Critical shoot Nitrogen curve for potato varieties Asante and Tigoni in Kenya

By

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DECLARATION

I Mugo James Njeru declare that this thesis is my original work and has not been presented for a degree in any other University.

Sign: .... Date: ....

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This thesis is submitted with our knowledge as supervisors from Meru University of Science and Technology and International Potato Centre (CIP)

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Dedication

I dedicate this work to my dearest wife Judy Mwikali, my daughter Nicole and my brothers and sisters, for their continuous support and prayers to see me through. I also dedicate it to all my lecturers and friends, most especially those of the MSc Research Methods Program and CIP potato team Nairobi.

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Abbreviations and Acronyms

CAN	Calcium Ammonium Nitrate
CIP	International Potato Center
DAP	Di Ammonium Phosphate
DM	Dry Matter
FAO	Food and Agriculture Organization
Ha	Hectare
K	Potassium
Kg	Kilo grams
N	Nitrogen
N_2O	Nitrous Oxide
NNI	Nitrogen nutrition index
NPK	Nitrogen Phosphorous Potassium
P	Phosphorous
P_2O_5	Phosphorous Oxide
PLRV	Potato leaf roll virus
PVY	Potato virus Y
SPAD	Soil Plant Analysis Development

Abstract

Potato is a major crop in Kenya with its production area increasing as a result of people opting for potatoes than other crops. The production is however lower than what is expected due to several challenges, among them being low fertility, diseases and inadequate certified seeds. Nitrogen as one of the major plant nutrients has a greater influence in potato yields as well as the quality. Critical nitrogen dilution curves have been used as a precise method of managing nitrogen fertilization in farms. Use of chlorophyll meters is also increasing due to its ease in taking measurements. A survey with specific objectives of determining potato nitrogen status in the farmer's field along Mau and West Aberdares potato growing gradients in Kenya. A field experiment with the aim of developing critical nitrogen dilution model for potatoes varieties Asante and Tigoni in Kenya, and determining the relationship between the total shoot nitrogen concentration and the chlorophyll content (SPAD index) in potatoes.

The survey was carried out during long rains of 2012 in two transect in the rift valley and it involved administering a questionnaire and collecting of soil and leaf samples. Field experiments were conducted in a split plot design at the university of Nairobi farm during the short and long rains season of 2012 using potato varieties Asante and Tigoni with four nitrogen fertilizer levels (0, 45, 90, 135 N kg/ha).

The survey revealed that majority of farmers (78%) use fertilizers but in levels lower than the recommended for Nitrogen. The critical nitrogen dilution model established is $N_c = 5.8W^{-0.16}$ for variety Tigoni and $N_c = 6.4W^{-0.18}$ for variety Asante with r^2 of 0.41 and 0.50 respectively. A linear relationship between shoot nitrogen content and the SPAD index was established for the two seasons with r^2 of 0.45 and 0.51. It can thus be recommended for extension service provider to use the tools in helping the farmers to apply adequate fertilizer in their crops.

CHAPTER 1

1.0 General Introduction

Potato (*Solanum tuberosum* L.) is the second most important food crop in Kenya in terms of bulk harvested. It is also an important staple and cash crop for smallholder farmers in the Kenyan highlands (Ogola, et al., 2011). There has been a slight increase in potato production in recent years. This is mainly due to the growth in population but also due to a diversification of crops to areas with favorable climatic conditions where maize has been the main crop (Ogola et al., 2011). Thus Kenya is classified as a potato growing country with a high potential (Ogola et al., 2011). Potato production in Kenya is concentrated in the highlands (1500-3000m) of Central, Eastern and Rift valley provinces (Kaguongo et al., 2008, FAO, 2008). Based on geographic location, production practices and variety preferences potato growing areas are divided into five regions which include; Mt. Kenya, mainly comprising of Meru Central, parts of Nyeri and Laikipia districts; Aberdares and Eastern Rift Valley, mainly comprising of Kiambu, Nakuru, Nyandarua and parts of Nyeri; Mau, comprising of Bomet, Narok and parts of Nakuru district; Mt. Elgon, comprising of Keiyo and Marakwet districts; and lastly other highlands, such as Taita in Taita Taveta in the southern border (Kaguongo et al., 2008, Kirumba et al., 2004).

Among potato production system in Kenya, Di-ammonium Phosphate (DAP) is the most commonly used type of fertilizer followed by Calcium Ammonium Nitrate (CAN) and compound fertilizer (NPK). Some farmers do not use fertilizer (Kaguongo et, al. 2008). Low fertilizer application is the major fertilizer challenges in potato production in Kenya.

Potatoes as shallow rooted crops need a high level of nitrogen to ensure acceptable yield (Darwish et al., 2006, FAO, 2008). Nitrogen (N) is among the most abundant elements on earth, it is also the major element limiting growth of plants in many agricultural systems because of its unavailability for plants and also due to the leaching effects (Vance, 2001). Due to this a lot of fertilizer is applied for improved production in most areas of the world. There are several nitrogen recommendations for various crops around the world. In the tropics, nitrogen requirement for most crops ranges from 50 to 80 kg/ha. The recommended fertilizer rate for nitrogen in Kenya is 90 N kg/ha (Kaguongo et al., 2008).

Nitrogen management, rate and timing of application are critical factors in optimizing potato tuber yield and quality (Haase et al., 2006, Poljak et al., 2007). Excessive use of nitrogen fertilizers contributes substantially to environmental pollution (Deutsch et al., 2006; Umar and Iqbal, 2007). It also affects the balance of the nitrogen cycle in soils, and has contributed to global warming because of gaseous loss as nitrous oxide (N_2O) into the atmosphere (Smith et al., 2003). Nitrogen management is a major factor to consider for better productivity. To test whether there is enough nitrogen available to the plant, nutrient analysis can be done on the crop itself or from the soil. Crop-related indicators can be classified mainly into three i.e. nitrate concentration, optical methods, or total N concentration. The concept of the critical N concentration which is defined as the minimum concentration of N necessary to achieve maximum above ground biomass, at any moment of vegetative growth was developed by Lemaire and Salette (1984). This critical N concentration is represented by a power equation 1.

$$N_c = aW^{-b} \qquad (1)$$

where W is the total shoot biomass expressed in g/plant, N_c is the total N concentration in shoot biomass expressed as a percentage of the shoot dry matter, and *a* and *b* are estimated parameters. *a* represents the N concentration in the total shoot biomass for 1g DM/plant, and the parameter *b* represents the coefficient of dilution describing the relationship between N concentration and shoot biomass.

It requires time consuming measurement procedures and destructive plant sampling at a precise growth stage (Lorene and Jeuffroy, 2007). Correlations between plant growth parameter which can easily be measured in the field and the critical nitrogen content would aid the farmers on when to add fertilizers. The chlorophyll meter is a more convenient, leaf clip-on device that determines the relative amount of chlorophyll present in plant leaves and this is related to the nitrate concentration in the plant (Lorene and Jeuffroy, 2007). Also closely related method is the plant petiole sap test for the nitrate content. Other methods to diagnose the nitrogen status are also being used such as aerial imagery and remote sensing.

1.1 Problem statement

As the world aims at achieving food security, potato farming is one way that Kenya can achieve food security. This means moving away from the overdependence on maize as the main crop. In Kenya potato ranks the highest horticultural crop in terms of hectares accounting for about 120,000 hectares and producing around 800,000 tonnes annually (FAO, 2005) this indicate a national production of 7 tons/ha against potential yield of about 40 tons/ha (FAO, 2008). The low productivity observed in Kenya is as a result of low quality seed, diseases, inadequate fertility management and poor crop husbandry (Muthoni and Nyamongo, 2009, Kaguongo et al., 2008). Low soil fertility and repeated planting in same sites is a major constraint to potato production in most parts of the country (Powon et, al., 2006). Other challenges are insect pests and diseases. Farmers use cattle manure as well as inorganic fertilizers like di-ammonium phosphate (DAP) and N.P.K (Muthoni and Nyamongo, 2009). To aid in fertilizer management there is the need to know the amount to apply to avoid under or over application. Plant-based diagnostic methods of N deficiency could be used as a prior diagnosis aimed at optimizing fertilizer N management to increase the economic crop return and minimize potentially negative effects on the environment. The extent of N emissions can often be reduced substantially by appropriate fertilizer application regimes (Janzen et al., 2003). There is no critical nitrogen dilution models developed for potato varieties grown in Kenya. The models will assist in fertilizer management in the country.

1.2 Justification

Potato is an important horticultural crop worldwide used as human food as well as animal feed. In many parts of Kenya potatoes are an important food and cash crop, thus increase in potato 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.

Fertilizer application has important effects on the quality and yield of potato (Westermann, 2005). Potato can absorb large quantities of plant nutrients, especially nitrogen (N), phosphorus (P), and potassium (K), from the soil during the growing period. An optimum dose of fertilization should be applied in order to obtain an economically optimal yield of potato. Inadequate or excess usage of fertilizers reduces tuber yield and quality.

To aid in optimum application of fertilizes it is good to apply the fertilizers in relation to the critical nitrogen dilution curve. A mechanistic understanding of the interactions between available nitrogen, plant nitrogen content and plant productivity will help to quantify crop N-demand under specific environmental and agronomic conditions. This knowledge will assist the development of fertilizer recommendations and may thereby help to avoid both the environmental risks of excess rates of fertilization and also the effects of N-deficiency in crops (Alt et al., 2000). The relationship between total nitrogen concentration and plant factors such as chlorophyll content for varieties grown in Kenya will assist in nitrogen diagnosis in the field.

1.3 Objectives

1.3.1. The main objective was to establish critical nitrogen dilution curve for potato varieties Asante and Tigoni in Kenya and relate the total shoot nitrogen concentration to the SPAD index in the leaves.

1.3.2. Specific objectives

1) To determine potato nitrogen status in the farmers field along Mau and West aberdares potato growing gradients in Kenya.
2) To develop critical nitrogen dilution model for potatoes varieties Asante and Tigoni in Kenya
3) To determine the relationship between the total shoot nitrogen concentration and the chlorophyll content (SPAD index) in potatoes.

1.4 Research Questions

The major research questions dealt with are;

1. What is the potato nitrogen status in farmer's field along Mau and West Aberdares potato growing gradients in Kenya?
2. What is the critical nitrogen dilution model for potato varieties Asante and Tigoni in Kenya?
3. Is there a relationship between total nitrogen concentration and SPAD index for potatoes

1.5 Hypothesis

H0: Potato nitrogen status in farmer's field along Mau and West aberdares are adequate

H1: Potato nitrogen status in farmer's field along Mau and West aberdares are low or high than adequate status.

H0: There is no nitrogen dilution in potato varieties Asante and Tigoni grown in kenya

H1: There is nitrogen dilution in potato varieties Asante and Tigoni grown in kenya

H0: There is no relationship between total shoot nitrogen concentration and chlorophyll content in potatoes

H1: There is relationship between total shoot nitrogen concentration and chlorophyll content in potatoes

CHAPTER 2

2.0 Literature review

2.1 Origin and distribution of potato

Potato crop (*Solanum tuberosum L.*) is an annual herbaceous dicotyledonous plant with underground stems that give rise to tubers and originated in the highlands of the Andes in South America(Lisinka and Leszcynki, 1989). Potatoes are currently produced in large quantities and consumed worldwide with China as the leading producers. In Africa Egypt is the leading potato producer. Kenya is among top potato producer in Africa (FAO, 2011). They were introduced in Kenya by the European settlers in the nineteenth century. Potatoes belong to the family *Solanaceae* and the specie *tuberosum*.

2.2 Importance of potato

Potato has a high potential to contribute to poverty reduction, food and nutritional security. The crop is second most important food crop in Kenya after maize (Ogola, et al., 2011). It is an important source of revenue, employing more than 2.5 million people in potato farming activities across the entire potato production chain. Initially they were subsistence crop but it's now becoming a major cash crop as it is a highly preferred food in urban areas where consumption is increasing rapidly (Cromme et al., 2010, Gildemacher et al., 2009, Kaguongo. 2009). Industrial demand is also rising rapidly, for the time being mainly satisfied by imports from outside the country. Apart from its contribution to rural food security, the potato is a dynamic cash crop with a high market potential. It has also been observed that during food crisis of 2007/08, potato and other roots and tuber crops prices fluctuated much less than prices of major cereals (Hoffler and Ochieng, 2008).

2.3 Potato production

Potato production in Kenya is concentrated in the highlands (1500-3000m) of Central, Eastern and Rift valley provinces (Kaguongo et al., 2008, FAO, 2008). These areas are characterized by high population densities, farms are small and agricultural productivity is challenged to meet the demands of the growing population (Lutaladio, 1995). In large commercial operations mono cropping is done and potatoes are usually rotated with other crops but most small scale farmers intercrop potatoes with maize, bean among other crops (Lutaladio, 1995; Nyankanga, 2004). The ability of potato to grow in the high altitude areas where maize does not do well and its nutritive value makes it an important food and cash crop for people living in these areas. The average yield achieved by the small-scale farmer is approximately 6 to 7 tons per hectare. Large-scale farmers generally achieve higher yields, approximately 10 to 14 tons per hectare (Gildemacher et al. 2009, Schulte-Geldermann et al. 2010, Muthoni and Kabira, 2010).

2.4 Constraints to potato production

2.4.1 Potato seed

There is inadequate supply of certified seeds thus farmers almost solely depend on informal seed sources (own farm, local markets or neighbors). Own farm seed is the major source of seed for most farmers (Kaguongo et al., 2008). The accumulation of seed-borne diseases in own farm saved seed potatoes used for several cropping cycles causing severe degeneration (Gildemacher et al. 2007). 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). Cost of certified seed has also led to farmers using own farm seed.

2.4.2 Potato diseases

Bacterial Wilt and Potato Late Blight are the major dieases in potato production. *Ralstonia solanacearum* the causal agent of Bacterial Wilt, has the ability to survive in soil, water bodies and other host plants and can cause yield losses of 20-70% (Kinyua et al. 2001, Lemaga et al. 2005, Otipa et al.,2003, Pirou et a., 2007). In all potato growing districts, bacterial wilt is regarded as an important disease contributing to yield reduction (Kaguongo et al., 2008, Otipa et al., 2003). Crop rotation can reduce the incidences and increase potato yields by 230 to 370% (Pirou et al., 2007) however small farming areas hinder this.

Potato Late Blight which is an airborne mold, is caused by the oomycete (fungus-like) pathogen *Phytophthora infestans,* can cause annual global losses estimated to be between US$ 3 and 5 billion (Judelson and Blanco, 2005). In Kenya farmers suffer from a tremendous breakout of the disease at germination and first leaf formation (Schulte-Geldermann et al., 2010).

Other common diseases in potato production system are the viruses caused by Potato virus Y (PVY) and Potato leaf roll virus (PLRV). Losses of 85% and 72 % have been reported for Potato virus Y (PVY) and Potato leaf roll virus (PLRV) respectively if the crop is recycled to the 5th generation (Rahman et al., 2010).

