EFFECTS OF INORGANIC FERTILISERS AND FARM YARD MANURE ON GROWTH, YIELD AND TUBER QUALITY OF POTATO (*Solanum tuberosum* L.)

EGERTON UNIVERSITY LIBRARY

By

Micah Pkopus Powon

A Thesis Submitted to the Graduate School in Partial fulfilment for the requirements of the Degree of Master of Science in Horticulture.

Egerton University

June, 2005

2008/13246

EULIB

022 535

Declaration and Recommendation

This is my original work and has not been presented for the award of any other degree elsewhere

Signed.....Date.....3rd June, 2005

Micah Pkopus Powon

Declaration by the University Supervisors

This Masters Thesis has been recommended for submission to the Graduate School by us as the University Supervisors

Signed.....Date.....June 6th, 2005

Dr. Joseph. N. Aguyoh, Ph.D.

Signed.....Date.....June 3rd 2005

Dr. Vasey Mwaja, Ph.D.

2008/13246 X

© 2005
This thesis may be reproduced with prior permission from the copyright owner.

Dedication

This thesis is dedicated to my dear wife, Jacklyne Cheptoo Powon, My children: Rachel Chepkemoi, Caleb Poghisho, Ruth Cheruto and Joshua Pyeko, my dear parents: Koo-Cheptoo and Kukoto Cheptoo, finally to my late grand father Lomuke Tumukow.

ABSTRACT

Arable land in Kenya is decreasing as a result of population pressure, therefore there is need to increase production per unit area. Potato (*Solanum tuberosum* L.) being a heavy feeder of plant nutrients in the soil requires high supply of external mineral nutrients in the form of inorganic fertilisers or organic manure. Decline in soil fertility and high cost of inorganic fertilisers are limitations to potato yield improvement in Kenya. The main objective of the study was to assess the potential for producing high potato yields of good quality through use of farmyard manure with reduced quantities of phosphorus and potassium fertilisers. Potato (Variety 'Asante') was planted for 2 seasons at National Agricultural Research Center – Kitale and one season at Psigirio village (West Pokot District) during 2002 and 2003. The experimental design was Randomized Complete Block (RCB) laid in a Split-plot arrangement with three replications. The potassium levels (0, 83 and 166 K kg ha^{-1}) formed the main plots, while phosphorus (0, 52 and 100 P kg ha^{-1}) and farmyard manure (0, 10 and 20MT FYM ha^{-1}) combinations formed the sub plots. Data were collected on plant height, tuber and shoot dry weights and tuber yield. Cost-Benefit-Ratios were computed to assess the profitability of treatments. The results showed that, potassium had significant ($p \leq 0.05$) influence on potato tuber quality but not on potato tuber yield. The application of 166-kg K ha^{-1} resulted to the highest tuber quality whereas treatments without K resulted to the lowest tuber quality. Phosphorus and FYM had significant ($p \leq 0.05$) influence on plant growth as well as tuber yield but not on tuber quality. The application of 100-kg P ha^{-1} with or without FYM resulted to the highest tuber dry weight, shoot dry weight and total tuber yield. Treatments without P showed the lowest tuber dry weight, shoot dry weight and total tuber yield. The optimum combination for P and FYM application for seed potato production was obtained at any level of P with FYM rate of 10 MT ha^{-1}. High ware potato production was realized at application of 20 MT of FYM ha^{-1}. The highest CBR was realized in the application of 100 P kg ha^{-1} at NARC - Kitale season 1, 50 Kg P ha^{-1} + 20 MT FYM ha^{-1} at NARC - Kitale season 2 and the application of 83 kg K ha^{-1} + 50 kg P ha^{-1} at the Psigirio site. Results indicate that the combined use of inorganic fertiliser and manure is feasible option for soil fertility improvement for potato production.

ACKNOWLEDGEMENT

I would like to appreciate those who assisted me in my Msc. Study.

I am grateful to Dr. J.N. Aguyoh, PhD and Prof. F. M. Itulya, Ph.D. of the Department of Horticulture, Egerton University and Dr.Vasey Mwaja, Ph.D, Bayer East Africa. Their guidance, encouragement, concern and useful suggestions throughout this study enabled me to accomplish part of my dream in life.

My special thanks go to the National coordinator soil management project, Dr. J.G. Mureithi for his encouragement and financial support during the implementation of this study. I am also grateful to the Center Director NARC Kitale, Mr. C. Nkonge for the support he extended to me throughout my study. I would not forget to thank Merrs: Milo, Wafula, Sitati, Wekesa and Kamunya of NARC Kitale for their assistance in soil and plant tissue analysis.

Finally, I wish to thank my dearest wife Jacklyne. Her and our children Chepkemoi, Poghisho, Cheruto and Pyeko were great inspiration and contributed vastly for the completion of my studies.

TABLE OF CONTENTS

Declaration and Recommendation ii
Dedication iv
Abstract v
Acknowledgement vi
Table of Contents vii
List of Tables ix
List of figures xi
List of Apendices xii
List of acronyms xiii

CHAPTER ONE 1

1.0 INTRODUCTION 1
1.1 Statement of the problem 3
1.2 Objectives 3
1.3 Hypotheses 3
1.4 Justification of the Study 4

CHAPTER TWO 5

2.0 LITERATURE REVIEW 5
2.1 Effects of organic fertilisers on soils 5
2.2 Effects of inorganic fertilisers on soils 7
2.3 Effects of Organic and Inorganic Fertilisers on Plant Nutrients 8
2.4 Effects of nitrogen, phosphorus and potassium on growth, yield and yield components of potato 9
2.5 Effects of FYM on potato growth and yield 11
2.6 Farmers Field Schools 12

CHAPTER THREE 13

3.0 MATERIALS AND METHODS 13
3.1 Study Sites 13
3.2 Duration of the study (NARC - Kitale) 13
3.3 Farmer Field School (F.F.S.) Psigirio 13
3.4 The Experimental design. 14
3.5 Fertilisers used 14
3.6 Treatments 15
3.7 Cultural practices. 17
3.8 Data taken 17
3.9.0 Quality of potato tubers 18
3.9.1 Determination of crisping quality 18
3.9.2 Determination of chips (French fries) quality 18
3.10 Data analysis 19
3.11 Economic analysis 19

CHAPTER FOUR 20

4.0 RESULTS AND DISCUSSIONS 20
4.1 Growing seasons precipitation and temperature NARC - Kitale 20
4.2.0 Effects of farmyard manure, phosphorus and potassium on growth of potatoes. 22

4.3 Effect of farmyard manure, phosphorus and potassium on potato yields and yield components 38
4.4 The effect of potassium on the chipping and crisping quality of potatoes 48
CHAPTER FIVE 54
5.0 CONCLUSIONS AND RECOMMENDATIONS 54
REFERENCES 59

List of Tables

Table (No) **Pp.**

1. The Effect of phosphorus and farmyard manure on plant height NARC - Kitale season 2, 2003 23
2. The Effect of phosphorus and farmyard manure on plant height Psigirio, 2003 24
3. The effects of Phosphorus and FYM on plant height, NARC – Kitale season 1 and season 2, and Psigirio, 2003 27
4. Chemical composition of FYM used in the NARC - Kitale and Psigirio trials, 2003 28
5. Chemical composition of soil samples from NARC - Kitale and Psigirio before planting, 2003 29
6. The effects of farm yard manure and phosphorus level on the tuber and shoot dry weight 70 DAP NARC - Kitale site season 2 and Psigirio site, 2003 33
7. The effects of potassium, phosphorus and farmyard manure on tuber and shoot dry weight 70 DAP, at NARC - Kitale season 2, 2003 35
8. The effects of Potassium, Phosphorus and FarmYard Manure on root and shoot dry weight 70 DAP, Psigirio site 2003 36
9. The effect of farmyard manure, potassium and phosphorus on the yield of potatoes in season 1 at NARC Kitale site, 2003 39
10. The effect of farmyard manure, potassium and phosphorus on the yield of potatoes in season 2 at NARC Kitale site, 2003 40
11. The effect of farmyard manure, potassium and phosphorus on the yield of potatoes Psigirio 2003 41
12. The effects of farm yard manure and phosphorus on the yield of potatoes, NARC - Kitale season 1 and 2 and Psigirio, 2003 44
13. The effects of farmyard manure and phosphorus on tuber number NARC - Kitale season 1 and 2, and Psigirio 2003 47
14. The effect of potassium on chipping and crisping quality NARC - Kitale Season 1 and 2, and Psigirio, 2003 49
15. Economic Analysis season 1 NARC - Kitale, 2003 51
16. Economic Analysis season 2, NARC - Kitale, 2003 52

17. Economic Analysis Psigirio 2003.....53

List of figures

Figure		Pp.
1.	Field Layout	16
2.	Temperature and Rainfall distribution at NARC – Kitale	21
3.	The effect of potassium on tuber dry weight	31

List of Appendices

Appendix **Pp.**

I. Chemical composition of soil samples from plots, NARC - Kitale season 2, after harvesting, 2003.....55

II. Chemical composition of soil samples from Psigirio after harvesting, 2003.....57

List of acronyms

KARI – Kenya Agricultural Research Institute

NARC - National Agricultural Research Center

SMP – Soil Management Project.

MOA & RD. – Ministry of Agriculture and Rural Development.

TSBF – The Tropical Soil Biology and Fertility

CHAPTER ONE

1.0 INTRODUCTION

Potato is an important horticultural crop used for human food as well as animal feed (CAB International, 2000). In Kenya, potato ranks the highest horticultural crop in terms of hectarage accounting for 108,516 ha, yielding 670,303 MT, followed by cabbages covering 18,702 ha and yielding 267,336 MT, (MOA & RD, Annual report, 2000). In West Pokot District, potato ranks first, accounting for 650 ha, yielding 4,950 MT, followed by cabbages, which occupies 175 ha (MOA & RD, West Pokot Annual report, 2000). The tubers are boiled or steamed, baked, roasted, or used as chips. Every 100 gms of potato is composed of; 78% water, 75 calories of energy, 2.0 g of protein, 19 g of carbohydrates, 10 mg calcium, 0.2 mg iron and 15 mg vitamin B_1 (CAB International, 2000).

Potato is herbaceous, dicotyledonous plant that grows to a height of 0.6–1.5 m or more depending on the variety and growing conditions. The leaves are compound, pinnate, oppositely paired. The root system, which is largely fibrous, is distributed within the top 40–50 cm of soil. The flowers are borne in clusters. The tuber is a fleshy stem bearing buds or 'eyes', which originate as swellings at the end of rhizomes. When rhizome tips come into contact with soil, the tuber starts to enlarge.

Potato requires well-distributed rainfall between 300-460 mm in a growing period of 90-105 days. Temperature influences potato growth. For optimum production, night temperatures should be below 20°C and day temperatures of 20-25 °C. Potato does well in a wide range of soils (with pH 4.8-7.0) except in heavy and water logged clays, which impairs it's growth (CAB International, 2000). Developing countries have to intensify food production in order to match food requirements for increasing population (Roy et al., 1981). Besides insect pests and diseases, low soil fertility is a major constraint to potato production in West Pokot District (SMP Annual Report 1995). The mean potato yield in West Pokot District is 8 MT ha^{-1} (MOA & RD, Annual report, 2000), which is much less than 30 - 40 MT ha^{-1} realized in Kenya and other parts of the world with the application of fertiliser N-P-K (60-60-40) (Nandasaba et al., 1999; Martin et al., 1995).

