site*Variety	1	7.79	1.33	0.15
Fungicide	2	3.31	12.40	13.62
Site*Fungicide	2	0.95	0.25	1.36
Variety*Fungicide	2	0.68	0.34	0.73
Site*Variety*Fungicide	2	66.95**	0.52	1.18
Fertilizer	2	42.84**	92.06**	96.73**
Site*Fertilizer	2	2.51	8.53	3.69
Variety*Fertilizer	2	0.175	10.40	2.79
Site*Variety*Fertilizer	2	0.66	4.86	5.67
Fertilizer *Fungicide	4	3.46	2.59	3.20
Site*Fertilizer*Fungicide	4	4.91	4.03	2.47
Variety*Fertilizer*Fungicide	4	1.27	5.31	4.93
Site*Variety*Fertilizer*Fungicide	4	2.81	2.97	2.29
Error	70	33.21	2.98	3.11
CV		17.17	29.73	27.02

*, ** Significant at ($P \leq 0.05$) and ($P \leq 0.01$) respectively