2.4.3 Soil fertility

Low soil fertility and repeated planting in same sites is a major constraint to potato production in most parts of the country (Powon et, al., 2006). Inefficient use of organic matter, farm manure, insufficient plant nutrition and soil nutrient mining are described as major management problems in maintaining soil fertility (Gildemacher et al. 2009, Lemaga et al., 2005, Labarta et al. 2011). Farmers use cattle manure as well as inorganic fertilizers like di-ammonium phosphate (DAP) and N.P.K (Muthoni and Nyamongo, 2009). Only less than 15% of the farmers use recommended fertilizer rates in potato production systems in Kenya, the rest use either less than the recommended rates or no fertilizer at all which can be attributed to factors such as the high cost of fertilizer, lack of soil testing facilities and farmers' educational levels (Ogola et al., 2011)

2.5 Potato nitrogen requirement

Proper N management is one of the most important factors required to obtain high yields of excellent quality potatoes. Potato crop N requirement is normally based on potato variety and planting date (Bernie et al, 2007). Potatoes also have low uptake efficiency of nitrogen which is due to the shallow root system; this means nitrogen present in soil layers deeper than 50 cm is poorly available to the potato crop (Olivier et al., 2006). Moreover, as potato crop is considered to have a high N needs. Secondly as a result of potatoes being a shallow-rooted crop and requiring well-drained soils, makes water and N management difficult since nitrate is susceptible to leaching losses.

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). This shows the recommendation for nitrogen is around the range of 80 to 90 Kg N/ha. 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). An earlier study in Nakuru region indicated most farmers prefer DAP to N.P.K (Kaguongo et al., 2008). In a field experiment set up to investigate the effects of different sources of nitrogen on potato at Tigoni area in Kenya for varieties Tigoni and Asante, NPK (20:20:20) at the rate of (90 kg N/ha) gave the highest yields of 86 and 62 t/ha (Muthoni and Kabira, 2011).

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, Gathungu et al., 2000). Average plant height of 88.4 cm, average of 22 leaves per plant as well as average of 13 shoot have been achieved in research (Yassen et al., 2011). Potato leaf area index at various growth stages differ with different N sources and time of application. Shoot dry mass increases between 21 and 49 days after emergence and decreases at 70 days after emergence (Gathungu et al., 2000). 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 and Kabira, 2011). Root dry mass and tuber dry mass increases with growth in potatoes (Gathungu et al., 2000). The total dry weight per plant reported by Gathungu et al (2000) is 60 grams per pant.

The application of nitrogen fertilizer in potato has positive effect on the yield. Tuber size, weight and total tuber yield increase with nitrogen application (Yassen et al., 2011). Specific gravity which is considered as an important quality character particularly for chips and flour making industries reduces with increasing rate of N application. High specific gravity of 1.071 was recorded with application 200 kg N and the low specific gravity of 1.062 with application of 250 kg of N (Yassen et al., 2011). On the quality of the potatoes, nitrogen has been reported to increase the protein content (Öztürk et al., 2010). Excess soil N late in the season can delay maturity of the tubers and result in poor skin set, which harms the tuber quality and storage properties (Davis et al., 2009).

2.6 Diagnosis of Nitrogen status

There are several plant growth parameters that farmers can use in the farm for nitrogen management, such as plant height, the greenness of the plants among others. The use of greenness (chlorophyll content) of the plants in nitrogen status determination has led to development of several chlorophyll meters. For example N tester, atleaf chlorophyll meter and Soil plant analysis development (SPAD) chlorophyll meter. SPAD has been tested as alternative to the nitrogen nutrition index (NNI) (Lorene and Jeuffroy, 2007, Tremblay et al., 2011).

Chlorophyll meter is a more convenient, leaf clip-on device that determines the index of greenness present in plant leaves. The greenness is related to the chlorophyll content in the plant leaves. Several factors affect greenness index readings when using chlorophyll meters. Some crop varieties are greener than others and will have higher readings. Stage of growth and environmental factors also affects the readings. The age of leaf on which to clip on the meter matters since older leaves tends to be less green than the young leaves. The readings must be calibrated for the variety and other environmental factors in order to be useful (Lloyd et al., 1997).

Studies by Lorene and Jeuffroy, 2007 have shown non-cultivar-dependent exponential relationship between the SPAD index and NNI at flowering, with an R squared (r^2) equal to 0.89 for wheat. This implies that the SPAD chlorophyll meter can be used as an alternative to NNI to measure N status in wheat.

Other diagnostic tools for nitrogen have also been tested. They include those that consider the canopy of a plant or few plants (portable radiometers) or even measure areas, such as a field, a farm, or a region (aerial photography) (Giorgio et al., 2011, Tremblay et al., 2011). Some of the methods for nitrogen diagnosis during the vegetative period of the plant are expensive to be used by many farmers.

2.7 Critical nitrogen dilution models

Modeling has been used in agriculture to create models used to explain the various plant processes as well as the cropping systems. Crop models have many current and potential uses for answering questions in research, crop management, and policy (Boote et al., 1996). They can assist in pre-season and in-season management decisions on cultural practices such as fertilization, irrigation, and pesticide use. Simulation models are applied at different application levels and there are several simulation models concerning nitrogen dynamics in soils and the plant. Use of models depends on whether the model is appropriate to answer the question and whether it is tested in diverse environments. Both complex and simple models are important but care should be taken to ensure adequacy and practicability of the model (Boote et al., 1996).

Crop N status throughout the growing season of crops has been modeled and the mostly used model is the nitrogen dilution curve. These concept of the critical N concentration which is defined as the minimum concentration of N necessary to achieve maximum above ground biomass, at any moment of vegetative growth was developed by Lemaire and Salette (1984). This concentration is represented by a power equation (equation 1).

Critical N curve has been used to determine the plants' N requirements and to calculate the Nitrogen Nutrition Index (N.N.I.) which quantifies the nitrogen status of the plants (Lemaire et al., 1989). N.N.I as a diagnostic tool of nitrogen status of crops can be calculated as (equation 2)

$$NNI = \frac{N_c}{N_t} \qquad (2)$$

Where N_t is the total N concentration measured in the aerial parts and N_c is the critical N concentration for the same biomass. The nitrogen nutrition index (NNI) is a precise indicator of nitrogen status. However, it requires a lot of time for destructive plant sampling and laboratory N analysis (Goffart et al., 2008). Moreover, it does not provide actual recommendation for supplemental N application. Its major interest is that it can be used as a reference to calibrate other quicker and simpler methods dedicated to crop N status assessment.

Critical nitrogen curves have been established for several crops such as tomato (Tei et al., 2002), corn (Ziadi et al., 2008), grain sorghum (Van Oosterom et al., 2001), annual ryegrass (Marino et al., 2004), and cotton (Xiaoping et al., 2007). Critical nitrogen dilution curves for potato have previously been determined but there are variations between varieties (Belanger et al., 2001). Under non-limiting water conditions they reported $N_c = 4.57W^{-0.42}$ for Russet Burbank variety and $N_c = 5.04W^{-0.42}$ of Shepody variety.

There is a research gap on critical dilution curves since no experimental trials to establish critical dilution curve have been reported in Africa. The amount of nitrogen fertilizer to be added in reference to the critical nitrogen is not known since it just describes adequacy of nitrogen.

Critical nitrogen curve needs to be established for varieties and be used as reference. Conducting this experiment in Kenya potato growing areas would allow the use of the critical nitrogen dilution model by farmers in Kenya for the varieties they grow.

CHAPTER 3

3.0 potato Nitrogen status in farmers field along two potato growing gradient in Kenya

Abstract

Potato is a major crop in the Kenya with its production area is increasing as a result of people opting for potatoes than other crops. The production is however lower than what is expected due to several challenges, among them being low amount of fertilizer, diseases and inadequate certified seeds. A survey was conducted to determine potato nitrogen status in the farmers' field along Mau and West aberdares potato growing gradients in Kenya. The survey revealed that majority of farmers (78%) use fertilizers but in rates lower than recommended rates for Nitrogen. Nitrate analysis on potato leaves showed that 42% of the farms had insufficient level of Nitrogen on potato leaves and adequate levels of nitrate in most soils from the sampled areas. In conclusion there is inadequate fertility rate in potato farmer's fields.

3.1 Introduction

Potato is the second most important food crop in the country and is now being considered by the Ministry of Agriculture as a possible alternative crop to maize which is having problems with lethal virus necrotic disease (Abong' and Kabira, 2013.The crop plays a major role in food security, alleviation of poverty through income generation and employment creation. 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 (Cromme et al., 2010).

Average farm production of 6.7 ton/ha is far below the expectation in terms of productivity and quality. These low yields have been attributed to the low or inappropriate application of inputs like clean seeds, fertilizers and fungicides for the control of the major potato diseases of late blight and bacterial wilt (Kaguongo et al., 2008). The low use of inputs is mainly as a result of low income levels and inadequate knowledge on potato management as only about 20% of potato farmers have received agricultural training.

Potato farmers in Kenya generally do practice crop rotation as a means of disease control and fertility management but the crop rotation is not always effective as some of them only do the rotation after growing the potato crop twice and do not weed the volunteer crop. Previous studies in Kenya have shown fertilizers are usually applied below the recommended rate (90 kg N /ha and 230 kg P_2O_5 /ha) for potato production (Kanguongo et al., 2008). Timing of fertilizer application is also important in potato systems. Foliar applications are being used in the country together with the fungicide applications for late blight control.

This survey was conducted to find out whether there were fertility management changes among potato farmers. The specific objective was to determine potato nitrogen status in the farmers' field along Mau and West aberdares potato growing gradients in Kenya. The research aimed at answering the following questions; (1) is the soils in Kenya having nitrogen fertility levels that can support potato production? (2) Are the potato plants nitrogen status indicating adequate nutrient? (3) Are Kenyan farmers using sufficient nitrogen fertilizers to the potato crops?

3.2 Materials and Methods

3.2.1Survey sites

Sampling areas were along two gradients in major potato growing areas in Rift valley. The areas were randomly selected among the potato growing regions. Each gradient had a region of higher, middle and low altitude areas where potatoes are grown. The first gradient was Mau where sampling was done in Narok -1400m, Bomet – 2000m and Molo – 2500m, while the second gradient was West Aberdare which included Naivasha – 1700m, Kinangop – 2500m, and Oljoro Orok – 3000m.

3.2.2 Sampling and sample size

Purposive sampling was done to select the districts where potatoes are grown and farmers growing potatoes. The sample size was influenced by cost where ten farmers were sampled from each of the areas above at an approximate distance of 10 kilometers from one farm to the other. The sample size represented approximately 0.05% of potato farmers in the areas. The farmers selected were farmers with potato crop in the field and the crop was in the vegetative stage. The survey was conducted through administration of questionnaires (appendix 1) to collect the information on farm practices.

3.2.3 Plant and soil sampling and analyses

Soil was sampled at the depth of 30cm using a soil auger and packed in polythene sampling bags which were stored in ice cool box. Plant leaves were sampled from third developed leaf from ten randomly selected plants and preserved in ice cool box. Nutrients analyses were conducted at Crop Nutrition Laboratories in Nairobi. The analysis involved total nitrogen for the leaf samples and nitrates and ammonium for the soil samples. The procedures for the analysis were obtained from laboratory manual by Okalembo et al., (2002) and were as follows:

Procedure for Nitrogen determination in plant tissue

0.3g of oven dried ground leaves was weighed into a test tube. 4.4 ml digestion mixture was added and 2 blank reagents. Digestion mixture contained selenium powder, lithium sulphate, hydrogen peroxide and sulphuric acid. Digestion was done for 2 hours at 360 ^{0}c (until solution was clear). The test tube were allowed to cool then 25 ml distilled water added and shook until all sediment were dissolved then topped to 50 ml. The 50 ml of digest was pipette to 500ml kjeldahl flask then added 200ml distilled water and 2 beads. Holding the kjeldahl at an angle of 45, 25 ml of sodium hydroxide was gently added and then distilled. The distillate was titrated with 0.01 sulphuric acid until it turned pink. Calculation of % N (equation 3)

$$\% N = \frac{\text{Ml acid} * 5 * 0.14 * 100}{\text{weight of plant tissue (mg)}} \tag{3}$$

Colorimetric for ammonium determination in soil

Soil extraction; 10 g of freshly sampled soil was weighed into a shake bottle. Then 100 ml of 0.5 M potassium sulphate added then the content shaken for 1 hour. It was filtered with number 5 whatman filter paper

Standards; 0, 5,10,15,20 and 50 ml of standard solution (100ppm NH_4^+) was pipetted into a volumetric flask and topped up to 100ml using 0.5 M potassium sulphate. 0.2 ml of sample extract, the blank and standard solution was pipetted into separate labeled test tube and reagent 1 added and left to stand for 15 minutes. Reagent 1 contained 34g sodium salicylate, 25 g sodium citrate and 25 g sodium tartrate into 750 ml water, then 0.12 g sodium nitroprusside added and topped to 1litre of water. 5 ml of reagent 2 was then added. Reagent 2 contained 30g sodium hydroxide into 750 ml water, and then 10 ml sodium hydrochlorite added and topped up to 1 litre. It was left for 1 hour after which absorbance was measured at 655 nm. Plotting of the calibration curve and reading of the concentration of ammonium nitrogen was done. Calculation of the concentration of ammonium nitrogen from oven dried soil (equation 4)

$$ammonium(ppm) = \frac{(a-b) * v * MCF * f * 1000}{w} \tag{4}$$

Where a= concentration of N in solution, b = concentration N in blank, v= volume of extract, w = weight of fresh soil, f = dilution factor and MCF = moisture correction factor

Colorimetric for Nitrate determination in soil

Standards; 0, 2, 4, 6, 8, and 10 ml of stardard solution was pipetted into separate volumetric flasks then filled to 100ml mark with 0.5 M potassium sulphate. 0.5 ml of sample extract, the blank, and standard solutions were pipetted into different labeled test tubes and 1 ml salicyclic acid added, was mixed well given 30 minutes.10 ml of 4M sodium hydroxide was added and mixed well then left for 1 hr. Absorbance was measured at 419 nm. Plotted calibration curve and calculated absorbency for a particular standard series, read off the values of the samples and the blank calculation (equation 5)

$$nitrate\ (ppm) = \frac{(a-b) * v * MCF * 1000}{w} \tag{5}$$

Where a= concentration of N in solution, b = concentration N in blank, v= volume of extract, w = weight of fresh soil, and MCF = moisture correction factor

3.2.4 Data analyses

Cspro 4.1 was used for entry of data collected using the questionnaire and Ms excel flat file for sample analysis data. The collected data and sample analysis data were subjected to Statistical analysis using Genstat 13 edition. The percentages of crops grown and their corresponding area data were calculated then presented in a pie chart. Frequencies of potato varieties grown by farmers in each area were calculated and presented in a bar graph. The percentages of number of farmers using fertilizers and those using manure as well as the fertilizer type they use was calculated and the results presented in tables. Amount of fertilizer used were grouped into three levels of adequacy and their percentages plotted in a bar graph. The nitrogen concentration from the leaves samples was also grouped into three groups of adequacy and the frequencies presented in a bar graph. Analysis of variance was carried out for the nutrient data of the samples with the areas being used as the block.