Although soil nutrient deficit can be met from various sources such as crop residue, farmyard manure, and fixation by legumes or inorganic fertilisers (Brady, 1990), farmers in West Pokot region have been using farmyard manure (FYM) on crops without any defined application rates. The use of FYM on low value crops, such as maize, is not as economical as when used on

high value crops, such as potatoes. Therefore, there is need to encourage the use of organic manure on high value crops to enhance productivity and farmers' income.

There has been an increasing concern that agricultural technologies that have been developed by extension and research institutions are inappropriate and have not adequately benefited small-scale farmers (Peter, 1983). To develop technologies that are easily adopted by small-scale farmers, alternative approaches for both extension and research have been initiated under Farming Research System (FRS). The FRS considered technology as a product, which directly targets the circumstances that surrounds the small-scale farmer. Hence, the knowledge about the small-scale farmer on the farming systems had to be incorporated in the process designing technologies (Cees et al., 1998). However, FRS has shortcomings in that it requires decentralized deployment in the field of expensive highly qualified staff. This has led to the adoption of Farmer Field School (FFS) in the development and scaling up of agricultural technologies (Cees et al., 1998). The FFS allows a shifting mix of Participatory Technology Development (PTD) and training. Involving farmers in field trials has always been part of FFS, as research is a methodological component of FFS (Cees et al., 1998). Studies have shown that farmer participation on research increases the adoption of generated technologies (Fischer and Wortman, 1999). Unlike Training and Visit (T &V) farmers' extension approach, which was used earlier in technology transfer, FFS is superior in that it also used in knowledge generation (Cees et al., 1999). If developing countries are to meet national food requirements and alleviate rural poverty, millions of small-scale farmers must become active participants in agricultural research and development process (Whyte and Boynton, 1983).

1.1 Statement of the problem

Arable land is decreasing as a result of population pressure, therefore there is need to increase production per unit area of land. Potato being a heavy feeder of plant nutrients in the soil requires high supply of external mineral nutrients in the form of inorganic fertilisers or organic manure. Decline in soil fertility is a widespread limitation to potato yield improvement in Kenya. Potato production in West Pokot is mainly constrained by poor soil fertility and high cost of inorganic fertilisers. Therefore, farmers use little or no fertiliser inputs, which lead to low crop yield.

1.2 Objectives

The main objective of the study was to assess the potential for producing high potato yields of good quality through use of farmyard manure with reduced quantities of phosphorus and potassium fertilisers.

The Specific Objectives

1. To determine the effect of inorganic (potassium and phosphorus) fertilisers, organic manures (FYM) and their combination on the yield and quality of potato.
2. To determine if interaction exists between FYM and inorganic fertilisers on the yield and quality of potato.
3. To determine the highest Cost Benefit Ratio (CBR) and the net returns of using FYM and inorganic fertilisers for potato production.

1.3 Hypotheses

The hypotheses tested in this study were;

1. Inorganic (potassium and phosphorus) fertilisers, organic manures (FYM) and their combination have the same effect on the yield and quality of potatoes.
2. There is no interaction that exists between FYM and inorganic fertilisers on the yield and quality of potato.
3. Farmyard manure and inorganic fertilisers use on potato production have similar effect on Cost Benefit Ratio (CBR) and the net returns.

1.4 Justification of the Study

The use of farmyard manure (FYM) in cultivation cycle is aimed at replenishing organic matter and plant nutrients. The use of cattle manure as a source of nutrients is common in most agro-pastoral systems and its effect can be boosted by combination with inorganic sources (Nhamo and Murwira, 2000). Maximizing fertiliser use efficiency through combined use of organic and inorganic resources is a promising entry point into smallholder systems (Woomer et al., 1999). Manure from livestock is an important source of plant nutrients for crop production and can help farmers reduce the use of inorganic fertilisers (Schleich, 1986). Previous work done by the Soil Management Project (SMP) involved trials that compared the effects of organic manure, organic/inorganic fertiliser combinations and inorganic fertilisers with the aim of developing low cost soil fertility improvement options (SMP Annual Report, 2000), for low value crops such as maize. However, its potential in improving potato yield is not clear.

Furthermore, agricultural technologies are poorly adopted by farmers due to lack of farmer participation in technology development and dissemination. Therefore, involvement of farmers in agricultural research right from technology development will enhance the acceptance of the technology.

CHAPTER TWO

2.0 LITERATURE REVIEW

Soil properties have great influence on yield and quality of potatoes. This review covers; (a) Effects of organic fertilisers on soils, (b) effects of inorganic fertilisers on soils (c) effects of organic and inorganic fertilisers on plant nutrients, (d) effects of nitrogen, phosphorus and potassium on potato growth, yield and yield components, (e) effects of farmyard manure on potato growth and yield, and (f) Farmers' Field Schools.

2.1 Effects of organic fertilisers on soils

Soil nutrient deficit can be met from four sources; crop residue, farmyard manure, legumes, and use of commercial fertilisers (Brady, 1990). Soil organic manure supply nutrients for plants and the carbon containing compounds that serve as food for small animals and microorganisms. Organic manures also improve soil structure directly by their action as bulky elements in the compacted soils, or indirectly when the waste products of animals or microorganisms act as cement to bind soil particles together (Cook 1967; Roy et al., 1981; Aggarwal et al., 1995). Woomer et al. (1999) reported that strategic application of organic manure and their supplementation with externally derived nutrients are fundamental principles of Integrated Nutrient Management (INM). Palm et al., 1997 reported that integrated use of various soil fertility amendment inputs aims at alleviating the limiting nutrients problem and improving their availability from soil reserves. For example, organic inputs can influence nutrient availability from the total nutrient added, controlling the net mineralization patterns, as a source of carbon and energy to drive microbial activities.

Jones and Wild (1975) reported that, farmyard manure has direct benefit and residual effects on crop yield due to its influence on nutrients in the soil and its effect in reducing the acidity due to it's base content in organic manure. Comparing farmyard manure and green manure, Drechsel and Reck (1997) observed that farmyard manure had higher nutrient value compared to green manure. Palm et al. (2000) reported that the functions of organic matter in the soil include nutrient supply and buffering, water retention, soil structure improvement and carbon sequestration. A Study carried out by Nyamangara et al. (2000) reported that the addition of FYM to soil resulted to an increase in carbon mineralization from the soil due to available

carbon for microbial respiration. In addition to the provision of nitrogen and phosphorus, FYM also provides potassium in the soil (Cook, 1967; Roy, 1981; Porter et al., 1999) and adds humus in the soil (Shewel et al., 1972; Porter et al., 1999). Every cultivation helps to break down humus and every crop reduces the organic matter content in the soil (Shewel et al., 1972). Work done by Martinez and Pell (2000) and Porter et al. (1999) found that addition of organic manure to the soil increases the amount of C, N, P and K in the soil and concomitantly the level of micronutrients. In their study, Misra et al. (1996) observed that, the addition of FYM in combination with straw promoted straw decomposition, which resulted into an increase in soil nutrient content. In other studies by Sharma et al. (2000) and Porter et al. (1999) it was reported that the addition of crop residues and FYM to the soil resulted to decrease in soil bulk density, improvement in water holding capacity, cation exchange capacity, available N, P and S.

Work done by Mwale (2000) found out that the residual effects of FYM on the soil remain for some years, but the supply of plant food may not. A yield of 20-22 MT ha^{-1} for potatoes exhausts nutrients from the soil immediately, especially for nitrogen, which may be leached, denitrified or volatilized from the soil. This problem can be solved by synchronizing nutrient availability to the plant demand by timely application of organic manure to the soil.

Studies in India by Sharma et al. (1995) showed that incorporation of *Lantana camara* to soil resulted to an increase in organic carbon and a decrease in bulk density of soil modified surface cracking pattern in clay loam soils. Organic matter has been found to decrease nutrient losses, especially nitrogen from the soil through leaching, control of biological transformation of organic substances and plant nutrients in the soil (Novak, 1983). Work done by Hegedorn et al. (1997) showed that the application of organic fertilisers has strong influence on N availability but the effect can be negated by high rainfall. Incorporation of leaves from 2.7-MT ha^{-1} of *Tephrosia vogelsi* and 7-MT FYM ha^{-1} doubled the mineralization flush after the first rains. Organic fertilisers also improve aeration, drainage and encourage root growth by providing pores of appropriate sizes in the structures that do become too rigid when dry or completely water logged (Cooke, 1967; Roy et al., 1981; Sikka, 1982).

The nutrients supplied by the farmyard manure are usually more important than the physical effect on agricultural crops, however improvement in soil condition may dominate its effect on some horticultural crops (Cooke, 1967). Ten tons of animal manure supplies on average 40 kg of potassium and this is fairly equal to the amount of nitrogen thus supplied as was reported by Brady, 1990. Ahn, (1993) reported that animal manures are mostly used in

maintaining fertility of cultivated soils in those areas where livestock and arable farming are either carried side by side or at least in the same area. However animal manure is bulky in relation to their nutrient content and the labour and the expenses of transporting it often discourage their use (Panjek and Jelanic, 1983; Woomer et al 1999; Smith et al., 2000). Nitrogen added to the soil can be fixed, or biologically incorporated into organic substances or incorporated into soil microorganisms.

Nitrogen in organic form is mineralized and nutrients made available for plant use (Amberger, 1983). Sharma et al. (2000) reported that, manure application to the soil has a strong liming effect, raises soil pH and increases magnesium, potassium levels and nutrient content of the soil. Work done on pigs by Bicudo et al. (1999) showed that the mean annual Total Kjedahl Nitrogen (TKN) increased with increase in average daily live animal weight per cubic meter of lagoon volume. Van Faassen and Vad Dijk (1987) reported that young animals which are fed with more digestible feed because of their lower digestive capabilities produced manure that was rich in N (eg. veal calf manure) and contained less fiber. A healthy pig supplied with high phosphorus feed material excretes manure with high phosphorus content as reported by Poulsen (2000).

2.2 Effects of inorganic fertilisers on soils

Woomer et al. (1999), reported that inorganic fertilisers offer several advantages to the soil; (i) they provide the most concentrated form of plant nutrient, (ii) rapidly dissolve into available forms upon application and buyers know the nutrient contents of purchased fertilisers which facilitates calculation of application rate and timing. However, inorganic fertilisers are disadvantageous in that, (i) excessive rates can cause pollution of ground water and aquatic system and (ii) can easily be leached or adsorbed in the soil colloids.