3.3 Results

3.3.1 Potato growing status in Kenya

The study established that farmers grow other crops alongside potatoes. The crops were mainly grown in a mixed cropping system though some had intercropping especially maize and potatoes. Wheat, Maize, and potatoes are the major economic enterprises. A number of other horticultural crops are also grown but in small scale (Figure 1).

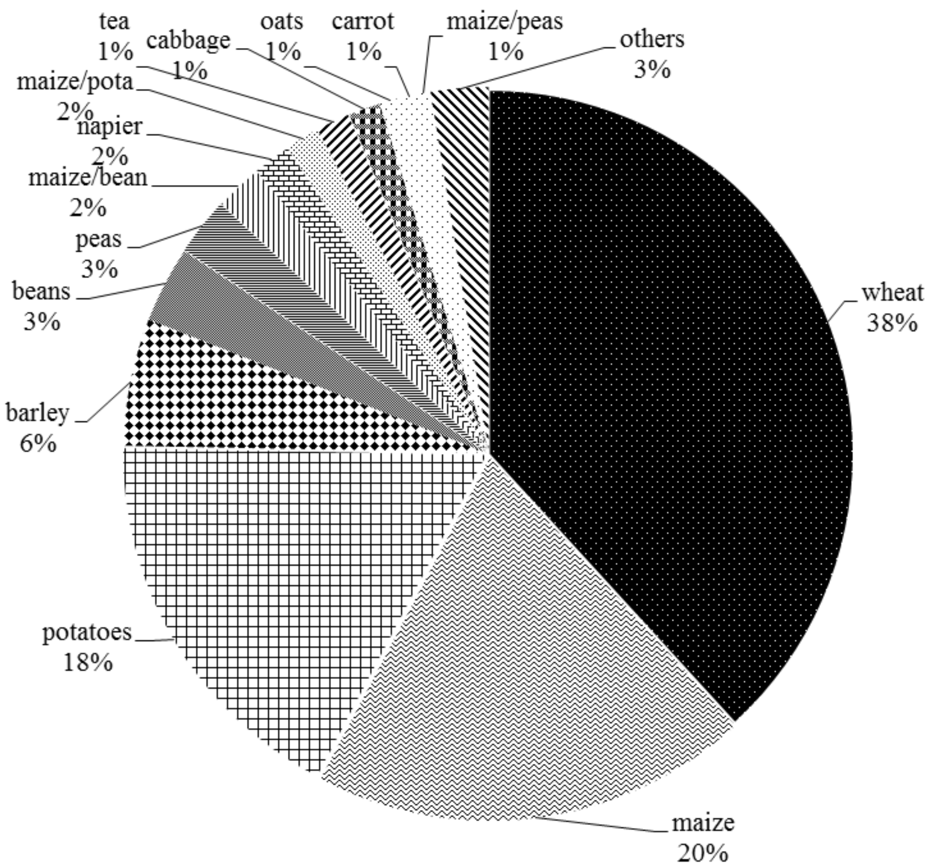


Figure 1 The percent acreage under various crops in the surveyed areas

Farmers grow different varieties of potatoes. In Bomet most of the farmers grew Dutch Robijyn while variety Shangi was grown mostly in Njambini and Ol njorok. The other commonly grown variety is Tigoni which was found to be grown in all the areas. Varieties which are not common and only found in some areas include Desiree in Bomet and Sherekea in Molo. In other areas some farmers do not plant pure varieties with the common mixture up being that of Asante and Tigoni, Shangi and Thimathuti, and Shangi and Nyayo. In areas like Molo, Naivasha, Narok and Ol njorok there are a wide number of varieties grown while in areas like Njambini and Bomet only a few varieties are grown (figure 2).

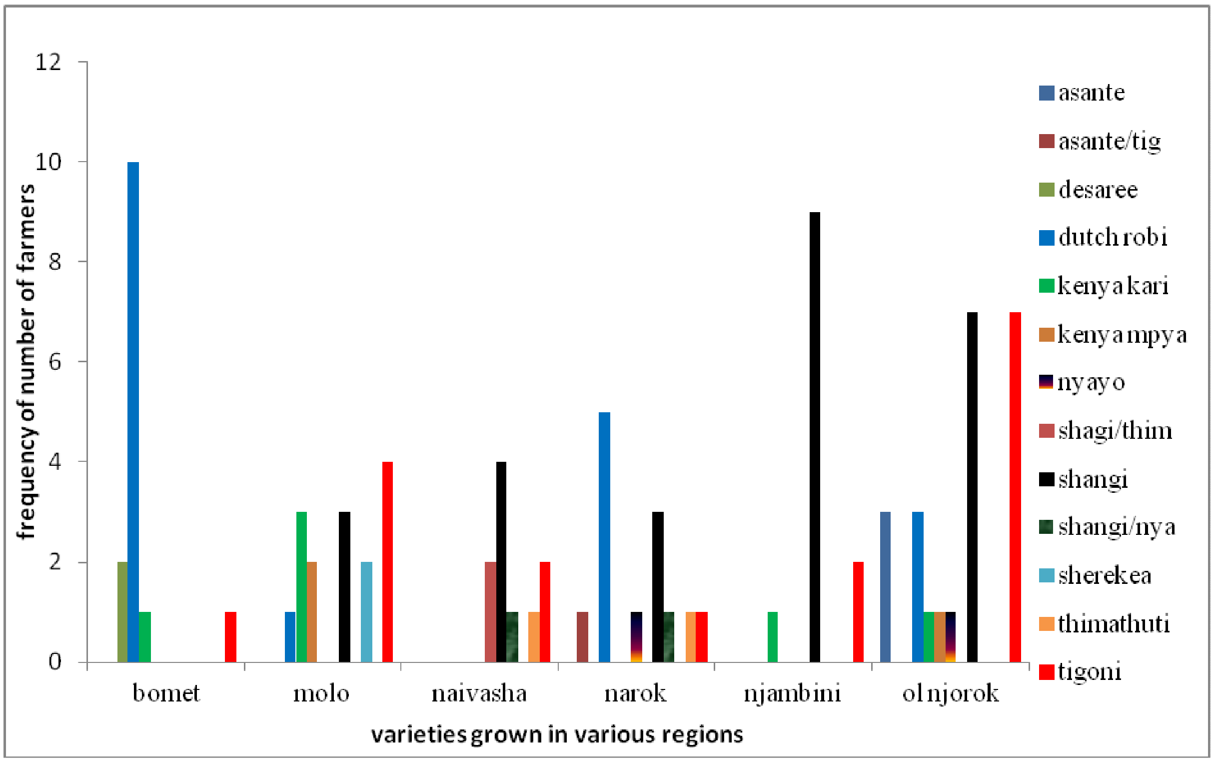


Figure 2 The frequencies of potato varieties grown in the sampled regions

The results show that fertilizer is an important input in potato production in all the sampled areas with 78% of the farmers using fertilizer (figure 3). However there are also quite a number (22%) who do not use fertilizers. Manure also plays an important part as an input in potato production system in Kenya. However the use is limited with only 34 % of the farmers observed preferring using manure with majority of them (66%) opting not to use manure in potato production. Around 24% of the farmers use both manure and fertilizers (Figure 3).

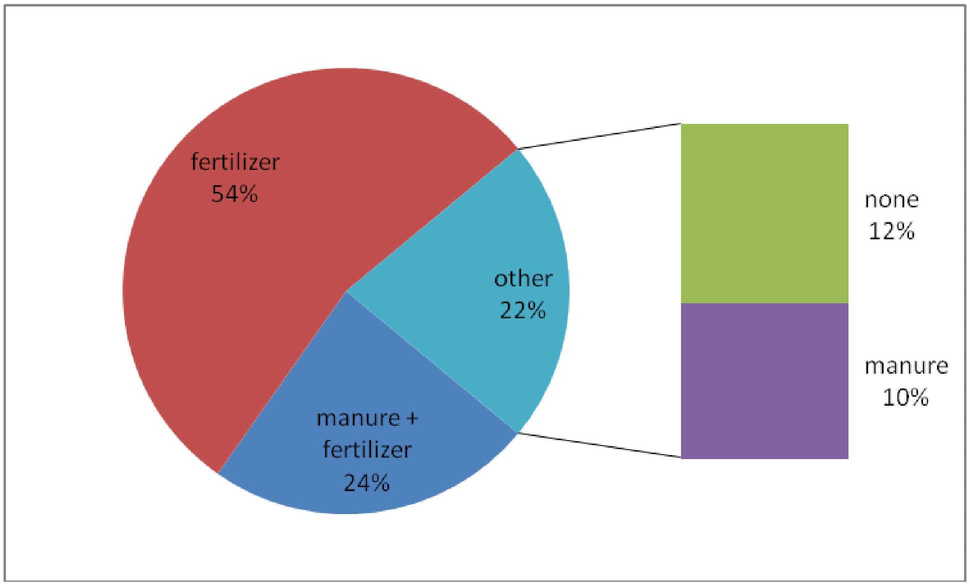


Figure 3. Fertilizer and Manure use in main potato growing areas in kenya

Farmers use different types of fertilizers during planting. Among them Di ammonium phosphate was the most used type of fertilizer during planting (96%). Other fertilizers used during planting included N.P.K and M.A.P. which accounted for 2 % each (Table 1). Top dressing fertilizer is rarely used among potato with the summary statistics showing less than 2% using Calcium Ammonium Nitrate (CAN) for top dress. However, substantial number of farmers (33%) uses foliar for additional nitrogen as well as micro nutrients (Table 1)

Table 1. Types of fertilizers used by farmers in the main potato growing areas in Kenya

Fertilizer types used by farmers		fertilizer types used during planting	
Fertilizer	**Percent**	**Fertilizer**	**Percent**
D.A.P	62.0	DAP	96
M.A.P	1.4	M.A.P	2
N.P.K	1.4	N.P.K	2
Foliar	33.8		
C.A.N	1.4		
Total	100	Total	100

Most of the farmers use low rates of fertilizer as observed in the study with only 6% of farmer using above 80 kg of N/ha. Majority of farmers (52%) were observed to use less than 45 Kg N/ha (figure 4) while 42% of the farmers used between 45 Kg N/ha and 80Kg N/ha.

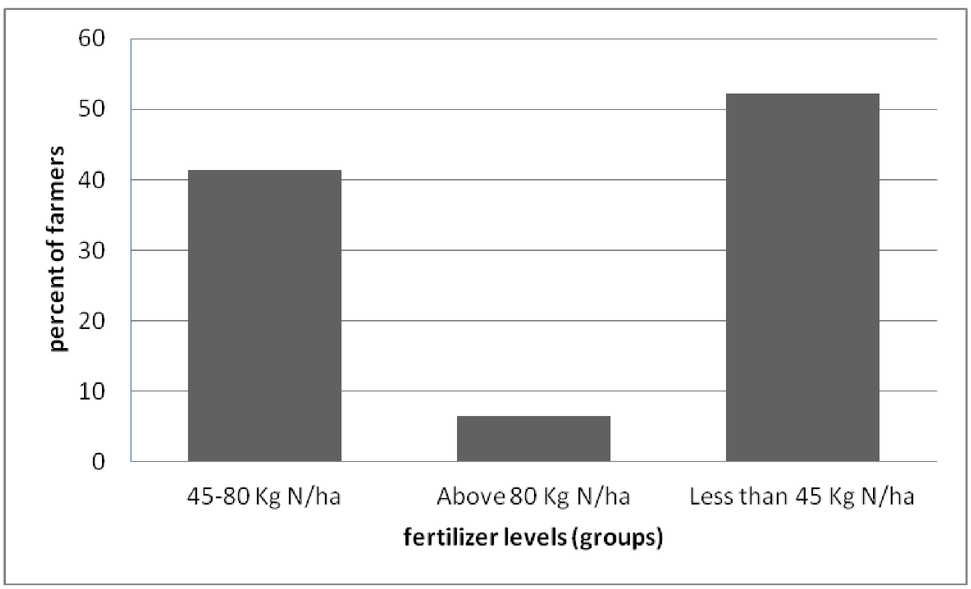


Figure 4. Quantities of fertilizers applied by farmers in sampled regions

No significant differences (P>0.05) were observed for Nitrate in the soil and the percent total nitrogen in the leaves for the different regions as the P values were 0.059 and 0.117 respectively. Lowest nitrate levels of 18.6 ppm were found in Naivasha region while the highest of 54 ppm were in Bomet. However there were significantly higher levels of Ammomium in soils from Bomet, Naivasha and Molo compared to Njambini and Narok (Table 2).

Table 2. Ammonium and nitrates content in the soil, and percent nitrogen in potato leaves, sampled from main potato growing areas in Kenya

Regions	Ammonium(NH_4) in soil (ppm)	Nitrate (NO_3) in soil (ppm)	% N in leaves
Njabini	2.91 a	32 a	5.4 a
Narok	3.79 a	47.5 a	5.26 a
Ol-njororok	5.13 ab	48.3 a	4.85 a
Molo	6.38 b	26.2 a	4.61 a
Naivasha	6.71 b	18.6 a	5.38 a
Bomet	7.46 b	54.1 a	5.07 a
P value (0.05)	0.005	0.059	0.117

Mean with the same letter along the columns are not significantly different at $L.S.D_{0.05}$

Cases of excess nitrogen in the plant was not common in the sampled regions with about half of leaf samples analysed having adequate nitrogen in them, however a substantial number had low nitrogen (Figure 5).

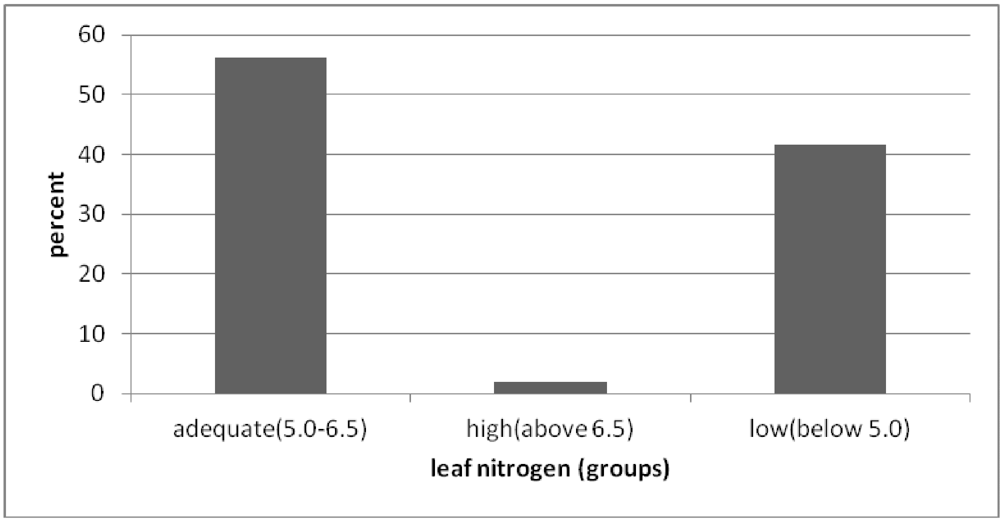


Figure 5. Percent nitrogen in potato leaves from sampled farms

3.4 Discussion and Conclusion

Potato is still regarded as an important crop coming third in terms of area under the crop in most of the sampled farms (Figure 1). These results relate to those showing potato as the second crop after the maize in terms of area (Ogola, et al., 2011). This justifies the role played by potato in food security in developing countries (FAO, 2008). Variety Shangi is widely grown (34%) with farmers regarding it as high yielding and early maturing which are good characteristics needed by the farmers. There is little information in literature on the origin of the variety. Dutch robjyn variety is second with the majority of farmers being from Bomet region. This was as a result of a local company contracting the farmers to grow the variety which is good for manufacture of crisps. A previous study in the rift valley indicated that the main varieties in the region were Dutch Robjyn, Tigoni and Asante (Kwambai and Komen, 2010).