Mugambi (1979) reported that potash application to the soil increases potassium availability, but at higher levels it induces magnesium (Mg) deficiency. However, nitrogen applied as calcium ammonium nitrate (CAN) enhances the availability of Mg in the soil. On the other hand, application of N, P and K to soil enhances the availability of phosphorous in the soil. Likewise nitrogen and potash application to the soil increases the soil nitrogen level because in organic elements when applied to the soil is readily available for plant absorption. Minhas and Gulap (1998) reported that the application of inorganic nitrogen with FYM to the soil increased N recovery, which resulted to increased crop yield when compared to application of inorganic

nitrogen alone. Inorganic phosphate application when applied to the soil in combination with FYM reinforces the generally low phosphate in FYM and reduces nitrogen losses as ammonia (Ahn, 1993). Sikka (1982) reported that nitrogen stimulates haulm development from sprouting to flowering period and subsequently increased leaf production, expansion and increase tuber yield in potatoes. The same author reported that phosphorus application increases meristematic activity, leaf expansion, improves development of vascular system, stimulates root growth and hastens maturity in potatoes. Potassium was also reported to play a great role in the synthesis of sugar and starch and enables growth to continue longer in dry weather (Sikka, 1982).

2.3 Effects of Organic and Inorganic Fertilisers on Plant Nutrients

A potato crop on average yield in the tropics may remove 50-80 kg N ha^{-1}, 20-30 kg P_2O_5 and 80-100 kg K_2O ha^{-1} from the soil. Therefore application of fertilisers and manure is essential to maintain economic yields (Sikka, 1982). Studies have shown that the method of handling, storage and management of farmyard manure is an important aspect on the quality of manure (Smith et al., 2000; Wanjekeche et al., 1999; Woomer et al., 1999). Poor handling may lead to especially loss of nitrogen through ammonia volatilization (Chambers et al., 2000; Nzuma and Murwira. 2000). Provision of shelter is an important aspect in maintaining the quality of manure (Chambers et al., 2000; Wanjekeche et al., 1999; Woomer et al., 1999). Russell (1921) reported that potatoes grown with sheltered manure gave higher yields than non-sheltered manure.

Although FYM will nourish a crop (Smith et al., 2000; Roy 1981) it has limitations since it cannot supply all the nutrients required by the plant. Studies in Aberdeen showed that increasing the amount of FYM from 10 - 20 MT ha^{-1} increased the yield of turnips from 22 - 37 MT ha^{-1} (Russell, 1921). Farmyard manure adds nutrients that are available for plant growth over a longer period of time (Ahn, 1993; Roy 1981), thus benefiting both the current crop as well as the subsequent crop in rotation (Ahn, 1993). For example in a rotation experiment at Cambridge, the addition of FYM not only increased the yield of marigold crop, but also two crops of oats and wheat which followed it, with higher yields being realized when there was combination of FYM and inorganic fertilisers (Russell, 1921).

The nutrient content of FYM varies widely depending on the type of animal, quality of its food supply, age and health of the animal. Sheep and goat manure are more concentrated than cow manure (Nkandu et al., 1999; Ahn, 1993). The use of FYM in combination with other quick acting inorganic fertilisers is more profitable. Phosphate in particular is mixed with animal

manure to reinforce the generally low phosphate content and reduce the nitrogen losses as ammonia (Ahn, 1993).

2.4 Effects of nitrogen, phosphorus and potassium on growth, yield and yield components of potato

Early application (at planting) of nitrogen to potatoes followed by split application (5 weeks after planting) of nitrogen at the rate of 150 kg N ha^{-1} led to a fast early growth and the greatest tuber yield when compared to late application of nitrogen (Gathungu et al., 2000). Maier et al. (1994) observed that the application of 360 kg N ha^{-1}, 320 kg P $ha^{-1}$and 480 kg K ha^{-1} at five experimental sites in Australia resulted to increased potato total tuber yield by 13 – 432%, 19 – 145% and 19 – 89%, respectively. The application of phosphates in the tropics favours its effect on starch content, hastens the ripening and promotes healthy condition of potato tubers as reported by Mugambi, 1979. Houghland (1960) reported that potatoes require large amounts of phosphorus because phosphorus is important in starch phosphorylation. Both potash and farmyard manure have been reported to increase K content in potato leaves and increase the available K in the soil. However, potash reduced magnesium content in potato leaves while manure increased the magnesium content in potato leaves. May be FYM enhanced the uptake of Mg by plants (Mugambi, 1981). Mwania, (1983) observed that the application of both nitrogen and phosphorus promotes leaf growth of potatoes during the early stage of development. However, in the later stages of growth, phosphorus hastened leaf senescence whereas nitrogen maintained high leaf area index (LAI).

In addition to increasing LAI, nitrogen also enhances the leaf area duration and increased tuber number per hill and tuber size (Mwania, 1983). Increasing nitrogen and phosphorus application resulted to increased percentage of ware size potato tubers and reduced the seed size potatoes. The concentration of nitrogen and phosphorus in leaves increased with increase in nitrogen and phosphorus application (Mwania, 1983). Nitrogen and phosphorus are important in tuber initiation, but they must be combined in the right ratio. For example, it has been found that the optimum combination is 100 kg. P_2O_5 ha^{-1} plus 75 Kg N ha^{-1} (Mwania, 1983).

Russell (1921) reported that potatoes often respond to complete dressing by inorganic fertilisers in addition to FYM. Large dressing of FYM at 50 MT ha^{-1} was not found to be much more effective than smaller quantities (25 MT ha^{-1}). However, best results were obtained by combining both inorganic fertiliser and FYM. This is so because; the potato nutrient

requirements (150 kg N ha^{-1}, 230 kg P_2O_5 ha^{-1}) are very high due to its shallow root system and short crop duration (AIC, 1981; Sikka, 1982). Also Jacob (1963) reported that potato forms large quantities of dry matter within a relatively short growing period. Such potatoes need high quantities of nutrients, which cannot be met by use of FYM or soil alone. Under these circumstances, organic manure must be supplemented in organic fertilisers.

The effects of nitrogen on potatoes are seen in the more rapid and larger development of haulms and leaves and delayed ripening. An excess of nitrogen if very little of K is present, promotes development of haulms at the expense of tuber formation and the starch content (Jacob, 1963). The findings of Panique et al. (1997) reported that increasing the application of K from 0-kg K ha^{-1} to 332-kg K ha^{-1} resulted to an increased average tuber weight of potatoes from 170g to 370g. Studies by Westermann et al. (1994) on potatoes reported that, while N application increased reducing sugars at the apical tuber ends, the reverse was true at the stem. However K application decreased reducing sugars in both tuber ends. Both N and K applications reduced dry matter and starch concentration in both tubers ends (Westermann et al., 1994).

Hill (1953) reported that potato chips made from tubers grown without potassium application were found to be dark brown and inferior quality whereas those grown with potassium application were less mealy and whiter after cooking. Walte and Muller (1966) reported that increased potassium supply to plants improved potato quality. This is because increased application of potassium to plants decreases the tendency of raw macerated tubers to darken. With increasing application of potassium to plants, sugars, polyphenol oxidase activity and amino acids (except glutamic and aspartic) decrease in tubers. Supply of potassium helps in hardening of cell tissue of potatoes. Potatoes suffering from potassium deficiency are susceptible to bruising, and therefore, short shelf life (Jacob, 1963). Bruised tubers expose the hilum cells of the potatoes to high respiration rate, which in turn results to susceptibility to pathogen attack and the whole tuber decays. The intensity of respiration is considerably reduced by good supply of potash and by this means losses in storage are correspondingly diminished (Jacob, 1963). Studies by James et al. (1994) found out that soil nitrogen has a large positive effect on petiole K and Mg levels and to a lesser extend petiole Ca levels.

2.5 Effects of FYM on potato growth and yield

Soil nutrient balance studies in Africa have shown evidence of widespread nutrient mining which has led to severe nutrient deficiencies across ecological zones (Esiliba et al., 2001). Palm et al. (2000) reported that nutrient depletion is a reversible constraint and high agricultural production can be realized with appropriate soil nutrient management including integrated use of organic and inorganic sources of plant nutrients. Woomer et al. (1999) reported that one way of replenishing nutrients in the arable lands is to recycle nutrients through application of organic materials such as litters, crop residues and manure. Burton (1966) reported that the application of FYM to potatoes resulted to an increase in yield of potatoes but may have had an adverse effect upon the percentage matter in potato tubers.

Studies by Irungu et al. (2000) showed that the application of 90 kg N ha^{-1} + 230 kg P_2O_5 ha^{-1} (full rate inorganic) and the application of 45 kg N ha^{-1} + 115 kg P_2O_5 ha^{-1} (half rate inorganic) combined with 2.5 MT FYM ha^{-1} (half rate organic) had no effect on the yield of potatoes. However, the application of FYM resulted to lower tuber yield compared to the application of inorganic fertilisers. Work done by Opena and Porter (1999) on soil amendment using FYM and poultry manure showed increased root length density and LAI with increase in poultry manure application. Both parameters were highly correlated with tuber yield. In a related study, Ranganathan and Selvaseelan, (1997) reported that the application of FYM and Spent Mushroom Compost (MSC) appreciably enhanced the uptake of N, Fe and Zn in potatoes which were almost comparable in their effects whereas the P uptake was significantly increased by FYM. A study carried out by Minhas and Sood (1994) showed that increased FYM application and closer spacing of potato resulted to increased potato yield. However, the N P K uptake increased with increase in FYM application rate but not with change of potato spacing. Studies by Porter et al. (1999) showed that soil amended with 45 MT FYM ha^{-1} resulted to increase of potato total yield by 23 % when compared to non amended soil. The soil amendment also resulted to increased soil organic matter, K, Mg, Ca, P, cation exchange capacity and decrease in soil bulk density. Work done by Porter et al. (1999) found out that soil amended with 22 MT ha^{-1} compost and 45 MT ha^{-1} of FYM resulted to increased organic matter, K, Mg, Ca, cation exchange capacity, phosphorus and decreased soil bulk density. The amendment also increased potato yield by 23 % in the first season, by 27 % in the second season and by 11 % in the third season.

2.6 Farmers Field Schools

In Farmers Field Schools (FFS), farmers and extension workers and/or researchers gather on a weekly basis. They study, analyze the progress of their crops, learn the biotic interactions between soil, plant and pests, chart the dynamics of insect populations, and finally bring this knowledge together to make informed crop management decisions (Quizon et al., 2000).

The FFS were introduced in 1989 at central Java, Indonesia, and mainly targeted the Indonesian Integrated Pest Management (IPM) rice programs (Mweri, 2001). The FFS approach in IPM was developed to allow farmers generate their own scientific innovations in their own fields as a basis for crop management decisions. The approach has undergone rapid development and has been applied in production of wide range of crops. Currently, Farmers Field Schools approach to extension is being implemented in many developing countries including Kenya (Quizon et al., 2000). The FFS approach was introduced in Kenya in 1995 (Mweri, 2001), and among the first crops to be addressed were maize, sweet potatoes and indigenous vegetables. The pilot districts were Kakamega, Bungoma, Busia, Kwale, and Kilifi (Mweri, 2001). In West Pokot District FFS was introduced in 2002.

Farmers Field School entails learning session, farmer experimentation and non-formal education methods targeting groups of farmers (Mweri, 2001). The FFS approach relies on participatory training methods to convey knowledge to field school participants so as to make them into technical experts self-teaching, experimenters and effective trainers of farmers (Rola, 1998). A study by Rola et al. (1998) at Indonesia, found out that those farmers who graduated from FFS were able to carry out their own experiments. Farmers experimented on planting different rice varieties in different plots during a season, using different mixes and new kind of fertilisers, which enabled farmers to verify and come up with suitable rice varieties and fertiliser rates for their locality.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Sites

The study was carried out at two sites

i) NARC - Kitale site at National Agricultural Research Centre (NARC) Kitale, which lies at longitude of 35° 7.5' E, latitude 1° N and an altitude of 1890 m above the sea level. The area receives an average rainfall of 1182- mm per annum.The soil type is Rhodic Ferrasols which are well-drained, very deep, dark to dark red, very friable to friable clay, with a pH of 6.8. The mean maximum temperature is 25°C, mean temperature of 18.3°C, and mean minimum temperature of 11.5°C (Jaetzold and Schmidt, 1983).

ii) A FFS established at Keringet Location (Psigirio village), West Pokot District, which lies at longitude of 35° 15' E, latitude 1° 15' N and an altitude of 2000 M above the sea level. The area receives an average rainfall of 1289-mm per annum The soil type is Humic Cambisols and Humic Acrisols which are well drained, moderately deep to deep, dark reddish brown to brown, friable to firm, sandy clay loam to clay, with a pH of 6.8. The mean maximum temperature is 23.4°C, mean temperature of 16.3°C, and mean minimum temperature of 9.3°C (Jaetzold and Schmidt, 1983).

3.2 Duration of the study (NARC - Kitale)

The study was conducted in two seasons at NARC Kitale. The first season commenced in October 2002, and ran for three months from (October 2002 to January 2003). The second season was from March 2003 to June 2003. During the dry season supplementary irrigation was done using sprinkler irrigation.

3.3 Farmer Field School (F.F.S.) Psigirio

A farmer field school was established at Psigirio village in West Pokot District. The farmer field school group consisted of fifty one (31 females and 20 men) farmers. The farmers were divided into three groups of eighteen farmers each. The Farmer Field School lasted for the entire potato-growing seasons (May to August 2003) for the observation of all stages of potato development. The school met once per week. The time schedule for a field school day took about three hours per day and it started early in the morning as proposed by Fliert et al. (1996) as shown bellow

08:00 – 09:00: Field Observation: The participants sampled an observation field with each group making observation in one main plot of block I. The school members were identified on the basis of those farmers who were willing to enroll in the school.

09:00- 10:00: Agroecosystem Analysis (AESA): The farmers took data on: days to germination, plant height, days to maturity, weight and number of tubers per plot.

10:00 – 11:00: Presentation and Discussion: On weekly basis, each sub groups presented their findings to other farmers and the participants decided on what action to take for example if the plots are weedy then weeding was recommended.

11:00 – 11.15: Group dynamic exercise: was done to enliven the school and strengthen the field school

11.15 – 12.00 Special topics: These included experiments, lesson exercises and discussions on special topics dealing with problems the field school farmers are facing at a given particular moment.

12:00: Closing the school.

3.4 The Experimental design

The experimental design was Randomized Complete Block (RCB) in Split-plot arrangement with three replications. The potassium levels formed the main plots, while phosphorus and farmyard manure combinations formed the sub plots. The potassium levels were considered in the main plot because of potassium high mobility in the soil. The main plot size was 10 m x 10 m separated by 1 m path and subplots were 3 m x 3 m with 0.5 m path separation between them. The potato variety used in this trial was Asante (source from Timboroa, Kenya), the most preferred variety in the north rift of Kenya (Nandasaba et al., 1999). Potatoes were planted at a spacing of 75 cm X 30 cm.

3.5 Fertilisers used

Two types of fertiliser sources were used in this study: organic and inorganic sources. The inorganic source was Triple Supper Phosphate (TSP), muriate of potash (KCl) and Calcium ammonium nitrate (CAN) applied at the rate of 75 kg N ha^{-1} uniformly to all plots five weeks after crop emergence, whereas the organic source was farmyard manure (FYM). The FYM used

was 'ripened boma manure' from the same 'boma'. The FYM was analyzed to determine the mean N, P and K content before application. The manure was spread (at the rate of 0, 10, 20 MT ha^{-1}) to their respective plots immediately after ploughing, and then incorporated into the soil. For the inorganic fertiliser, TSP and KCl were drilled along the furrows and mixed well with the soil (to avoid scorching) before planting but CAN applied as a top dress five weeks after emergence before the second earthing up of the potatoes.

3.6 Treatments

Main plot

Potassium: K_1 = no K

K_2 = 83 kg K ha^{-1}

K_3 = 166 kg K ha^{-1}

Subplots

Phosphorus: P_1 = no P

P_2 = 50 kg P kg ha^{-1}

P_3 = 100 kg P kg ha^{-1}

FYM: FYM_1 = No FYM

FYM_2 = 10 MMT ha^{-1}

FYM_3 = 20 MMT ha^{-1}

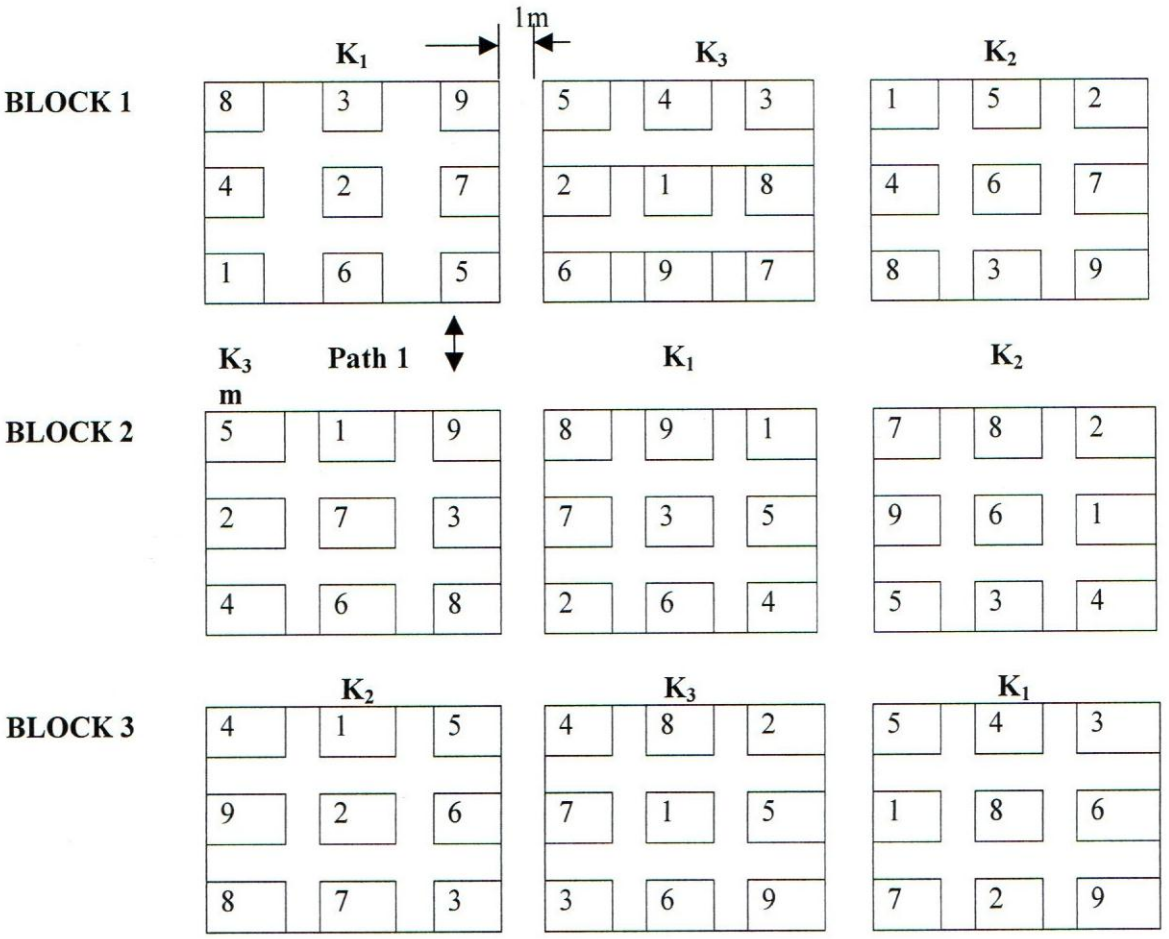


Figure 1. Field Layout

KEY

Main plot treatments

K_1 = no K K_2 = 83 kg K ha^{-1} K_3 = 166 kg K ha^{-1}

Sub-plot treatments

1 = P_1 FYM_1 4 = P_2 FYM_1 7 = P_3 FYM_1

2 = P_1 FYM_2 5 = P_2 FYM_2 8 = P_3 FYM_2

3 = P_1 FYM_3 6 = P_2 FYM_3 9 = P_3 FYM_3

Phosphorus levels

P_1 = no P P_2 = 50 kg P ha^{-1} P_3 = 100 kg P ha^{-1}

FYM levels

FYM_1 = No FYM FYM_2 = 10 MT FYM ha^{-1} FYM3 = 20 MT FYM ha^{-1}

3.7 Cultural practices.

The standard cultural practices such as weeding, pest and disease control were carried out uniformly in all plots. Routine spraying to prevent fungal diseases, such as late blight was done using Dithane M 45 (Mancozeb) at 2-kg ha^{-1}. For insect (whiteflies, aphids etc) control, Bulldock (Beta cyfluthrin) at the rate of 1 L ha^{-1} was used. Weeding commenced after the potatoes had germinated (3 weeks after planting) to avoid uprooting the seed tubers. Earthing up (ridging) along the rows was carried twice before the plants fully covered the spaces between the rows (8 weeks after planting), after which no more weeding or earthing up was done to avoid destruction of haulms.

3.8 Data taken

(i) Soil analysis

Soil sampling was done before planting the potatoes. This was done to compare the soil nutrient status before planting and after harvesting potatoes. Soil samples were taken by use of an auger randomly in the plots where the potatoes were planted. Two sample depths were taken, top soil (0 – 15 cm) and sub soils (15 – 30 cm) from each plot. A total of 27 samples were taken from each site. The soil samples were then oven dried at 65 °C for 24 hours, after which the soils were then passed through a 2-mm sieve and 0.6 mm sieve. The soil particles that passed through a 0.6 mm sieve were used for carbon determination while those retained by 2-mm sieve were used for analysis of other elements such as Na, K, Ca, Mg, Mn and P.

(ii) Plant height

The heights of 5 plants randomly selected from the center of each plot were recorded at 30, 37, 44, 51, 58, 65 and 72 days after planting (DAP). The plant heights were taken using a meter rule when all haulms were held upright.

(iii) Potato biomass and plant tissue analysis

Dry mass of haulms (all parts above the ground level) and tubers (roots, stolon and tubers) were determined 70 DAP by digging out three hills at random from the inner rows. The plant parts were oven dried at 70 °C until constant weights were attained. The tubers were chopped into smaller pieces to facilitate uniform drying. The plant tissues were milled using a laboratory hammer mill to make a powder for use in plant tissue analysis.