Highest percentage of farmers have been observed to use fertilizer during planting with Di ammonium phosphate (DAP) as the most used type of fertilizer (table 1), this could be as a result adequate nitrogen (18%) and the high phosphorous in the fertilizer as it contains 46% of P_2O_5 and thus it is easy to achieve the recommended amount of 230 Kg of P_2O_5/ha (Kanguongo et al., 2008). The amount of fertilizers used is low in most of the areas which could be as a result of cost of the fertilizer (Ogola et al., 2011). The results on the fertilizer use are similar to those reported in an earlier study in Nakuru region indicating DAP as the preferred fertilizer and only less than 15% of farmers use adequate amount of fertilizers (Ogola et al., 2011).

The nitrate analysis indicates adequate levels of nitrate in most soils from the sampled areas. The levels observed relate to the adequacy levels of 20 – 50 ppm under high rainfall, and acidic to neutral soils found in other research (Joseph, 2003, Brian et al., 1994). Ammonium is a mobile form of Nitrogen which is evident in the results as it varied significantly in the different areas. Nitrate analysis on potato leaves from different areas showed that 42% of the farms had insufficient level of Nitrogen on potato leaves. Nutrient concentrations based on whole leaf samples has been used in diagnosing nutrient disorders. Nitrogen concentration sufficiency level of 5% in recently mature leaves (fourth leaf from the top) taken 45 to 55 days after emergence is considered as the adequate level for potatoes (Carl, 1991).

Potato is regarded as an important crop in most of the farms. The most preferred variety in the two regions is Shangi which they attribute to early maturity and high yields. Potato farmers in Kenya recognize the use of fertilizer to improve potato yields. The most preferred fertilizer type is Di Ammonium Phosphate (DAP). The amounts of fertilizer application are low ranging from no application to 90 kg N/ha.

In conclusion nitrogen fertility status in most potato farms was adequate as most of the nitrogen levels were within adequate range of 20- 50 ppm. Potatoes plants show inadequacy as more than 40% of plant leaves had nitrogen concentration of below 5 percent.

CHAPTER 4

4.0 Nitrogen dilution model for potato varieties Tigoni and Asante

Abstract

Nitrogen is an important nutrient since it has a positive effect on growth of plants. Potatoes have low uptake efficiency of nitrogen which is due to the shallow root system thus nitrogen management is important. Critical nitrogen dilution models and chlorophyll meter can be used in nitrogen management. The aim of the experiment was to develop critical nitrogen dilution model for potatoes varieties Asante and Tigoni in Kenya as well as establish relationship between SPAD index and total shoot nitrogen. Two Field experiments were conducted in a split plot design at the university of Nairobi farm using widely grown potato varieties Asante and Tigoni with three nitrogen fertilizer levels (45, 90, 135 N kg/ha) and a control with no fertilizer application. The critical nitrogen dilution model established is $N_c = 5.8W^{-0.16}$ for variety Tigoni and $N_c = 6.4W^{-0.18}$ for variety Asante with r^2 of 0.41 and 0.50 respectively. A linear relationship between shoot nitrogen content and the SPAD index was established for the two seasons with r^2 of 0.45 and 0.51. Extension services to farmers should use booth tools when advicing farmers on nitrogen management.

4.1 Introduction

Potatoes also have low uptake efficiency of nitrogen which is due to the shallow root system (Olivier et al., 2006). In areas where potatoes are grown, there are challenges of nitrate leaching thus good nitrogen management is needed. Nitrogen uptake becomes intensive about 15 days after emergence (Olivier et al., 2006). Nitrogen is an important nutrient since it has a positive effect on chlorophyll concentration, photosynthetic rate, leaf expansion, total number of leaves and dry matter accumulation and higher yields and potato quality (Isreal et, al. 2012, Bernie et al, 2007, Davis et al., 2009). Average plant height of 88.4 cm, average of 22 leaves per plant and an average of 13 shoots per tuber have been achieved in research (Yassen et al., 2011). Shoot dry mass increases between 21 and 49 days after emergence and decreases at 70 days after emergence (Gathungu et al., 2000).

The application of nitrogen fertilizer in potato has positive effect on the yield. Tuber size, weight total tuber yield are increased with nitrogen application (Yassen et al., 2011). Specific gravity which is considered as an important quality character particularly for chips and flour making industries reduces with increasing rate of N application. High specific gravity of 1.071 was recorded with application 200 kg N and the low specific gravity of 1.062 with application of 250 kg N (Yassen et al., 2011). Excess soil N late in the season can delay maturity of the tubers and result in poor skin set, which harms the tuber quality and storage properties (Davis et al., 2009).

There are various fertilizer recommendation in Kenya such as rate 90 kg N/ha and 230 kg P_2O_5 /ha (Kanguongo et al., 2008), 80 kg N and 90 kg P/ha (Fischer et al., 2004). Farmers apply mostly DAP when planting (Kaguongo et al., 2008). A research study has indicated highest yields with NPK (20.20.20) (Muthoni and Kabira, 2011) thus nitrogen source for the growth of potatoes is important.

Nitrogen fertilizer management is key to achieving good returns in potato production. Nitrogen fertilizer management can be carried out in different ways. The chlorophyll meter is a more convenient, leaf clip-on device that determines the index of greenness present in plant leaves. The greenness is related to the chlorophyll content in the plant leaves. Several factors affect greenness index readings when using chlorophyll meters. Some crop varieties are greener than others and will have higher readings. Stage of growth also affects the readings and environmental factors. The age of leaf on which to clip on the meter matters as the older leaf tends to yellow than the other. The readings must be calibrated for the variety and other environmental factors in order to be useful (Lloyd et al., 1997).

Studies by Lorene and Jeuffroy, 2007 have shown non-cultivar-dependent exponential relationship between the SPAD index and NNI at flowering, with an R squared (r^2) equal to 0.89 for wheat. This implies that the SPAD chlorophyll meter can be used as an alternative to NNI to measure N status in wheat. Although dependent on sites, chlorophyll meter measurements have been correlated with the NNI of various crops (Nicolas et al., 2011, Lorene and Jeuffroy, 2007).

Critical nitrogen models can be used in nitrogen management. For potatoes critical nitrogen models have been established in other areas and for different varieties. Under non-limiting water conditions they reported $N_c = 4.57W^{-0.42}$ for Russet Burbank variety and $N_c = 5.04W^{-0.42}$ of Shepody variety in cananda (Belanger et al., 2001), $N_c = 3.6W^{-0.37}$ for potato cultivar Asterix (Andriolo et al., 2006). These show variations in the nitrogen dilution models and thus critical nitrogen model need to be established for varieties in Kenya.

The objectives of this experiment were; (1) to develop critical nitrogen dilution model for potatoes varieties Asante and Tigoni in Kenya. (2) To determine the relationship between the total shoot nitrogen concentration and the chlorophyll content (SPAD index) in potatoes.

4.2 Materials and Methods

4.2.1 Experimental site

The experiment was conducted at university of Nairobi farm in Kabete with an altitude of 1737 m above sea level during the long and short season of 2012. The soil type is well-drained, very deep dark reddish, brown to dark red, friable clay classified as a Humic Nitisol according to the Soil Map of the World and known locally as the Kikuyu Red Clay Loam. The rainfall in the region is bimodal with the long rains in March to July and short rains in October to December. The average annual rainfall is about 1500mm.

4.2.2 Treatments and experimental design

The potato varieties used for the experiment were Tigoni and Asante; this is because of their wide cultivation by many farmers. Asante is a short season variety and high yielding while Tigoni is a long season variety. Clean planting seed of medium size (50g) were used. The seed were sourced from international potato center (CIP) in Nairobi.

In the experiment inorganic source (N.P.K 17:17:17) was used to provide nitrogen. It was applied once during planting and at four levels (0, 45, 90, 135 Kg N/ha). Treatment level of 90 kg N/ha is the recommended rate. The formula used to calculate the amount of fertilizer used per plot was (equation 6)

$$\text{amount(g)} = \frac{fert.lev * plot.size * 1000}{\%\ N\ in\ fertilizer} \tag{6}$$

Where *fert.lev* is the treatment level (0, 45, 90, 135 Kg N/ha), *plot.size* is the plot area in hectares and *% N in fertilizer* is the fertilizer specification by manufacturer. The applied amount per plot was (0, 79, 158, and 238 g of NPK)

A split plot design was used in both experiments where the varieties were the sub plot while the fertilizer treatments were the main plot. The experiment was replicated four times. The sub plot had the dimensions of 4.5 m (4 rows of 0.75 m) by 4 m (a spacing of 30 cm in between plants). There was a spacing of 1 m between the main plots and a small trench was dug to prevent nitrate spillage which would affect the treatments.

4.2.3 Crop management

Initial soil samples were collected using a soil auger and analyzed to establish the fertility of the experimental field. The soil was sampled at the depth of 30cm. Five samples were collected in a diagonal manner and they were mixed in a bucket to make one composite sample.

Ploughing was done using a tractor in the long rain season but no ploughing was done in the short rain season. After ploughing the plot were measured and demarcated using wooden pegs. The sub plot had the dimensions of 4.5m by 4m.

Small fallows of approximately 10cm deep were dug in each plot. A spacing of 75cm was left between the fallows thus a total of 6 fallows in each plot. Planting line was used to ensure the lines were straight. Fertilizer was then applied in the fallow and mixed thoroughly with the soil to prevent fertilizer affecting the emergence of the seed tuber. The sprouted potatoes tubers were then arranged with a spacing of 30cm between tubers. Each row contained 13 tubers. The tubers were then covered completely with soil until the tuber was approximately 5 cm deep. The crop was completely grown under rain in the two seasons. Once it rained the exposed tubers were covered again. Weeding was done three times each season. When weeding, hilling was also done to ensure the stolon are well covered in the soil. Insecticide was used in the early weeks after emergence to control cut worms. Fungicides were sprayed five times each season to prevent and control late blight. Foliar fertilizers which are commonly used by the farmers were avoided.

4.2.4 Data collection

Random destructive plant sampling was done at 33, 47, 71 and 84 days from planting during the long rains season and at 32, 45, 54, and 69 days after planting in the short rains season. The sampling days mainly represented the various growth stages of potatoes. Days around 30 represent vegetative stage; around 45 represent the flowering phase while around 75 represent the beginning of senescence. Destructive sampling involved uprooting the whole plant and the underground part separated from the above ground parts. Fresh weight of the above ground was weighed in the field using a digital weighting scale. The border plants were not sampled to reduce on external influence. The samples were put in khaki bags and oven dried at 65^0c for 72 hours. The nitrogen concentration was determined using the following procedure. 0.3 g of oven dried ground potato shoot was weighed into a test tube. 4.4 ml digestion mixture was added and 2 blank reagents. Digestion mixture contained selenium powder, lithium sulphate, hydrogen peroxide and sulphuric acid. Digestion was done for 2 hr at 360 ^{0}c (until solution was clear). The test tubes were allowed to cool then 25 ml distilled water added and shook until all sediment were dissolved then topped to 50 ml. The 50 ml of digest was pipetted to 500ml kjeldahl flask then added 200ml distilled water and 2 beads. Holding the kjeldahl at an angle of 45, 25 ml of sodium hydroxide was gently added and then distilled. The distillate was titrated with 0.01 sulphuric acid until it turned pink. Calculation of % N (equation 3)

Three sequential harvesting were done at 84, 98, 111 days after planting during long rains season and 69, 84, and 98 days in the short rains season. The fresh weight was weighed in the field and tuber samples and shoot samples were collected for oven drying. The tubers were dried for around 96 hours in the oven. The dry weight was then weighed in the laboratory using a digital weighing balance. The sequential harvesting involved the harvesting of tubers in one entire row leaving the border plants. The final harvest was done at 126 days after planting during long rains season and 114 days in the short rains season. During the final harvest the remaining three rows were harvested. Only tuber samples were collected for oven drying in the final harvest. To hasten the drying the tubers were chopped into small pieces.

The chlorophyll content index was measured using Minolta SPAD meter. Measurements were taken during sampling at 33, 47, 71 and 84 days from planting in the long rains season and at 32, 45, 54, and 69 days after planting in the short rains season. The measurement was taken in the morning hour at around 10 O'clock. This was to avoid variation in the measurement as a result to the time of the day. The fourth fully expanded leaf was used when taking the measurement. Data was entered in Microsoft Windows Excel flat file.

4.2.5 Data analysis

The collected data were subjected to statistical analysis procedures of Statistical Analysis System (SAS) software and Genstat 13 edition. Data were mainly analyzed for the variance in the split plot design. The % nitrogen in the potato shoot was non linearly fitted against above ground shoot dry weight (g). The model used was $N_t = aW^{-b}$, where N_t is the % nitrogen in the shoot while W is the above ground dry matter of the crop. The negative power model explains the dilution of the nitrogen in the plant as the dry weight increases. The model was fitted for each of the fertilizer level and varieties separately. For the model to be valid, the 95 % confidence limits must not have zero in them since the equation cannot predict when the estimate parameters are zero. Where that condition was not met a linear model was fitted. The model was fitted using gauss-Newton method and the non linear Least of Square was used to select the best fit. This was done by fitting the negative power equation discussed previously. The total nitrogen was used as the response variable while the dry weight of the plant was used as the explanatory variable. The curve corresponding to optimum yield was selected as the critical nitrogen curve.

Regression analysis was also done to establish the relationship between total nitrogen in the plant and the SPAD reading in which a linear model was fitted. The SPAD values for the optimum fertilizer level were plotted against shoot nitrogen so as to be able to guide the use of SPAD in fertilizer management in potatoes.

4.3 Results

4.3.1 Potato shoot dry weight

Significant differences ($p<0.05$) in shoot dry weight were observed in three harvest days i.e. 33, 47, and 71 days after planting in the long rain season and in 32, 54 and 69 days after planting in the short rain season (table 3). The fertilizer level of 135 Kg N/ha always gave a higher shoot dry weight at all sampling days but not significantly different from that of 90 Kg N/ha. In the control where no fertilizers were applied the weights were mostly the least (table 3). There were no significant ($P>0.05$) interactions between the treatments (fertilizer levels and varieties) in all the sampling days in the two seasons.