(iv) Number and weight of tubers

The number of tubers were determined by harvesting an area of 2.25 m^2 (10 hills) at the center of each plot and counting the number of tubers before sorting them in to ware, seed and chats. The weights and the number of ware and seed were then determined and the results expressed per hectare. Grading was done using a sieve. Tubers that did not pass through a 62.5-mm sieve were recorded as ware, while those that passed through a 62.5-mm sieve but not through a 32.25-mm was recorded as seed and tubers that passed through a 32.25-mm sieve were recorded as Chats (Biotechnology Trust Africa, 2001).

3.9.0 Quality of potato tubers

This was determined on the basis of consumer's preferences for chips and crisps as described in sub sections 3.9.1 and 3.9.2.

3.9.1 Determination of crisping quality

A representative tuber sample of 1kg was used in the determination of crisp quality. Peeled thin slices of the tubers were then deep-fried in cooking oil for 10 minutes. Trained panel of seven members (from National Agricultural Research Center, Kitale) was used to evaluate the quality of fried slices. Their judgment were based on colour (golden yellow), flavour (real taste of potatoes), texture (crispy) and overall acceptability. The scale used in the evaluation was 1 - 6 (where 1 refers to extremely disliked; 2, disliked; 3 fairly disliked; 4, fairly liked; 5, liked and 6 extremely liked). Trained seven-member panel determined the criteria used.

3.9.2 Determination of chips (French fries) quality

A representative tuber sample of 1kg was used in the determination of chipping quality. Potatoes were peeled and chipped into thin slices using a potato chipper. The chips were then deep-fried in cooking oil for 10 minutes. Trained panel of seven members (from National Agricultural Research Center, Kitale) was used to evaluate the quality of fried chips, depending on the colour (golden yellow), flavour (real taste of potatoes), texture (crispy) and overall acceptability. The scale used in the evaluation was 1 - 6 (where 1 refers to extremely disliked; 2, disliked; 3 fairly disliked; 4, fairly liked; 5, liked and 6 extremely liked).

3.10 Data analysis

The data collected was subjected to analysis of variance (ANOVA) using SAS program. Duncan's Multiple Range test were used to separate treatment means, which were significantly different ($p \leq 0.05$), (Gomez and Gomez, 1984). Some parameters (tuber yield and tuber number) were transformed by taking the logarithms to base 10 before subjecting to the analysis of variance (Gomez and Gomez, 1984). The transformed data were reconverted to the original form before reporting.

3.11 Economic analysis

Economic analysis (Cost-Benefit-Ratio) was done to assess the profitability of various fertiliser combinations (Upton, 1987). The Cost Benefit Ratio (CBR) was calculated using the formula: CBR = (Gross income–Variable Cost)/Variable Cost. Partial budget was performed in order to ascertain the net income of the treatments.

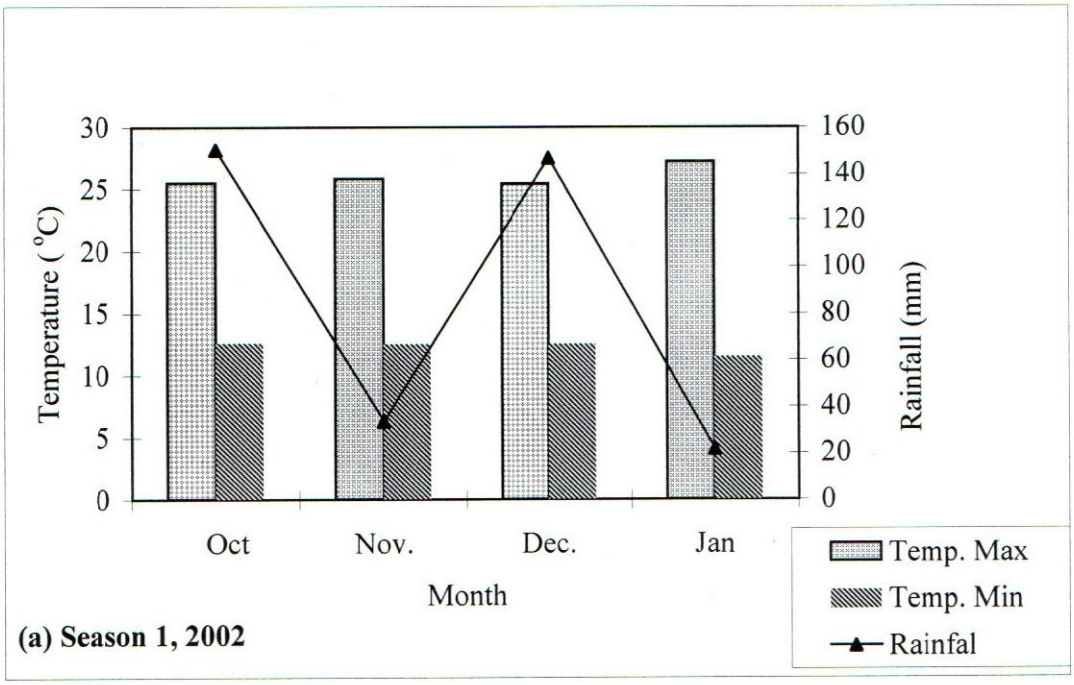
CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

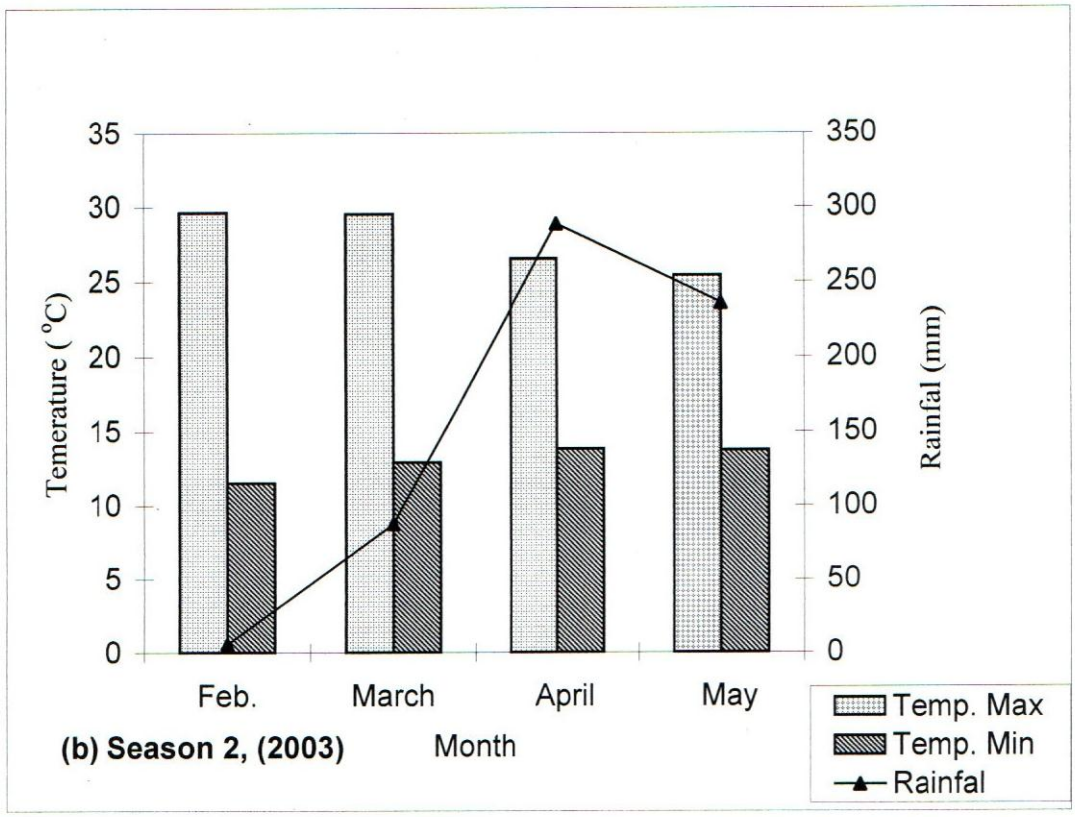
The results of this study are presented under the following sub – topics: (i) Growing seasons' precipitation and temperature, (ii) effects of farmyard manure, phosphorus and potassium on growth of potatoes (iii) effect of potassium, phosphorus and farmyard manure on plant height, (iv) effect of potassium on shoot and tuber dry weight, (v) effects of phosphorus and farmyard manure and their combinations on shoot and tuber dry weight, (vi) effects of phosphorus and farmyard manure on shoot and tuber dry weight, (vii) effects of phosphorus and farmyard manure on yield and yield components, (viii) effects of farm yard manure, potassium and phosphorus on shoot and tuber dry weight, (ix) effects of farm yard manure phosphorus and potassium on yield and yield components, (x) effects of farm yard manure and phosphorus on total tuber yield, (xi) effects of potassium on total tuber and seed yield of potatoes, (xii) effects of phosphorus on total tuber yield, ware and seed yield potatoes and (xiii) effect potassium on chipping and crisping quality of potatoes.

4.1 Growing seasons precipitation and temperature NARC - Kitale

The distribution of moisture and temperature are shown in Table 1 for the NARC - Kitale. There was no temperature and rainfall record taken at Psigirio. The total amount of rainfall received in season 1 (Oct. 2002 to Jan. 2003) at NARC – Kitale was 352.8 mm and in season 2 (January to April 2003) it was 620.5 mm. In both seasons 1 and 2 NARC - Kitale, there was fair distribution of rainfall throughout the potato-growing period but supplemental irrigation was done in season 1 at NARC - Kitale but no irrigation was done in season 2. In season 2 there was high amount of rainfall compared to season 1, which resulted to high incidence of early blight when compared to season 1 NARC - Kitale. The distribution for average monthly temperature and rainfall distribution is shown in Figure 2.



(a) Season 1, 2002



(b) Season 2, (2003)

Figure 2. Monthly temperature (°C) and rainfall (mm), NARC Kitale, 2002 - 2003

EGERTON UNIVERSITY LIBRARY

4.2.0 Effects of farmyard manure, phosphorus and potassium on growth of potatoes.

4.2.1 The effect of potassium, phosphorus and farmyard manure on plant height.

At NARC - Kitale (season 1 and 2) and Psigirio, potassium had no effect on plant height. Phosphorus and FYM had no effect on plant height at different days after planting at NARC – Kitale, season 1. However, at NARC - Kitale season 2 and Psigirio, P and FYM had effect ($P \leq 0.05$) on plant height at different days after planting (Tables 2 and 3). The control plots resulted to significantly the lowest plant height, whereas plots applied 100 Kg P ha^{-1} with or without FYM resulted to the tallest plants.