Table 3. Potato shoots dry weight (g/plant) at various days after planting for different N levels

Fertilizer level	Days after planting long rains					Day after planting Short rains			
	33	47	71	84	98	32	45	54	69
0 Kg N/Ha	4.44 a	7.30 a	28.90a	67.29a	69.14a	3.18 a	8.82 a	17.17a	65.27 a
45 Kg N/Ha	8,07ab	11.97a	34.55ab	62.92a	74.36a	6.03ab	14.70a	29.42ab	48.67 a
90 Kg N/Ha	9.45 b	20.97ab	43.26bc	71.52a	82.93a	6.59 b	15.85a	31.97 b	82.11ab
135 Kg N/Ha	9.92 b	30.42 b	53.20 c	89.81a	80.95a	7.25 b	14.04a	32.46 b	138.26b
P value	0.003	0.002	<0.001	0.095	0.336	0.007	0.083	0.033	0.011
$L.S.D_{0.05}$	2.54	9.97	7.32	22.27	17.77	2.06	5.67	10.72	47.63

Mean with the same letter along the columns are not significantly different at $L.S.D_{0.05}$

The results from the long rains season did not show significant differences (p>0.05) in the shoot dry weight between the variety Asante and Tigoni apart from 33 days after planting which had a P value of 0.009 (table 4). However, during the short rains season there was significant differences (p<0.05) in the dry weight during 45, 54 and 69 days after planting (table 4). Variety Tigoni was found to have higher shoot dry weight than variety Asante.

Table 4. Potato shoots dry weight (g/plant) at various days after planting for variety asante and tigoni

variety	**Days after planting long season**					**Day after planting Short season**			
	33	**47**	**71**	**84**	**98**	**32**	**45**	**54**	**69**
Asante	9.79	18.07	40.50	69.40	74.30	5.27	11.24	22.04	56.90
Tigoni	6.18	17.25	39.40	76.30	79.40	6.25	15.46	33.47	110.25
P value (0.05)	0.009	0.595	0.701	0.381	0.408	0.274	0.016	0.016	0.007
L.S.D	2.55	3.23	5.92	16.24	12.76	1.85	3.30	0.298	36.09

4.3.2 Tuber yields

There were significant differences (P<0.05) of tuber yield in 84 and 98 days after planting in the long rain season with the difference being between treatments with fertilizers and control, however there were no significant differences within the treatments with fertilizers. In 111 days after planting no significant difference in tuber yields was observed between the different nitrogen fertilizers levels used. The highest recorded yield in the long rain season was 6.91 kg /3 m^2 at 111 days after planting and at fertilizer level of 135 kg N/ha while the lowest was 2.48 kg

/3 m^2 at 84 days after planting and with no fertilizer applied (table 5). During the short rains season there were statistical differences in the various treatments and the different harvesting dates. The lowest yield of 0.85 kg/3 m^2 was at 69 days after planting and in the treatment where no fertilizers while the highest yield of 5.81 kg in an area of 3 m^2 was at 98 days after planting with fertilizer treatment of 135 Kg N/ha (table 5). There were no significant ($P>0.05$) treatment interactions during all sampling days in the two seasons.

Table 5. Potato yield (Kg/ 3m^2) at various days after planting for different fertilizer level

Fertilizer level	Days after planting long rains			Day after planting Short rains		
	84	**98**	**111**	**69**	**84**	**98**
0 Kg N/Ha	2.48 a	3.83 a	4.91 a	0.85 a	2.10 a	2.51 a
45 Kg N/Ha	3.79 ab	5.55 ab	6.09 a	2.40 a	3.06 a	4.66 b
90 Kg N/Ha	4.66 b	5.63 b	6.41 a	4.08 b	4.65 b	4.81 b
135 Kg N/Ha	4.71 b	5.45 ab	6.91 a	3.98 b	5.15 b	5.81 c
P value	0.032	0.039	0.196	<.001	<.001	<.001
$L.S.D_{0.05}$	1.42	1.42	1.95	1.04	0.88	0.45

Means with the same letter along the columns are not significantly different at $L.S.D_{0.05}$

Variety Asante yielded slightly higher than variety Tigoni in the long rains season with the highest yield for Asante being 6.38 kg/3m^2 while the lowest being 4.49 kg per row while the highest for Tigoni being 5.78 kg/3m^2 and the lowest being 3.33 kg/3m^2 (table 6). In the short rains season Tigoni yielded higher than Asante apart from 69 days after planting. It also shows that the highest yield for Tigoni and Asante were 4.94 kg/3m^2 and 3.95 kg/3m^2 respectively (table 6). The P values were significant on 84 and 98 days after planting in the long rains season while in short rains significant P values ($p<0.05$) were only on 98 days after planting. The P values were 0.011, 0.01 and <0.001 respectively (table 6).

Table 6. Potato yield ($Kg/3m^2$) at various days after planting for variety Asante and Tigoni

Variety	Days after planting long season			Day after planting Short season		
	84	**98**	**111**	**69**	**84**	**98**
Asante	4.49	5.78	6.38	2.77	3.61	3.95
Tigoni	3.33	4.45	5.78	1.88	3.87	4.94
P value	0.011	0.010	0.123	0.935	0.563	<.001
$L.S.D_{0.05}$	0.85	0.96	0.79	0.62	0.74	0.47

The yield on the final harvest in the long rains did not show significant difference ($p>0.05$) but the 135 kg N/ha treatment gave the highest yield of 18.86 $kg/9m^2$. In the short rains there was a significant differences ($p<0.05$) with the optimum yield of 17.54 $kg/9m^2$ was at the treatment of 90 kg N/ha (Table 7). There was no significant difference in the yield of the varieties in the long rains season but in the short rains variety Tigoni Yielded significantly higher. Test for treatment interactions revealed no significant interactions.

Table 7. Potato yield from the final harvest (Kg/ 9 m^2)

Fertilizer level	long rains	Short rains	Variety	long rains	Short rains
0 Kg N/Ha	15.19 a	9.61 a	**Asante**	17.85	13.22
45 Kg N/Ha	17.87 a	14.10 ab	**Tigoni**	16.85	17.26
90 Kg N/Ha	17.49 a	17.54 bc			
135 Kg N/Ha	18.86 a	19.72 c			
P value	0.152	0.007	**P value**	0.337	0.005
L.S.D$_{0.05}$	3.03	3.40	**L.S.D$_{0.05}$**	2.16	2.37

Means with the same letter along the columns are not significantly different at L.S.D$_{0.05}$

4.3.3 Potato shoot nitrogen

Total nitrogen concentration in the shoot of the potato plant declined with time as the plant grew. The highest amounts of nitrogen 4.97 was achieve with 135 kg N/ha at 32 days after planting in the long rains season. In the short rain season, day 32 after planting gave the highest nitrogen 4.76 with the application of 135 kg N/ha. There were significant differences ($P<0.05$) in nitrogen concentration in the plant for the various fertilizer levels in 33, 47 days after planting in long rains season and 32, 45 and 54 days after planting in the short rains season (table 8). Treatment interactions were not significant ($P>0.05$) during the long rain and short rains.

Table 8. Percent shoot nitrogen concentration of potato grown in the long and short rains of 2012 (fertilizer level)

Fertilizer level	Days after planting long rains					Day after planting Short rains			
	33	**47**	**71**	**84**	**98**	**32**	**45**	**54**	**69**
0 Kg N/Ha	4.28 a	3.77 a	3.95a	3.94a	3.2 a	4.25ab	3.78 a	3.05 a	2.60a
45Kg N/Ha	4.52ab	4.09ab	4.02a	3.92a	2.69a	3.91 a	4.04ab	3.65ab	2.73a
90Kg N/Ha	4.89 b	4.24ab	3.99a	3.81a	3.09a	4.34ab	4.63 b	3.47ab	2.79a
135Kg N/Ha	4.97 b	4.52 b	4.38a	3.65a	3.51a	4.76 b	4.54 b	4.17 b	2.87a
P value	0.006	0.030	0.451	0.686	0.309	0.004	0.006	0.022	0.905
$L.S.D_{0.05}$	0.36	0.46	0.65	0.59	0.94	0.37	0.45	0.64	0.88

Mean with the same letter along the columns are not significantly different at $L.S.D_{0.05}$

Tigoni variety had relatively higher nitrogen content than Asante throughout the growth period. At around 33 days after planting in both seasons there are no significant differences ($p>0.05$) in nitrogen concentration between the two varieties with P values of 0.869 and 0.661. There were however significant difference in nitrogen content between the two varieties at around 70 days after planting with P values of < 0.001 (table 9).

Table 91. Percent shoot nitrogen concentration of potatoes grown in the long and short season of 2012 (varieties)

Variety	Days after planting long rains					Day after planting Short rains			
	33	47	71	84	98	32	45	54	69
Asante	4.65	3.99	3.84	3.36	3.02	4.28	4.11	3.63	2.40
Tigoni	4.68	4.31	4.33	4.23	3.30	4.35	4.38	3.54	3.09
P value	0.869	0.012	0.005	<.001	0.285	0.661	0.256	0.633	<.001
$L.S.D_{0.05}$	0.36	0.24	0.31	0.22	0.45	0.29	0.49	0.42	0.31

4.3.4 Potato SPAD index

During the long rains there was no significant difference of the SPAD index at the three data collection days after planting. Treatment with 135 kg N/ha however gave the highest index of 45.94 at 33 days after planting. The index decrease with the growth of the crop and the lowest SPAD index of 38.7 was recorded at 71 days after planting. During the short rains season the trend was the same as long rains but higher SPAD index of 50.52 were recorded at 32 days after planting while the lowest index of 33.06 was recorded at 69 days after planting (table 10). Interactions between nitrogen supply and variety for SPAD index were not significant ($p>0.05$) in the two seasons. The P values were 0.164 and 0.117.

Table 2. Mean of leaves SPAD index at different days after planting for different N levels

Fertilizer level	Days after planting long season			Day after planting Short season		
	33	**47**	**71**	**32**	**45**	**69**
0 Kg N/Ha	44.38 a	40.33 a	38.8 a	41.61 a	39.30 a	35.46 a
45 Kg N/Ha	44.29 a	40.95 a	39.40 a	41.74 a	41.29 a	36.16 a
90 Kg N/Ha	43.38 a	40.03 a	38.70 a	46.80 b	45.00 a	33.06 a
135 Kg N/Ha	45.94 a	42.20 a	39.71 a	50.52 b	47.30 a	37.32 a
P value	0.729	0.702	0.324	<.001	0.033	0.356
L.S.D$_{0.05}$	5.12	4.432	1.286	2.585	5.383	5.208

Means with the same letter along the columns are not significantly different at L.S.D$_{0.05}$

When comparing the SPAD index for the two varieties, the long rains results show that there were significant differences ($P<0.05$) with variety Tigoni having higher SPAD index values than variety Asante. The highest values were 47.7 and 41.3 at 33 days after planting while the lowest were 42.36 and 36.0 at 71 days after planting for Tigoni and Asante respectively (table 11). During the short rains there were no significant differences ($p>0.05$) but SPAD index for variety Tigoni were slightly higher. The highest values were 45.58 and 44.24 at 32 days after planting while the lowest were 35.3 and 35.7 at 69 days after planting for Tigoni and Asante respectively (table 11).

Table 3. Mean of leaves SPAD index at different days after planting for variety Asante and Tigoni

variety	Days after planting long season			Day after planting Short season		
	33	47	71	32	45	69
Asante	41.3	38.50	36.00	44.76	42.24	35.70
Tigoni	47.7	43.25	42.36	45.58	44.20	35.30
P value	0.031	0.002	0.007	0.408	0.089	0.788
$L.S.D_{0.05}$	4.96	0.989	2.354	2.067	2.290	3.065

4.3.5 Critical nitrogen models

4.3.5.1 Critical nitrogen model for Variety Tigoni

All the models had a significant P-value ($p<0.05$) after non linear regressions however some of the models could not be used to predict nitrogen status in the plant since their confidence limits of the negative power (-b) included zero. The confidence limits at 95% for control (0 kg N/ha) were -0.15 to 0.04 for the negative power (table 13). The model of $N_t= 5.87W^{-0.1}$ was achieved at recommended fertilizer rate the 90 kg N/ha and it was valid. The model had confidence limits of 5.03 to 6.7 for parameter (a) and -0.15 to -0.06 for parameter (b) (Figure 6a). During the short season all models met the criteria of validity. Their 95% confidence limits did not include zero in them. The model at the recommended nitrogen fertilizer rate of 90 Kg N/Ha was $N_t= 6.39W^{-0.21}$. The confidence limits were 3.78 to 9.0 for parameter (a) and -0.36 to -0.06 for parameter (b) (Table 12, Figure 6b).

The nitrogen dilution curve for variety Tigoni in the long rains indicate that the treatment differences are clear in the early stage of growth but late in the growth stage it is not easy to use the curve. Most of the points for the treatment with lower fertilizer level than recommended are below the curve while those with higher level are above the curve (figure 6a). During the short rain the dilution trend was more clearer with the points of the treatment with no fertilizer being below the curve while those of 135 Kg N/ha being above the curve. However the points at the 45 Kg N/ha are interacting with those of 90 Kg N/ha (figure 6b).

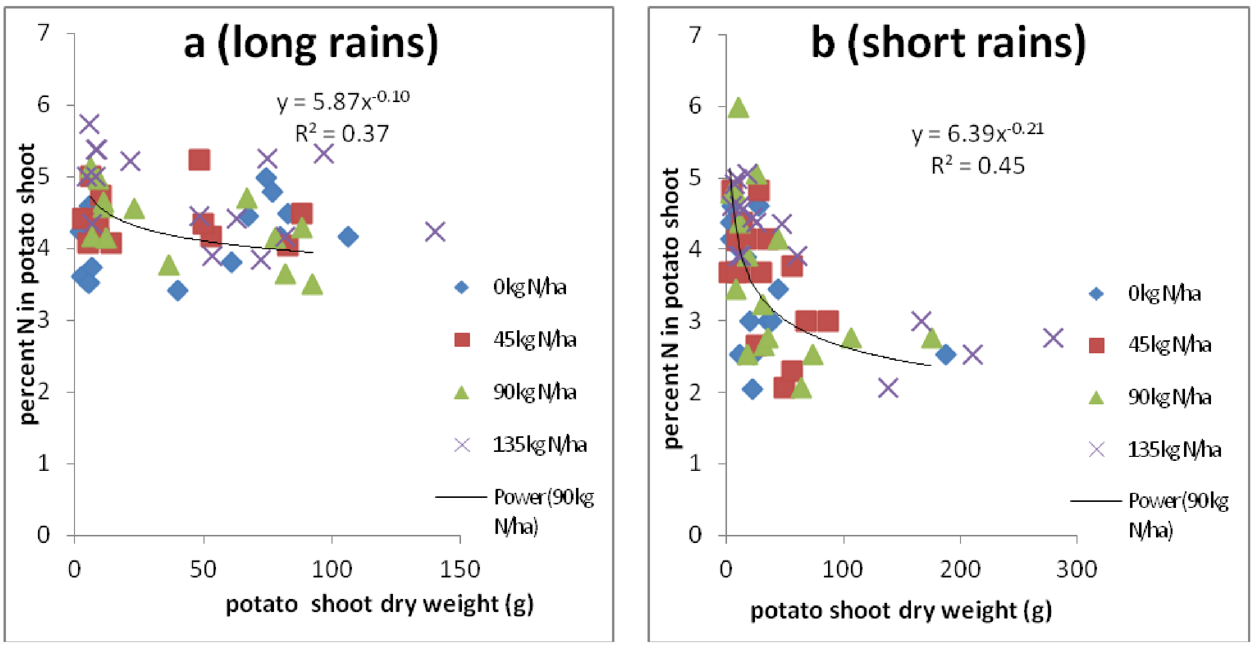


Figure 6. Potato nitrogen dilution models for variety Tigoni in the long and short rains of 2012

Table 12.Nitrogen dilution model estimates for potato variety Tigoni

N level	Parameters	Long rains Estimates	Confidence Limits		P value	Short rains Estimates	Confidence Limits		P value
0	**a**	4.76	3.34	6.18	0.0002	4.93	3.94	5.92	<.0001
	b	-0.06	-0.15	0.04		-0.11	-0.18	-0.03	
45	**a**	4.99	0.8	9.19	0.0029	4.88	3.54	6.22	<.0001
	b	-0.06	-0.31	0.20		-0.10	-0.20	-0.01	
90	**a**	5.87	5.03	6.70	<.0001	6.39	3.78	9.00	<.0001
	b	-0.10	-0.15	-0.06		-0.21	-0.36	-0.06	
135	**a**	6.83	3.05	10.60	0.0007	5.77	4.54	7.02	<.0001
	b	-0.18	-0.27	0.04		-0.10	-0.18	-0.03	

4.3.5.2 Critical nitrogen model for variety Asante

The results of non linear regression for nitrogen content and the shoot dry weight of long season showed a significant P values at 0.05 significant level for all the treatments. All models did not have zero within their confidence limits at 95%. The model at the recommended fertilizer rate of nitrogen in Kenya (90 Kg of N/ha) during the long season was $N_c= 9.51W^{-0.26}$ (table 13). During the short season the P values for all the models were all significant at 0.05 significant level and they did not have zero within their confidence limit. The model at the recommended nitrogen rate was $N_t= 6.29W^{-0.20}$ (table 13).

During the long rains the dilution curve for variety Asante indicate that majority of the points were below the curve at the recommended fertilizer rate of 90 Kg N/ha (figure 7a). During the short season the dilution model indicated that the points for the control were below the curve, those of the 45 Kg N/ha were interacting with those of 90 Kg N/ha while those of 135 Kg N/ha fertilizer level were above the critical dilution curve (figure 7b).

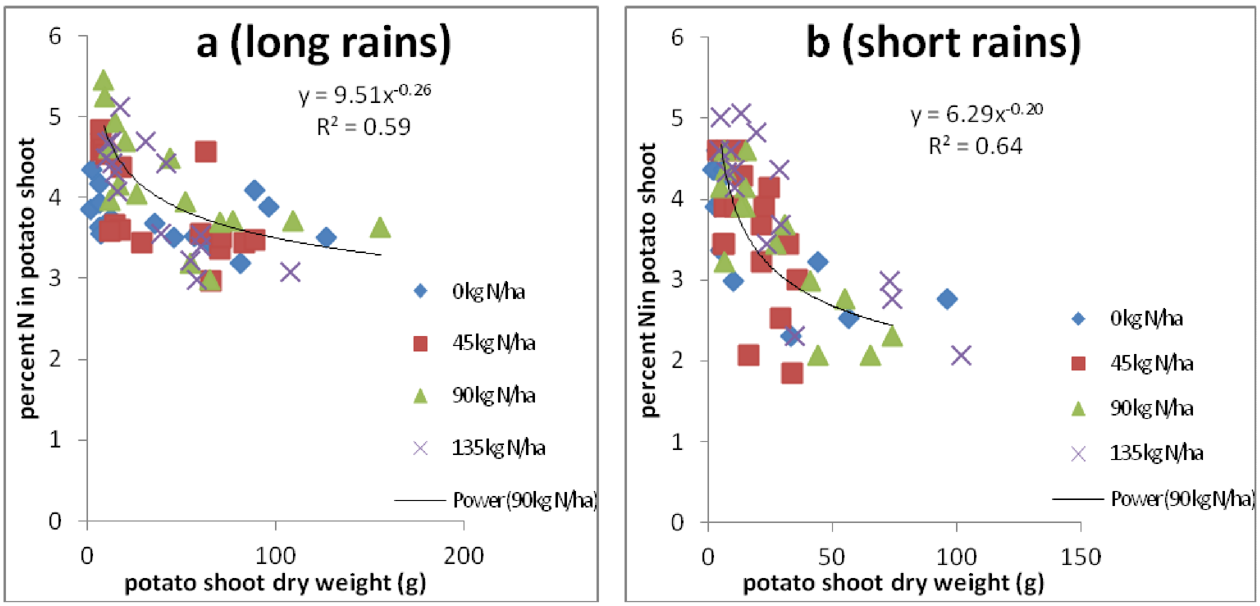


Figure 7. Potato nitrogen dilution models for variety Asante in the long and short rains of 2012

Table 4. Nitrogen dilution model estimates for potato variety Asante

		Long rains			Short rains		
N level	**parameter**	**Estimates**	**Confidence Limit**	**P value**	**Estimates**	**Confidence Limits**	**P value**
0	**a**	4.75	4.11 5.51	0.001	4.81	4.11 5.51	<.0001
	b	-0.10	-0.15-0.06		-0.12	-0.19 -0.04	
45	**a**	7.29	6.2 8.38	0.001	5.46	3.36 7.56	<.0001
	b	-0.23	-0.27-0.18		-0.16	-0.32 -0.01	
90	**a**	9.51	4.02 14.99	0.001	6.29	4.44 8.15	<.0001
	b	-0.26	-0.43 -0.09		-0.20	-0.31 -0.09	
135	**a**	7.08	4.19 9.98	<.001	6.55	4.76 8.34	<.0001
	b	-0.16	-0.27 -0.04		-0.18	-0.28 -0.07	

The model estimates for the recommended fertilizer rate after combining the data for the two seasons was $N_c = 5.8W^{-0.16}$ for variety Tigoni and $N_c = 6.4W^{-0.18}$ for variety Asante (table 11).

Table 14. Nitrogen dilution model estimates at the recommended fertilizer rate (90 kg N/ha)

varieties	Parameter	estimates	Std error	C.I (95%)		R squared
Asante	a	6.40	0.70	4.95	7.85	0.50
	b	-0.18	0.04	-0.25	-0.10	
Tigoni	a	5.86	0.65	4.51	7.23	0.41
	b	-0.16	0.04	-0.24	-0.07	

4.3.6 Relationship between SPAD index and total nitrogen

The correlation between the SPAD index and the nitrogen content in the shoot for all the data combined in the first season was found to be 0.58 and 0.75 in the second season. Simple linear regression between the SPAD readings and % nitrogen in the shoot gave the highest R squared of 0.45 and 0.53 for the long and short rains respectively. However these R squared were generally low. In the long rains season the models were SPAD index = 5.03(%N) + 21.68 with r^2 of 0.48 and SPAD index = 5.0(%N) + 21.79 with r^2 of 0.53 for variety Asante and Tigoni respectively (figure 8b).The models in the short rains season were SPAD index = 4.3(% N) +20.59 with r^2 of 0.43 and SPAD index = 4.56(% N) +23.85 with r^2 of 0.59 for variety Asante and Tigoni respectively (figure 8a). The probability value for all the regressions were <0.001

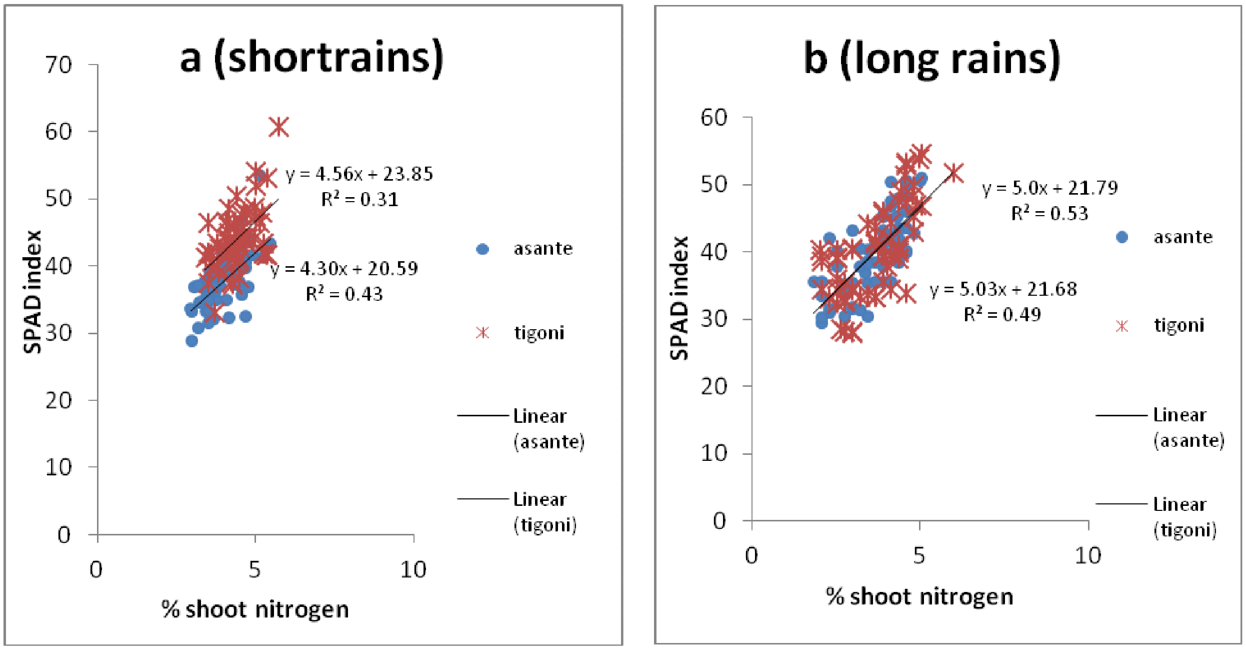


Figure 8; Scatter plot of SPAD index against % shoot nitrogen in LR2012 and SR2012

4.4 General discussions

The shoot dry weight of the two varieties increased with the increase in the nitrogen fertilizer levels. Similar trend was also observed in other researches (Najm et al., 2010, Wenjun et al., 2012). Variety Tigoni gave a higher shoot dry weight than variety Asante; this can be attributed to the morphological characteristic of the two varieties since variety Tigoni is taller than variety Asante (Muthoni and kabira, 2011). The optimum fertilizer level would be that of 90 kg N/ha but at some sampling days the optimum was at the 45 kg N/ha. This difference could have been influenced by fertility of the field, mineralization of the previous crop residues or nitrate leaching. The recommended rate however is that of 90 kg N/ha (Muthoni and Kabira, 2011, Kaguongo et al., 2008).

In general, the fertilizer treatment of 135 Kg N/ha gave the highest yields but at every sequential harvest there was no significant difference with the yields of the fertilizer level of 90 Kg N/ha. These re-affirms the recommended rates of nitrogen though in several occasions there was no significant difference between the fertilizer level of 45 Kg N/ha and the recommended rate of nitrogen (Fischer et al., 2004, Muthoni and kabira, 2011, Kaguongo et al., 2008). The average yields of (21.13) t/ha for Tigoni and (22.33) t/ha for Asante were however low than those of reported in other studies. Yields of 86 and 62 t/ha for varieties Tigoni and Asante respectively have been reported (Muthoni and kabira, 2011) these differences could be due to the different experimental sites since where high yields were achieved is in a cooler place than the experimental site used for this experiment. The results of the yields are however close to those achieved in an experiment of variety Asante (Powon et al., 2006).

The results indicate that there are differences in the level of nitrogen during the leaf development and inflorescence emergence of the potatoes, which is up to around 50 days after planting. This is as a result of the increased nutrient uptake after the development of the roots and also during the initiation of tuber formation (Peter and Gary, 2009, Rodrigues et al., 2005). Potatoes respond to the slightest fertilizer application as there are significance differences between the three fertilizer levels and the control. There were no differences during the tuber growth stage of potatoes this could be attributed to the shift of nutrient to the tuber bulking (Peter and Gary, 2009, Rodrigues et al., 2005). The total nitrogen in the shoot reduced with growth. This condition has been referred to as nitrogen dilution. This occurs due to the self shading of leaves and also due to change in leaf: shoot ratio as the plant grows (Justes et al., 1994). Variety Tigoni had slightly higher nitrogen content in the shoot as compared to variety Asante though most of the time there were no significant differences.

The SPAD index for the two varieties shows that Tigoni had higher SPAD index values than variety Asante. SPAD index of 47.7 and 41.3 was the highest and the lowest was 42.36 and 36.0 at for Tigoni and Asante respectively in long rains while in the short rains it was high of 45.58 and 44.24 and the low of 35.3 and 35.7 for Tigoni and Asante respectively. This can be attributed to the varietal characteristics of the two varieties where Tigoni is greener than Asante. Greenness of the leaves indicate level of chlorophyll which is measured using the SPAD index (Lorene and Jeuffroy, 2007). The index decrease with the growth of the crop. The highest index of 45.94 was at day 33 after planting in long rains and 50.52 at 32 days after planting in short rains. The lowest was 38.7 at 71 days after planting in long rains and 33.06 at 69 days after planting in short rains. Andrijana et al (2012) reported the similar decrease in SPAD index and report high SPAD values of 53 to 63 for potatoes. Research on variety Desiree also gave SPAD values within the range of 49-60 (puiu et al., 2012)

The dilution of the shoot nitrogen concentration with the increase in shoot weight occurred during the two seasons. The dilution was however not valid in some fertilizer treatment since the models could not be used to predict the nitrogen status of the crop. The dilution models in the long season was $N_c= 5.9W^{-0.10}$ and $N_c= 9.5W^{-0.26}$ for variety Tigoni and Asante respectively. In the short season the dilutions models were $N_c= 6.4W^{-0.21}$ and $N_c= 6.3W^{-0.20}$. The model in the long season are quite different but in the short seasons they are closely related they are however different from potato models developed in other countries and with other varieties (Belanger et al., 2001, Andriolo et al., 2006, Giletto and Echeverría 2012). The other reported models are $N_c = 4.57W^{-0.42}$ for Russet Burbank variety and $N_c = 5.04W^{-0.42}$ of Shepody variety in cananda (Belanger et al., 2001), $N_c = 3.6W^{-0.37}$ for potato cultivar Asterix (Andriolo et al., 2006) and $N_c = 5.3W^{-0.42}$ for cultivar innovator in Argentina (Giletto and Echeverría, 2012).

On combining the data of the two seasons for the two varieties the models developed were $N_c= 5.8W^{-0.16}$ for variety Tigoni and $N_c= 6.4W^{-0.18}$ for variety Asante. The R squared for the two models were 0.41 and 0.50 respectively. The data was combined since there were no significance differences between the two models. The differences in the model could be due to the variety differences and also due to the regional ecological differences.