At maturity (70 days after planting), at NARC - Kitale season 2, the tallest plants (73.5 cm) were observed in plots with 100 kg P ha^{-1}+ 20 MT FYM ha^{-1} (Table 1). However, the control treatment and the application of 10 MT FYM ha^{-1}, gave the shortest plant height (55.4-cm). At Psigirio at maturity (70 days after planting), the application of 100 kg P ha^{-1} + 10 MT FYM ha^{-1}, resulted in to the tallest plants (48.2 cm) compared to the control treatment which had significantly the shortest plants 31.4 cm (Table 2). Low phosphorus treated plants showed plants of reduced height. The results were similar to studies by Sikka, 1982 who reported P deficiencies retard the growth of potato plants particularly during the early stages of development. However enhanced availability of phosphorus was associated with increased meristematic activities, leaf area expansion and root growth. These attributes might have resulted into significant increase of potato plant height with increase in phosphorus application as was observed (Tables 1 and 2).

Table 1. The effects of phosphorus and farmyard manure on plant height (cm), NARC - Kitale season 2, 2003

	DAYS AFTER PLANTING (DAP)						
	30	37	42	49	56	63	70
Treatments	Plant height (cm)						
Control	15.8d*	25.5c	33.7b	34.4b	46.2d	52.9d	55.4d
10 MT FYM ha^{-1}	16.7cd	27.4c	34.3b	34.9b	47.5d	53.2d	55.4d
20 MT FYM ha^{-1}	18.9bcd	30.5bc	35.7b	36.5b	48.7d	54.2d	55.7d
50 kg P ha^{-1}	21.4abc	32.9ab	42.1a	43.0a	55.9c	63.1c	65.0c
50 kg P ha^{-1}+ 10 MT FYM ha^{-1}	24.3a	35.0ab	43.0a	44.3a	57.5bc	63.4c	65.1c
50 kg P ha^{-1}+ 20 MT FYM ha^{-1}	22.8ab	33.3ab	40.9a	41.8a	56.8c	64.6bc	66.1bc
100 kg P ha^{-1}	24.3a	34.3ab	43.6a	45.0a	61.6ab	68.9ab	70.3ab
100 kg P ha^{-1}+ 10 MT FYM ha^{-1}	23.9ab	34.0ab	42.6a	43.8a	63.2ab	70.7a	72.2a
100.2 kg P ha^{-1}+ 20 MT FYM ha^{-1}	25.4a	35.8a	43.8a	44.9a	64.7a	72.2	73.5a
LSD	5.3	5.3	4.6	4.8	5.0	4.4	4.3
C.V. (%)	25.9	17.5	12.1	12.4	8.9	7.4	7.1

*Means followed by the same letter in a column are not significantly different ($p \leq 0.05$)

Table 2. The Effect of phosphorus and farmyard manure on plant height (cm) Psigirio, 2003

	DAYS AFTER PLANTING (DAP)						
	30	37	42	49	56	63	70
Treatments	Plant height (cm)						
Control	17.5bc*	20.5e	26.3e	26.1f	28.4f	30.6e	31.4f
10 MT FYM ha^{-1}	16.7cd	26.3d	32.1d	32.0e	32.1e	34.2d	34.9e
20 MT FYM ha^{-1}	17.1bcd	30.1bd	36.3c	34.3de	35.1bcd	38.4d	38.4cd
50 kg P ha^{-1}	17.7bc	31.9ab	33.9bc	32.7e	33.1de	36.1cd	36.6de
50 kg P ha^{-1}+ 10 MT FYM ha^{-1}	17.8bc	34.7a	37.7ab	37.4bcd	35.7cd	39.4bc	39.4cd
50 kg P ha^{-1}+ 20 MT FYM ha^{-1}	16.1de	28.4cd	39.1ab	39.3ab	39.8ab	43.3a	43.3ab
100 kg P ha^{-1}	19.4a	29.9bc	35.9bc	36.6cd	37.3c	39.8ab	40.9bc
100 kg P ha^{-1}+ 10 MT FYM ha^{-1}	15.0e	27.3cd	39.8a	48.8a	41.0a	44.1a	46.2a
100.2 kg P ha^{-1}+ 20 MT FYM ha^{-1}	18.3a	32.7ab	38.9ab	39.3abc	40.3ab	39.3c	44.1a
C.V. (%)	7.6	11.8	9.6	9.6	9.4	10.6	8.1
LSD	3.2	3.2	3.2	3.2	3.2	3.9	3.0

*Means followed by the same letter in a column are not significantly different ($p \leq 0.05$)

4.2.2 The effects of phosphorus and farmyard manure on plant height.

Phosphorus and FYM had no effect on plant height during the first season at NARC – Kitale. The seasonal (season 1 and 2) difference observed at NARC – Kitale might have been due to high soil fertility in the experimental area that resulted to vigorous growth in the first season even where there was no fertiliser application. However, in season 2 and Psigirio site phosphorus and FYM affected ($P \leq 0.05$) plant height (Table 3).

At NARC - Kitale site, season 2, plots applied with 100 kg P ha^{-1} had the tallest (51.5 cm) plants compared to the control treatments which showed the shortest plants (37.8 cm) Table 3. Comparing treatments with phosphorus application alone at NARC Kitale, the application of 100 kg P ha^{-1} resulted to significantly ($P \leq 0.05$) the highest plant height whereas treatment without P resulted to the lowest plant height Table 3. The application of farmyard manure alone at NARC - Kitale season 2 resulted to no significant effect on plant height (Table 3).

At the Psigirio site, the application of 100 kg P ha^{-1} + 20 MT FYM ha^{-1} gave the tallest plant height of 36.57 cm compared to control treatment which gave the shortest plant height of 25.7 cm (Table 3). Comparing treatments with phosphorus application alone at the Psigirio site, the application of 100 kg P ha^{-1} resulted to significantly ($P \leq 0.05$) the highest plant height whereas treatment without P resulted to the lowest plant height (Table 3). The application 20 MT FYM ha^{-1} resulted to significantly the highest plant height compared to no FYM application (Table 3).

The application of 100 kg P ha^{-1} resulted to significantly ($P \leq 0.05$) the highest plant height whereas treatment without P resulted into the lowest plant height. This is so because phosphorus deficiency in potato plants retarded growth especially during early stages of growth (Sikka, 1982). The application 20 MT FYM ha^{-1} had significant ($P \leq 0.05$) effect on plant height compared to no FYM application at Psigirio site but not at NARC – Kitale (Table 3). This is so because of the high soil fertility at NARC – Kitale compared to the Psigirio site (Table 5). For example the amount of P available in the soil at NARC – Kitale is 68 P ppm whereas at the Psigirio site it is 47 P ppm.

The results (Table 3) indicate that the combination of 10 MT FYM ha^{-1} and 50 kg P ha^{-1} was more economical than combining 20 MT FYM ha^{-1} with 100 kg P ha^{-1} to achieve higher plant height. These results were in agreement with the findings of Minhas and Gulap (1998) who found out that organic phosphate application in combination with phosphorus reinforced the

generally low phosphate in FYM and reduced N losses as FYM increases N recovery. This may explain why plant heights increased with increase in FYM application.

Table 3. The effects of Phosphorus and FYM on plant height 70 DAP, NARC - Kitale season 1 and season 2, and Psigirio, 2003

	NARC - Kitale season 1	NARC - Kitale season 2	Psigirio
Treatments		Plant height (cm)	
Control	40.3	37.8c*	25.7c
10 MT FYM ha^{-1}	41.0	38.5bc	29.9bc
20 MT FYM ha^{-1}	42.8	39.8bc	32.7ab
50 kg P ha^{-1}	39.6	46.2abc	31.8ab
50 kg P ha^{-1}+ 10 MT FYM ha^{-1}	39.2	47.2ab	34.5ab
50 kg P ha^{-1}+ 20 MT FYM ha^{-1}	43.8	46.4abc	35.6a
100 kg P ha^{-1}	45.1	49.7a	33.6ab
100 kg P ha^{-1}+ 10 MT FYM ha^{-1}	41.1	50.1a	36.5a
100 kg P ha^{-1}+ 20 MT FYM ha^{-1}	43.4	51.5a	36.6a
LSD	NS	9.2	5.0
C.V.(%)	18.2	10.8	8.0

*Means followed by the same letter in a column are not significantly different ($p \leq 0.05$)

Table 4. Chemical composition of FYM used in the NARC - Kitale and Psigirio trials, 2003

pH	Na me %	K me %	Ca me %	Mg me %	Mn me %	P ppm	N %	C %
8.5	0.5	15.0	52.9	8.3	0.2	171	43	4.3

Table 5. Chemical composition of soil samples from NARC - Kitale and Psigirio before planting, 2003

	Depth of sampling	pH	Na me %	K me %	Ca me %	Mg me %	Mn me %	P ppm	N %	C %
NARC -	0 – 15 cm	5.8	1.04	0.53	2.2	5.5	0.52	68	14	1.4
Kitale	15 – 30 cm	5.5	0.81	0.34	1.6	4.7	0.57	30.5	14	1.4
Psigirio	0 – 15 cm	5.8	0.65	0.42	2.4	1.9	0.44	47	12	1.2
	15 – 30 cm	5.3	1.03	0.34	2.0	1.9	0.41	21.5	12	1.0

4.2.3. Effect of potassium on shoot and tuber dry weight

Potassium levels had no effect on tuber and shoot dry weight of plants grown at NARC - Kitale during the first season and Psigirio sites but had significant effect on tuber dry weight of plants grown at NARC - Kitale season 2 (Figure 3). Tuber dry weight increased with increase in potassium application. The application of potassium at the rate of 166 kg ha^{-1} at NARC - Kitale season 2 gave the highest tuber dry weight (6.6 MT ha^{-1}) whereas treatments without potassium resulted to the lowest tuber dry weight of 5.4 MT ha^{-1} (Figure 3). Photosynthates from leaves are translocated and stored in tubers, which may explain the significant difference noticed on tuber dry weight and not shoot dry weight with increase in potassium application in season 2 of the NARC - Kitale. Tuber dry weight increased with increase in K application. These results agree with those reported by Ward (1959), who reported that growth and development of potatoes is directly proportional to the amount of K applied in nutrient solution. He reported that leaf and stem growth as well as number and tuber size increased with K application. The increase in the above parameters was attributed to the involvement of potassium in the synthesis of simple sugars, starch and translocation of carbohydrates (Ward, 1959; Sikka, 1982). Also potatoes with potassium deficiency, have shortened internodes and reduced tuber size (Sikka, 1982).