The correlation between nitrogen content and the SPAD index show a positive relationship where there is increase in SPAD readings with the increase in the nitrogen content in the plant with correlation coefficient (r) of 0.58 and 0.75 for the two seasons respectively. These results partially agree with that of Ian and Grady, (2000) who also reported a positive correlation with correlation coefficient (r) of 0.71 on St Augustine grass. Increase in SPAD readings in potato leaves with increase in N rate were also reported by other authors (Camilo et al., 2010, Gil et al., 2002). The corresponding R squared for the two seasons were 0.45 and 0.51. A lower r^2 of between 0.32-0.53 and 0.26-0.42 has observed on Benjamin fig and cotton wood respectively (Felix et al., 2002). Relationship between SPAD and nitrogen concentration has been found to vary greatly with genotypes and environments (Lemaire et al., 2008).

4.5 Conclusions

Applying nitrogen at the rate of 90 Kg N/ha gives optimum shoot dry weight and potato yields. Shoot nitrogen concentration and the SPAD index values are higher for variety Tigoni than Asante.

The model developed for Tigoni was $N_c= 5.8W^{-0.16}$ while Asante was $N_c= 6.4W^{-0.18}$ comparing these from models developed for other varieties in other area it can be concluded that critical nitrogen dilution models for potato may differ in terms of variety and the region.

The result from the study has shown a linear relationship between SPAD index and the total shoot nitrogen in potato.

5 General conclusions and recommendations

5.1 Conclusions

Nitrogen fertility status in most potato farms was adequate as most of the nitrogen levels were within adequate range of 20- 50 ppm. Potatoes plants show inadequacy as more than 40% of plant leaves had nitrogen concentration of below 5 percent.

The developed critical dilution models are $N_c = 5.8W^{-0.16}$ for variety Tigoni and $N_c = 6.4W^{-0.18}$ for variety Asante.

A linear relationship between SPAD index and the total shoot nitrogen in potato was established. The models were SPAD index = 4.3(% N) +20.59 with r^2 of 0.43 and SPAD index = 4.56(% N) +23.85 for variety Asante and Tigoni respectively.

5.2 Recommendations

Developed critical nitrogen dilution models should be used as a diagnosis tool to improve the nitrogen management in the farmers' fields.

The extension service providers and large scale farmers can use SPAD meter so as to be able to diagnose nitrogen status in the potatoes.

5.3 Suggestion for further research

There is need to evaluate the critical nitrogen dilution models with other varieties and also in other regions. This will assist in having more valid models to be used in fertility management in

Kenya. Other nitrogen status indicators which could be cheap, easy to use and efficient can be tried for farmers to use themselves.

There in need to develop a tool which will assist in the approximate amount of fertilizer needed to attain the critical nitrogen in plants bearing in mind nutrient availability on the different soil types.

6 References

Abong', G.O. and Kabira, J.N. (2013). The current status of potato value chain in Kenya. Trends and opportunities in the production, processing and consumption of staple food crops in Kenya held on 25-26 April 2013 at Intercontinental hotel, Nairobi, Kenya.

Alt, C., Kage, H. and Stuetzel, H. (2000). Modelling Nitrogen Content and Distribution in Cauliflower (*Brassica oleracea* L. *botrytis*). *Annals of Botany 86*, 963-973.

Adrijana M., Milan, P., Ana, S. Zrinka, K. and Tea, H. (2008). Efficiency of use of chlorophyll meter and cardy-ion meter in potato nitrogen nutrition supply, *alps adria scientific workshop*

Andriolo, J. L., Bisognin, D. A., Paula, A. L., Paula, F., Luiza, M., Godoi, R. S. and Barros, G. T. (2006). Curva crítica de diluição de nitrogênio da cultivar Asterix de batata. *Pesquisa Agropecuária Brasileira*, *41*(7), 1179-1184. Retrieved February 02, 2013, from http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0100-204X2006000700015&lng=en&tlng=10.1590/S0100-04X2006000700015

Belanger, G., Walsh, J. R., Richards, J. E., Milburn, P. H. and Ziadi, N. (2001). Critical nitrogen curve and nitrogen nutrition index for potato in eastern Canada. *American Journal for Potato Research 78*, 355–364.

Bernie, Z., Charles, K., Peter, S., Daniel, S. and Gilles, M. (2007). Nitrogen Management for Potato: General Fertilizer Recommendations. GHG Taking Charge Team Factsheet

Boote, K. J., Jones, J. W. and Pickering, N. B. (1996). Potential Uses and Limitations of Crop Models *Agronomy journal* 88, 704–716

Brian, H., Jim, J., Dale, L. and Tim P. (1994). Soil test methods & guidelines for interpretation of soil results [fact sheet], retrieved from http://www.senrm.sa.gov.au/Portals/10/PDF/saltland/Soil%20FSheets/Saspas-Guidelines%20for%20interpreting%20Soil%20data.pdf

Camilo, B., Paulo, C. Rezende, F., Heder, B. and Paulo R. C. (2010). Seasonal variation and threshold values for chlorophyll meter readings on leaves of potato cultivars, *Journal of Plant Nutrition, 33:14*, 2148-2156

Carl, J. R. (1991) Potato Fertilization on Irrigated Soils, retrieved from http://www.extension.umn.edu/distribution/cropsystems/dc3425.html.

Cromme, N., Prakash, A. B., Lutaladio, N. and Ezeta, F. O. (2010). Strengthening potato value chains; Technical and policy options for developing countries, pp. 1-147. FAO, Rome, CFC, Amsterdam, Rome.

Darwish, T.M., Atallah, T.W., Hajhasan, and Haidar, A. (2006). Nitrogen and water use efficiency of fertigated processing potato. *Agricultural Water Management 85,* 95-104

Davis J.D., Davidson, R.D. and Essah, S.Y.C. (2009). Fertilizing Potatoes (Fact sheet). Retrieved from http://www.ext.colostate.edu/pubs/crops/00541.html

Deutsch, B., Mewes, M., Liskow, I. and Voss, M. (2006). Quantification of diffuse nitrate inputs into a small river system using stable isotopes of oxygen and nitrogen in nitrate. *Organic Geochemistry 37*(10), 1333-1342.

Felix C. L., Jason, C. G. and Nina, L. B. (2002). Using the SPAD 502 Meter to asses Chlorophyll and nitrogen content of Benjamin fig and cottonwood leaves. *HortTechnology 12*(4), 682-686

Fischer, T., Neil, T., John, A., Lyne, M., Michael, R., Andrew, B. and David, L. (2004). New directions for a diverse planet: Proceedings for the 4th International Crop Science Congress, Brisbane, Australia, 26 September – 1 October 2004.

FAO. (2005). FAOSTAT Database. Food and Agriculture Organization of the United Nations. http://faostat.fao.org/site/339/default.aspx.

FAO. (2008). International Year of the Potato, www.potato2008.org

FAO. (2011). FAOSTAT Database http://faostat3.fao.org/home/index.html#DOWNLOAD

Gathungu, G.K., Shibairo, S.I,. Githiri, S.M., Mburu, M.W.K,. Ojiambo, P.S. and Kidanemariam, H.M. (2000). Effect of source, time and method of nitrogen application on growth and yield components of potato in kenya, *African Crop Science Journal 8*(4), 387-402

Gil, P. T., Fontes, P. C. R., Cecon, P. R., and Ferreira, F. A. (2002). SPAD index for nitrogen status diagnosis and potato yield prognosis. *Horticultura Brasileira 20*, 611–615.

Giletto, C. M. and Echeverría, H. E. (2012). Critical Nitrogen Dilution Curve for Processing Potato in Argentinean Humid Pampas. *American Journal of Potato Research* 89(2), 102-110. Retrieved from. http://dx.doi.org/10.1007/s12230-011-9226-z

Kinyae, P., Wakahiu, M., Nyongesa, M. and Zschocke. T. (2007). Positive selection to improve farm saved seed potatoes, trainers manual. *International Potato Center (CIP).* 126. www.cipotato.org/publications/pdf/003812.pdf.

Gildemacher, P., Demo, P., Barker, I., Kaguongo, W., Woldegiorgis, G., Wagoire, W., Wakahiu, M., Leeuwis, C. and Struik. P. (2009). A Description of Seed Potato Systems in Kenya, Uganda and Ethiopia. *American journal of potato research 86*, 373-382.

Giorgio, G., Francesco, O., Paolo, S. and Matilde, P. D. (2011). The Use of Diagnostic Optical Tools to Assess Nitrogen Status and to Guide Fertilization of Vegetables. *HortTechnology 21*, 287-292.

Goffart, J. P., Olivier, M. and Frankinet, M. (2008). Potato Crop Nitrogen Status Assessment to Improve N Fertilization Management and Efficiency: Past–Present–Future. *Potato Research 51*, 355-383.

Haase, T., Schüler, C. and Heb, J. (2005). The effect of different N and K sources on tuber nutrient uptake, total and graded yield of potatoes (*Solanum tuberosum* L.) for processing. *European Journal of Agronomy 26,* 187-197.

Hoffer, H. and Ochieng, B. O. (2008) High Commodity Prices–Who gets the Money? Preliminary findings for World Food Day2008. Heirich Boll Foundation.

Ian R. R. and Grady, L. M. (2000). Using a Chlorophyll Meter to Determine the Chlorophyll Concentration, Nitrogen Concentration, and Visual Quality of St. Augustine grass, *hortscience 35*(4), 751–754.

Israel, Z., Ali, M. and Solomon, T. (2012). Effect of Different Rates of Nitrogen and Phosphorus on Yield and Yield Components of Potato (*Solanum tuberosum* L.) at Masha District, South western Ethiopia. *International Journal of Soil Science 7,* 146-156.

Janzen, H.H., Beauchemin, K.A., Bruinsma, Y., Campbell, C.A., Desjardins, R.L., Ellert, B. H. and Smith, E.G. (2003). The fate of nitrogen in agroecosystems: An illustration using Canadian estimates. *Nutrient Cycling in Agroecosystems. 67,* 85–102.

Joseph R. H. (2003). Soil Nitrate Testing as a Guide to Nitrogen Management for Vegetable Crops [factsheet] http://njveg.rutgers.edu/assets/pdfs/soil/e285-jhSoil%20Nitrate_Testing_as_Guide_to_Nitrogen_Management_for_Vegetable.pdf

Judelson, H. S. and Blanco, F. A. (2005). The spores of *Phytophthora*: weapons of the plant destroyer. *Nature Review Microbiology 3, 47-58*

Justes E, Mary B, Meynard JM, Machet JM, Thellier-Huché L. (1994). Determination of a critical nitrogen dilution curve for winter wheat crops. *Annals of Botany 74, 397–407.*

Kaguongo, W. (2009). Baseline study on farmers' willingness to pay for high quality seed. Funded by GTZ, Kenya unpublished

Kaguongo, W., Gildemacher, P., Demo, P., Wagoire, W., Kinyae, P., Andrade, J., Forbes, G., Fuglie, K. and Thiele, G. (2008). Farmer practices and adoption of improved potato varieties in Kenya and Uganda. *International Potato center (CIP)*, Lima, Peru. Social Sciences Working Paper 2008-5. 85 p

Kinyua, Z.M., Smith, J.J., Lungaho, C., Olanya, M. and Priou, S. (2001). On-farm successes and challenges of producing bacterial wilt-free tubers in seed plots in Kenya. *African Crop Scince Journal 1,* 279-285.

Kirumba, W., Kinyae, P., and Muchara, M. (2004). Irish Potato Market. Survey Promotion of Private Sector Development In Agriculture. GTZ/MOA

Kwambai, T. K. and Komen, S. K. (2010). Multi-institutional partnership to promote certified seed potato production and distribution in the north rift region of kenya, *KARI science conference proceedings 12,* 1369-1375.

Labarta, R., Mulwa, C., Schulte-Geldermann , E., Borus, D., and Lemaga B. (2011). Adoption of seed quality improvement strategies among potato producers in Kenya. International Conference on Increasing Agricultural Productivity & Enhancing Food Security in Africa: New Challenges and Opportunities— Addis Ababa, November 1-3, 2011

Lemaga, B., Kakuhenzire, R. Bekele, K., Ewell, P.T. and Priou, S. (2005). Integrated control of potato bacterial wilt in Eastern Africa: The experience of African Highlands Initiative. Pg. 145-158. In: Bacterial Wilt Disease and the *Ralstonia Solanacearum* Species Complex. (Eds.) C. Allen, P. Prior and A.C. Hayward, APS Press, St. Paul, Minnesota USA, 510 pg

Lemaire, G., Gastal, F. and Salette J. (1989). Analysis of the effect of N nutrition on dry matter yield of a sward by reference to potential yield and optimum N content. *Proceedings XVI International Grassland Congress,* Nice, France (179-180)

Lemaire, G., Jeuffroy, M. and Gastal, F. (2008). Diagnosis tool for plant and crop N status in vegetative stage. Theory and practices for crop N management. *European Journal Agronomy* 28; 614–624

Lemaire, G. and Salette, J. (1984) Relation between growth dynamics and nitrogen dynamics levy for a stand of grass forage. 1. Study of the effect of the medium. [Relationship between herbage growth and N uptake in a pure stand. I. - Environmental effects.] *Agronomy 4*, 423-430.

Lisinka, G. and Leszcynkl, W. 1989. Potato science and technology. Elsevier science publishers LTD. England

Lloyd, M., Scott, J., Chris, B., Phillip, N., John, J. and Paula H. (1997). Using a Chlorophyll Meter to Make Nitrogen Recommendations on Wheat, *University of Kentucky Cooperative Extension Service*.

Lorene, P. and Jeuffroy, M.H. (2007). Replacing the nitrogen nutrition index by the chlorophyll meter to assess wheat N status. *Agronomy for Sustainable Devevelopment. 27* (4), 321-330

Lutaladio, N.B., Ewell, P.T. and Kidanemarian, H. (1995). Advances in Potato Research in Eastern and Central Africa. In: Root Crops and Poverty Alleviation: Proceedings of the Sixth Triennial Symposium of the International Society for Tropical Root Crops-Africa Branch (ISTRC-AB). October 22-28.

Marino, M. A., Mazzanti, A., Assuero, S.G., Gastal, F., Echeverría, H.E. and Andrade, F. (2004). Nitrogen dilution curves and nitrogen use efficiency during winter-spring growth of annual ryegrass. *Agronomy Journal 96,* 601–607.

Muthoni, J., and Kabira, J. N. (2011). Effects of different sources of nitrogen on potato Tigoni Kenya. Journal of Soil Science*, 2.* 167-174.

Muthoni, J. And Nyamongo, D. O. (2009). A review of constraints to ware Irish potatoes production in Kenya. *Journal of Horticulture and Forestry 1*(7), 098-102 http://www.academicjournals.org/jhf

Najm, A., Haj Seyed Hadi, M. R., Fazeli, F., Taghi Darzi, M., and Shamorady, R. (2010). Effect of Utilization of Organic and Inorganic Nitrogen Source on the Potato Shoots Dry Matter, Leaf Area Index and Plant Height, During Middle Stage of Growth. *International Journal of Agricultural and Biological Sciences 1*:1

Nicolas, T., Edith, F. and Noura, Z. (2011). Sensing of Crop Nitrogen Status: Opportunities, Tools, Limitations, and Supporting Information Requirements. *HortTechnology 21*(3) 274-281.