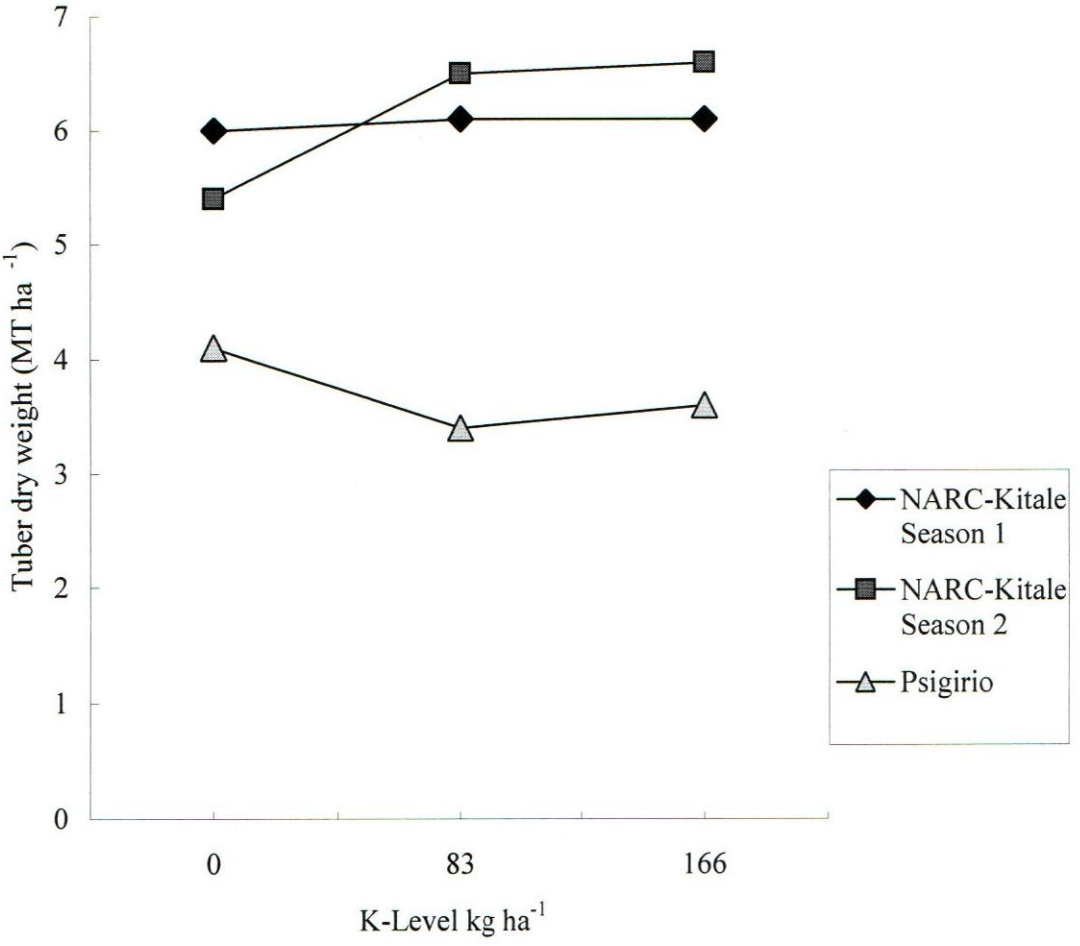


Figure 3. The effect of potassium on tuber dry weight (MT ha^{-1}) at NARC Kitale Season 2

4.2.4 Effect of phosphorus and farmyard manure combinations on root and shoot dry weight.

Phosphorus and farmyard manure combinations had no effect on either tuber or shoot dry weight at NARC - Kitale season 1 (Table 6). This may have been probably due to high soil fertility in the experimental area that resulted to vigorous growth even where there was no fertiliser application. Phosphorus and farmyard manure combinations had effect on tuber and shoot dry weight may be due to the mining of some of the nutrients by the potato crop in the first season. This is so because potato is a heavy feeder of soil nutrients in the soil (Sikka, 1982).

During season 2 at NARC - Kitale and the Psigirio sites, various levels of phosphorus application ($p \leq 0.05$) affected tuber and shoot dry weight (Table 6). At NARC - Kitale season 2 and Psigirio sites, the application of 100-kg P ha^{-1} + 20 MT FYM ha^{-1} resulted into the highest tuber dry weight of 8.1 MT ha^{-1} and 5.4 MT ha^{-1} respectively (Table 6). The control treatment resulted into the lowest ($p \leq 0.05$) tuber dry weight of 3.9 MT ha^{-1} at NARC - Kitale season 2 and 1.2 MT ha^{-1} for the Psigirio site (Table 6). In general, tuber dry weight increased with increase in phosphorus application. The Psigirio site showed lower tuber dry weight compared to the NARC – Kitale site (Table 6). This can be explained by the fact that the NARC – Kitale site has higher amount of available P (68 P ppm) compared to the Psigirio sit which has lower available P (47 P ppm) (Table 5).

The application of 100 kg P ha^{-1} + 20 MT FYM ha^{-1} resulted into highest shoot dry weight (2.5 MT ha^{-1}) at NARC - Kitale season 2 and 1.1 MT ha^{-1} at the Psigirio site. The control treatment resulted to the lowest ($p \leq 0.05$) shoot dry weight of 1.8 MT ha^{-1}, at NARC - Kitale season 2 and 0.2 MT ha^{-1} at the Psigirio site (Table 6). At NARC - Kitale season 2, P and FYM combinations had effect ($p \leq 0.05$) on tuber and shoot dry weight because some of the soil nutrients had already been utilized by the first crop since potato is heavy feeder on soil nutrients (Sikka, 1982). The increase in tuber and shoot dry weight with increase in phosphorus and FYM application can be attributed to increased root length density and leaf area index (LAI) which positively correlates with potato tuber yield (Opena and Porter, 1999). Tuber and shoot dry weight increased with increase in FYM application at NARC - Kitale season 2 and Psigirio sites. This observation could be attributed to increased P uptake as a result of FYM application (Ranganathan and Selvaseelan, 1997). The increased P uptake resulted increase into better tuber initiation (Mwania, 1983), which translated to higher dry weights as FYM was increased (Table 6).

Table 6. The effects of farm yard manure and phosphorus on tuber and shoot dry weight 70 DAP NARC - Kitale site season 2 and Psigirio sites, 2003

	Tuber Dry weight (MT ha^{-1})			Shoot Dry weight (MT ha^{-1})		
	NARC- Kitale			NARC- Kitale		
Fertiliser	Season 1	Season 2	Psigirio	Season 1	Season 2	Psigirio
Control	5.4	3.9c*	1.2e	1.7	1.8b	0.2e
10MT FYM ha^{-1}	6.0	4.1c	2.0d	1.8	1.9b	0.4de
20 MT FYM ha^{-1}	5.3	4.2c	2.6d	1.8	1.9b	0.5d
50 kg P ha^{-1}	4.5	6.3b	3.7c	1.8	1.9b	0.7c
50 kg P ha^{-1} +10 MT FYM ha^{-1}	6.5	6.3b	4.1bc	1.7	2.0ab	0.8c
50 kg P ha^{-1}+ 20 MT FYM ha^{-1}	6.6	6.5b	4.2bc	1.9	2.0ab	0.8c
100 kg P ha^{-1}	5.9	7.7a	4.8ab	1.6	2.3ab	0.9bc
100 kg P ha^{-1} + 10 MT FYM ha^{-1}	6.4	8.2a	5.0a	2.0	2.4ab	1.0ab
100 kg P ha^{-1} + 20 MT FYM ha^{-1}	7.3	8.1a	5.4a	2.3	2.5a	1.1a
LSD ($p \leq 0.05$)	NS	0.8	0.7	NS	0.2	0.2
C.V. (%)	22.5	7.3	10.4	2.8	5.9	11.5

*Means followed by the same letter in a column are not significantly different ($p \leq 0.05$)

4.2.5 The effects of farm yard manure, potassium and phosphorus on the tuber dry weight

Farmyard manure, potassium and phosphorus had no effect on tuber dry weight during season 1 in the NARC - Kitale site. At NARC–Kitale Season 2 and Psigirio sites phosphorus application affected ($p \leq 0.05$) tuber dry weight. However, potassium application had no effect on tuber dry at the two sites. Treatments with 100 kg P ha^{-1} gave significantly ($p \leq 0.05$) higher tuber dry weights compared to treatments with 50 kg P ha^{-1} (Tables 7 and 8). Similarly the application of 50 kg P ha^{-1} gave significantly ($p \leq 0.05$) higher tuber dry weight compared to those treatments without phosphorus (Tables 7 and 8).

The application of K, P and FYM had positive interaction on tuber dry weight in both Psigirio and NARC - Kitale season 2 (Tables 7 and 8). Tuber dry weight was highest, 8.5 MT ha^{-1} and 5.5 FYM ha^{-1} at the application of 166 kg K ha^{-1} + 100 kg P ha^{-1} + 20 MT FYM ha^{-1} at NARC - Kitale season 2 and Psigirio sites respectively (Tables 7 and 8). Tuber dry weight was lowest, 3.0 MT ha^{-1} and 1.4 MT ha^{-1} in the control treatments at NARC - Kitale season 2 and Psigirio sites respectively (Tables 7 and 8). Tuber dry weight increased with increase in phosphorus application by 150% at NARC - Kitale season 2 and by 300 % at Psigirio. This increase may be attributed to the effect of P and N promoting leaf growth during early plant development (Mugambi, 1979). Also P and N increased meristematic activity, improved development of vascular system, stimulated root growth and increased the number of tubers in potatoes as reported by Sikka, 1982. The deficiency of P and N in potatoes resulted to retarded growth of plants, reduced tuber size and number (Sikka, 1982). Phosphorus use in potatoes may have increased tuber initiation, which in turn resulted to increase in tuber dry weight with increase in P application (Mwania, 1983). Phosphorus application may have also resulted to increased root length density and LAI consistently during the potato growing period, which accounted for increased tuber dry weight with increased phosphorus application (Opena and Porter, 1999).

Table7. The effects of potassium, phosphorus and farmyard manure on tuber and shoot dry weight 70 DAP, at NARC – Kitale season 2, 2003

Potassium level	0 kg K ha^{-1}		83 kg K ha^{-1}		166 kg K ha^{-1}	
Treatments	Tuber dry weight (MT ha^{-1})	Shoot dry weight (MT ha^{-1})	Tuber dry weight (MT ha^{-1})	Shoot dry weight (MT ha^{-1})	Tuber dry weight (MT ha^{-1})	Shoot dry weight (MT ha^{-1})
Control	3.0n*	1.7fgh	4.0lm	1.9efgh	4.7l	1.9defg
10 MT FYM ha^{-1}	3.3mn	1.7fgh	4.2l	1.9efgh	4.6l	2.0de
20 MT FYM ha^{-1}	3.3mn	1.7fgh	4.7l	1.9efgh	4.6l	1.9def
50 kg Pha^{-1}	5.6k	1.8efgh	6.7fgh	1.8efgh	6.4hij	1.9defgh
50 kg P ha^{-1}+ 10MT FYM ha^{-1}	5.7jk	1.8efgh	6.9fgh	1.9defgh	6.5ghi	2.1d
50 kg P ha^{-1}+ 20MT FYM ha^{-1}	5.8ijk	1.7efgh	7.1efgh	2.0de	6.9fgh	2.1d
100 kg P ha^{-1}	7.3defg	2.0defgh	7.8cde	2.4c	8.8cd	2.6bc
100 kg P ha^{-1}+ 10MT FYM ha^{-1}	7.6def	2.0defgh	8.3bc	2.3c	9.1a	2.9a
100 kg P ha^{-1}+ 20MT FYM ha^{-1}	7.1 def	2.0de	8.7ab	2.8ab	8.5abc	2.8a
LSD (0.05)	0.8	0.2	0.7	0.2	0.7	0.2
C.V. (%)	7.3	5.9	7.3	5.9	7.3	5.9

*Means followed by the same letter in a column are not significantly different ($p \leq 0.05$)

Table 8. The effects of potassium, phosphorus and farmyard manure on root and shoot dry weight 70 DAP, Psigirio site 2003