Nyankanga, R.O., Wein, H.C., Olanya, O.M. and Ojiambo, P.S. (2004)**.** Farmers' cultural practices and management of potato late blight in kenya highlands: implications for development of integrated disease management. *International Journal of Pest Management. 50* (2), 135-144.

Ogola, J. B. O., Milton, W. A., Apollo, O. O., and Fredah, W. K. (2011). Analysis of fertiliser use in potato production in Nakuru district, Kenya. *African Journal of Agricultural Research 6*(16), 3672-3677,

Okalembo, J. R., Gathua, K. W. and Woomer, P. L. (2002) *Laboratory methods of soil and plant analysis: A working manual*; TSBF-CIAT and SACRED Africa, Nairobi, Kenya

Olivier, M., Goffart, J. P., Ledent, and Jean, F. (2006). Threshold Value for Chlorophyll Meter as Decision Tool for Nitrogen Management of Potato. *Agronomy journal*, 496–506

Otipa, M.J., Wakahiu, M.W., Kinyae, P. and Thuo, D.N. (2003). A report on survey of the bacterial wilt of potatoes caused by *Ralstonia solanacearum* and its spread in the major potato growing areas. *International Potato Centre, Kenya,* pp: 33-35.

Öztürk, E., Kavurmacı, Z., Kara, K., and Polat, T. (2010). The Effects of Different Nitrogen and Phosphorus Rates on Some Quality Traits of Potato. *Potato Research*, 53(4), 309-312.

Peter, D., and Gary, C. (2009). Crop Nutrition for Potatoes. Retrieved from www.nutrientmanagement.org/.../PCL-Crop-nutrition-for-potatoes

Poljak, M., Herak-Custic, M., Horvat, T., Coga, L., and Majic, A. (2007). Effects of nitrogen nutrition on potato tuber composition and yield. *Cereal Research Communication, 35*(2). 937-940.

Powon M.P., Aguyoh J.N., and Mwaja. A V. (2006). Growth and tuber yield of potato (solanum tuberosum l.) under different levels of phosphorus and farm yard manure. *agriculturatropica et subtropica 39*(3)

Priou, S., Gutarra, L., Aley P. and Quirroz, Y. (2007). Soil abiotic characteristics affecting survival of *Ralstonia solanacearum* in bare soil and effect of soil mineral amendments and crop rotation in the management of potato bacterial wilt. *Working paper, International Potato Center (CIP)*, Lima, Peru.

Puiu, I, Olteanu, G. Morar, G. and Maria I. (2012). Monitoring the vegetation status of potato, *agricultura ştiinţă şi practică* 1(2), 81-82

Rahman, M. S., Akanda, A. M., Mian, I. H., Bhuian, M. K. A. and Karim, M. R. (2010). Growth and yield performance of different generations of seed potato as affected by PVY and PLRV› *Bangladesh Journal Agricultural. Research 35*(1), 37-50.

Rodrigues M.A., Coutinho, J., Martins, F. and Arrobas, M. (2005), Quantitative side dress nitrogen recommendations for potatoes based upon crop nutritional indices, *European Journal of Agronomy 23,* (1), 79-88, ISSN 1161-0301, 10.1016/j.eja.2004.10.001. http://www.sciencedirect.com/science/article/pii/S1161030104000917

Schulte-Geldermann, E., Wachira, G. AND Ouma, A. E. (2010). Assessing the potential of applying phosphonite fungicides to enhance host tolerance in potato to late blight. 8[TH] african potato association conference, 5-9 December 2010, Cape Town, South Africa

Smith, K. A., Ball, T., Conen, F., Dobbie, K. E., Massheder, J., and Rey, A. (2003). Exchange of greenhouse gases between soil and atmosphere: interactions of soil physical factors and biological processes. *European Journal of Soil Science*, *54*(4), 779-791.

Tei, F., Benincasa, P. and Guiducci, M. (2002). Critical nitrogen concentration in processing tomato*, European Journal of Agronomy, 18*(1-2), 45-55.

Tremblay, N., Fallon, E. and Ziadi, N. (2011). Sensing of Crop Nitrogen Status: Opportunities, Tools, Limitations, and Supporting Information Requirements. *HortTechnology* 21(3) 274-281.

Umar, S., and Iqbal, M. (2007). Nitrate accumulation in plants, factors affecting the process, and human health implications. *Agronomy for sustainable development 27* (1), 45-57

Vance, E.D. and III, F.S.C., (2001). Substrate limitations to microbial activity in taiga forest floors. *Soil Biology and Biochemistry, 33*(2), 173-188.

Van-Oosterom, E.J., Carberry, P.S. and Muchow, R.C. (2001). Critical and minimum N contents for development and growth of grain sorghum. *Field Crops Research.70,* 55–73.

Wenjun L., Ping H. and Jiyun J. (2012). Critical nitrogen curve and nitrogen dilution index for spring maize in north east China, *journal of Plant Nutrition, 35*(11), 1747-1761

Westermann D. T. (2005). Nutritional requirements of potatoes. *American Journal for Potato Research 82*, 301–307

Xiaoping, X., Jianguo, W., Zhiwei, W., Wenqi, G. and Zhiguo, Z. (2007). Determination of a critical dilution curve for nitrogen concentration in cotton. *Journal of Plant Nutrition and Soil Scince 170*, 811–817.

Yassen, A.A., Safia, M.A. and Sahar, M. Z. (2011). Impact of Nitrogen Fertilizer and Foliar Spray of Selenium on Growth, Yield and Chemical Constituents of Potato plants, *Australian Journal of Basic and Applied Sciences, 5*(11), 1296-1303,

Ziadi, N., Brassard, M. Bélanger, G. Cambouris, A.N. Tremblay, N. Noli, M.C. Claessens, A. and Parent, L.É. (2008b). Critical nitrogen curve and nitrogen nutrition index for corn in eastern Canada. *Agronomy Journal 100*, 271–276.

6- Appendices

Appendix 1. Fertilizer application survey among potato growing farmers in kenya

Section 1: farm identification

Team/trip_______________(team A and B, trip 1 and 2)

Correspondent name _____________________ gender __farm code _______________

District name (DIST) ____________________ District code _____________

Location name (LOC) ___________________ Location code ____________

GPS coordinates (easting) ________________________ (nothings) _______________

Altitude ________________________________

Farmer's details

Gender __ Highest Level of education _________________

Contact; mobile _______________ box __________________, email __________________

Section 2: information about the farm

Part 1; farm size, crop grown and potato varieties

What is the total acreage of the farm _________ (acres?) (FSIZE)

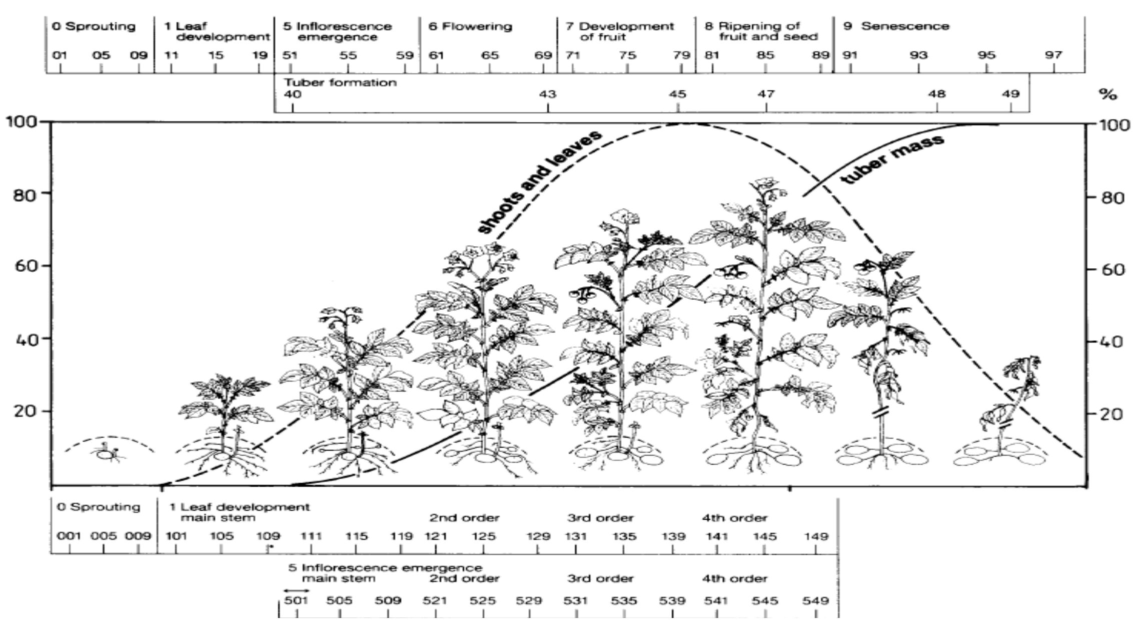
Crops grown

Crop	Acre

Potato varieties grown

Variety	Area (acre)	Growth stage (BBCH key 2 digit code)	General crop status scale of 1- V. poor to 10 V. vigorous	Seed source 1- Own 2- Market/neighbor 3- Seed multiplier 4- Certified source 5- Positive selection 6- other	Reason for growing variety

The 2-digit decimal code



Part 2: fertilizer application

Have used fertilizer in the potato field this season (yes or no) __________

If yes above which fertilizers have you used

Fertilizer used	Fertilizer type (solid, foliar etc)	No. of applications	Amount applied 1st app	Amount applied 2nd app	Amount applied 3rd app	Units of measurement	Time of application

Have you used organic fertilizer/ manure this season (yes or no) _________

Organic fertilizer/ manure type	Amount applied(appx kg/ acre)	Number of application

Part 3; Crop rotation history

Season	Crops grown	Yield	Units (1-90 kg bags, 2-kilos, 3-2 kg tins)	Amount of fertilizer (not for foliar application)	Amount of manure

Part 4: diseases (late blight and bacterial wilt) in a plot of 10 m by 10 rows

Potato variety____________________

Score of Bacterial **Wilt in %** _________

Score of the **Late blight infection in%**______________

Score of **severe virus** symptomsin%______________

Score of the **mild virus** symptomsin%______________

Measure taken to control B**ACTERIAL WILT**						Quantity app	units
Spraying		No. of application		Chemical used			
rotation		How many seasons		Crop used			
Field hygiene		specify					
Clean seed		source					
fallowing		No of seasons					
other							

N/b; tick alongside control used and leave blank if not used

Measure taken to control **late blight**						Quantity app	units
Spraying		No. of application		Chemical used			
rotation		How many seasons		Crop used			
Field hygiene		specify					
Clean seed		source					
fallowing		No of seasons					
other							

Measure taken to control **viruses**						Quantity app	units
Spraying		No. of application		Chemical used			
rotation		How many seasons		Crop used			
Field hygiene		specify					
Clean seed		source					
fallowing		No of seasons					
other							

What are you doing with volunteer potatoes in other crops field e.g. maize? _________________

(1 = Roughing, 2 = Spraying, 3 = Letting them grow and harvest them)

Other diseases and pest (specify)	Severity (%)

Part 5; Seed technologies

Do you practice positive selection (yes or no) ______________

If yes what is the experience in terms of?

1) yield _______ (1 = more, 2= same, or 3 = lower),
2) diseases _______ (1 = more, 2= same, or 3 = lower)

Do you practice Small Seed Plot Technology (yes or no) ______________

If yes what is the experience in terms of?

1) yield _______ (1 = more, 2= same, or 3 = lower),
2) diseases _______ (1 = more, 2= same, or 3 = lower)

Do you replace your seed (yes or no) __________

If yes what are the reason for seed replacement _________________________________

How often do you replace the seeds? _______________ (seasons)

What is the seed source when replacing the seed?_______________

1 – Market, 2 – neighbor, 3 - Seed multiplier, 4- Certified source, 5 - other

Part 6; Training

Have you attended any potato training? _________ Yes/no

If yes above which potato training was attended

What was the trained about	Who trained	When trained (year)

Appendix 2. Laboratory procedures for nitrogen, nitrate and ammonium determination

Procedure for Nitrogen determination in plant tissue

0.3 g of oven dried ground plant tissue was weighed into a test tube

4.4 ml digestion mixture added and 2 blank reagents. Digestion mixture (selenium powder, lithium sulphate, hydrogen peroxide and sulphuric acid)

Digestion was done for 2 hr at 360 ^{0}c (until solution was clear)

Allowed to cool then 25 ml distilled water added and shook until no sediments then topped to 50 ml

50 ml of digest was pipette to 500ml kjeldahl flask; added 200ml distilled water and 2 beads

Holding the kjeldahl at an angle of 45 gently added 25 ml of sodium hydroxide and distilled

Titrated the distillate with 0.01 sulphuric acid until it turns pink

Calculation of % N (equation 4)

Equation 4. $\% N = \frac{\text{Ml acid} * 5 * 0.14 * 100}{\text{weight of plant tissue (mg)}}$

Colorimetric for ammonium determination in soil

Soil extraction

10 g of freshly sampled soil was weighed into a shake bottle

100 ml of 0.5 M potassium sulphate added shook the content for 1 hour

It was filtered with number 5 whatman filter paper

Standards

0, 5,10,15,20 and 50 ml of stardard solution (100ppm NH4+) was pipette into a volumetric flask and topped up to 100ml using 0.5 M potassium sulphate

0.2 ml of sample extract, the blank, and stardard solution was pipette into separate labeled test tube and reagent 1(34g sodium salicylate, 25 g sodium citrate and 25 g sodium into 750 ml water, add 0.12 g sodium nitroprusside in to 1l of water) added and left to stand for 15 minutes

5 ml of reagent 2 (30g sodium hydroxide into 750 ml water, then add 10 ml sodium hydrochlorite and make up to 1 l) added and allowed to stand for 1 hour

Absorbance was measured at 655 nm

Plotting of the calibration curve and reading of the concentration of ammonium nitrogen was done

Calculation of the concentration of ammonium nitrogen from oven dried soil

Equation 5. $ammonium(ppm) = \frac{(a-b) * v * MCF * f * 1000}{w}$

Where a= conc of N in solution, b = conc N in blank, v= volume of extract, w = weight of fresh soil, f dilution factor and MCF = moisture correction factor

Colorimetric for Nitrate determination in soil

Soil extraction

10 g of freshly sampled soil was weighed in to a shake bottle

100 ml of 0.5 M K_2SO_4 added shook the content for 1 hour

Filtered with number 5 whatman filter paper

Standards

0, 2, 4, 6, 8, and 10 ml of stardard solution (50ppm nitrate nitrogen ml and make up to 100ml using) was pipetted into separate volumetric flasks then filled with 0.5 M potassium sulphate

0.5 ml of sample extract, the blank and standard solution were pipetted into labeled test tubes and 1 ml salicyclic acid added, was mixed well given 30 minutes.

10 ml of 4M sodim hydroxide added and mixed well then left for 1 hr.

Absorbance was measured at 419 nm

Plotted calibration curve and calculated absorbency for a particular standard series, read off the values of the samples and the blank calculation

Equation 6. $nitrate\ (ppm) = \frac{(a-b) * v * MCF * 1000}{w}$

Where a= conc of N in solution, b = conc N in blank, v= volume of extract, w = weight of fresh soil, and MCF = moisture correction factor