Potassium level	0 kg K ha^{-1}		166 kg K ha^{-1}			
Treatments	Tuber dry weight (MT ha^{-1})	Shoot dry weight (MT ha^{-1})	Shoot dry weight (MT ha^{-1})	Tuber dry weight (MT ha^{-1})	Shoot dry weight (MT ha^{-1})	
Control	1.4klm*	0.3fg	1.3lm	0.2g	0.8m	0.2g
10 MT FYM ha^{-1}	2.4jk	0.4bcdefg	1.8klm	0.3efg	1.8klm	0.3defg
20 MT FYM ha^{-1}	3.5hi	0.5abcdefg	2.1kl	0.4cdefg	2.1kl	0.5bcdefg
50 kg Pha^{-1}	4.3defgh	0.8abcdefg	3.2ij	0.7abcdefg	3.7fghi	0.7abcdefg
50 kg P ha^{-1}+ 10MT FYM ha^{-1}	5.0abcde	1.0abcd	3.6ghi	0.7abcdefg	3.7fghi	0.8abcdefg
50 kg P ha^{-1}+ 20MT FYM ha^{-1}	4.6abcdef	0.9abcdef	3.9fghi	0.6abcdefg	4.2efghi	0.9abcde
100 kg P ha^{-1}	5.0abcde	0.8abcdefg	4.4cdefgh	0.8abcdefg	5.1abcde	1.0abc
100 kg P ha^{-1}+ 10MT FYM ha^{-1}	5.1abcde	1.1ab	4.5bcdefg	0.9abcdefg	5.3abc	1.0abc
100 kg P ha^{-1}+ 20MT FYM ha^{-1}	5.6a	1.1a	5.3cd	0.9abcde	5.5ab	1.1a
LSD (0.05)	1.0	0.6	1.0	0.6	1.0	0.6
C.V. (%)	10.4	11.5	10.4	11.5	10.4	11.5

*Means followed by the same letter in a column are not significantly different ($p \leq 0.05$)

4.2.6 The effects of farm yard manure, potassium and phosphorus on the shoot dry weight

During season 1 at NARC - Kitale site, K, P and FYM did not influence shoot dry weight. This can be attributed to high soil fertility where the experiment was conducted. However, during season 2 NARC - Kitale and Psigirio sites, K, P and FYM had influenced on shoot dry weight at varying levels of P application. The application of K, P and FYM had a positive interaction on the shoot dry weight at both Psigirio and season 2, NARC - Kitale (Tables 7 and 8). The highest shoot dry weight was realized at higher combinations of K, P and FYM.

Shoot dry weight was highest (2.8 MT ha^{-1} and 1.1 MT ha^{-1}) at the application of 166 kg K ha^{-1} + 100 kg P ha^{-1} + 20 MT FYM ha^{-1} at NARC - Kitale season 2 and Psigirio sites respectively (Tables 7 and 8). However tuber dry weight was lowest (1.7 MT ha^{-1}) and (0.3 MT ha^{-1}) in the control treatments at NARC - Kitale season 2 and Psigirio sites respectively (Tables 7 and 8). Shoot dry weight increased with increase in phosphorus application by 64 % at NARC - Kitale season 2 and by 266 % at Psigirio (Tables 7 and 8). Shoot dry weight increased with increase in P application because P resulted to increased root length density and leaf area index with increase in P application (Opena and Porter, 1999).

4.3 Effect of farmyard manure, phosphorus and potassium on potato yields and yield components

Phosphorus and farmyard manure had no significant effect on the tuber yield (ware, seed and total tuber yield) and tuber number in season 1 at the NARC - Kitale site (Table 9). However, during season 2 at NARC - Kitale and the Psigirio sites, phosphorus and farmyard manure combination had significant effect on the tuber yield (Tables 10 and 11). At NARC - Kitale season 2, the application of 166 kg K ha^{-1} + 100 kg P ha^{-1} + 10 MT FYM ha^{-1} gave significantly ($p \leq 0.05$) the highest total tuber yield of 30.1 MT ha^{-1} compared to the control treatment which resulted to 8.2 MT ha^{-1} (Table 10). At the Psigirio site, the application of 100 kg P ha^{-1} + 10 MT FYM ha^{-1} without K gave significantly ($p \leq 0.05$) the highest total tuber yield of 32.7 MT ha^{-1} compared to the control treatment which resulted to the lowest tuber yield of 11.8 MT ha^{-1} (Table 11).

The above results agree with Maier et al. (1994) findings in Australia. They reported that the application of 360 kg N ha^{-1}, 320 kg P ha^{-1} and 480 kg K ha^{-1} resulted to increased potato total tuber yield by 13 – 432 %, 19 – 145 % and 19 – 89 % respectively. Nitrogen, phosphorus and potassium uptake by plants increased with increase in FYM application (Minhas and Sood 1994). This explains why tuber yield increased with increase in farmyard manure and phosphorus application. The amendment of soil with FYM resulted to increase in root length density, which was highly correlated with final tuber yields (Opena and Porter, 1999). Phosphorus, potassium and nitrogen deficiencies, on the other hand have been found to retard growth, reduce tuber size and tuber number (Sikka, 1982).

Table 9. The effect of farmyard manure, potassium and phosphorus on the yield of potatoes season 1 NARC - Kitale 2003.

Treatment		Total Yield (MT ha^{-1})	Ware (MT ha^{-1})	Seed (MT ha^{-1})	Ware No ha^{-1} $X10^3$	Seed No ha^{-1} $X10^3$	Total tuber No ha^{-1} $X10^3$
Main plot	Sub plot						
K = 0 Kg ha^{-1}	1	25.2	11.8	13.3	51.9	105.1	157.0
	2	31.9	18.5	13.3	77.0	167.0	244.0
	3	27.6	16.4	11.1	74.1	94.8	168.9
	4	32.3	17.8	14.5	80.0	162.9	242.9
	5	30.4	17.1	13.3	69.6	130.3	199.9
	6	34.8	21.5	13.3	10.2	125.9	136.1
	7	41.5	23.0	18.5	96.3	195.5	291.8
	8	32.9	17.8	15.1	81.5	145.2	226.7
	9	27.1	16.8	10.8	72.6	137.8	210.4
K = 833 Kg ha^{-1}	1	25.6	14.7	11.0	74.1	119.9	194.0
	2	28.8	17.8	11.1	81.4	109.6	191.0
	3	26.7	16.3	10.4	74.1	105.2	179.3
	4	30.3	19.3	11.1	66.6	100.7	167.3
	5	24.7	17.0	7.7	88.9	91.8	180.7
	6	25.9	14.0	11.9	72.6	106.6	179.2
	7	29.6	17.0	12.6	75.5	131.8	207.3
	8	25.0	11.7	13.3	56.3	154.1	210.4
	9	34.4	20.0	14.4	99.2	131.9	231.1
K = 166 Kg ha^{-1}	1	25.2	13.3	11.9	44.4	115.5	159.9
	2	31.9	14.2	17.8	74.1	137.7	211.8
	3	20.0	8.9	11.1	35.5	100.7	136.2
	4	24.7	12.2	12.6	56.3	134.8	191.1
	5	27.4	17.0	10.4	77.0	118.5	195.5
	6	21.1	11.5	9.6	65.2	115.5	180.7
	7	22.8	14.8	8.1	72.6	96.3	168.9
	8	22.9	11.8	11.1	63.7	125.9	189.6
	9	20.7	11.9	8.9	47.0	97.7	144.7

Key: 1 = Control
2 = 10 MT FYM ha^{-1};
3 = 20 MT FYM ha^{-1};
4 = 50 kg P ha^{-1};
5 = 50 kg P ha^{-1} + 10MT FYM ha^{-1};
6 = 50 kg P ha^{-1} + 20 MT FYM ha^{-1};
7 = 100 kg P ha^{-1};
8 = 100 kg P ha^{-1} + 10 MT FYM ha^{-1};
9 = 100 kg P ha^{-1} + 20 MT FYM ha^{-1}

Table 10. The effect of farmyard manure, potassium and phosphorus on the yield of potatoes in season 2 at the NARC - Kitale site 2003.

Treatment		Total Yield (MT ha^{-1})	Ware (MT ha^{-1})	Seed (MT ha^{-1})	Ware number ha^{-1} X 10^4	Seed number ha^{-1} X 10^4	Total tuber No ha^{-1} X 10^4
Maim plot	Sub plot						
K = 0 Kg ha^{-1}	1	8.2k*	2.3f	5.8o	2.0 k	0.8n	1.0o
	2	8.8k	3.5def	5.4mn	1.3k	0.8n	1.0o
	3	11.0ijk	2.6ef	8.3ijklmn	2.0jk	1.6ij	1.7k
	4	16.3fghij	4.0def	12.3efghi	1.6k	1.8g	1.9j
	5	18.2defgh	7.5bcdef	10.7fghijkl	4.3def	1.5j	2.0j
	6	19.1defg	7.6bcdef	11.5fghij	4.8cde	1.9f	2.4g
	7	17.9defghi	8.4bcdef	9.5ghijklm	4.0fg	1.3l	1.6l
	8	19.0defgh	7.1bcdef	11.8fghi	3.5gh	1.6hi	2.0j
	9	24.3cd	7.3bcdef	16.9abc	4.0fg	2.5b	2.9d
K = 833 Kg ha^{-1}	1	9.6jk	2.1f	7.5jklmn	2.0ij	1.3k	1.5l
	2	12.7ghijk	3.9def	8.8hijklmn	2.0jk	1.1l	1.3mn
	3	12.0hijk	5.4cdef	6.6lmn	2.0hi	1.1l	1.4m
	4	22.6bcdef	13.3ab	9.3ghijklmn	3.0fgh	1.7gh	2.1hi
	5	12.9ghijk	6.1cdef	6.8klmn	2.0ij	1.2l	1.4m
	6	12.2ghijk	5.7cdef	6.4mn	4.1efg	0.6p	1.0o
	7	21.4def	10.4abcd	10.8fghijk	5.3bc	2.0cd	2.5ef
	8	23.9bcde	11.5abc	12.5efghi	5.7b	1.9ef	2.5f
	9	22.2cdef	9.4bcde	12.7defgh	4.3def	1.7gh	2.1h
K = 166 Kg ha^{-1}	1	9.4jk	4.3def	5.1n	2.5ij	0.7o	1.0o
	2	20.4def	14.0b	6.6mn	2.5ij	1.0m	1.3n
	3	17.0efghi	4.4def	12.6defgh	2.9hi	2.0de	2.3g
	4	22.1cdef	6.0cdef	16.3cde	3.1hi	3.2a	3.5b
	5	24.4abcd	11.4abc	13.0cdefg	4.3def	1.7gh	2.1h
	6	24.6abcd	8.1bcdef	16.6abcd	4.9cd	2.0cd	2.5f
	7	28.0abc	10.1abcd	17.5ab	5.1bc	2.6b	3.1c
	8	31.0a	16.7a	14.4bcdef	5.5bc	2.1c	2.6e
	9	29.6ab	8.9bcde	20.7a	7.6a	3.3a	4.0a
LSD (0.05)		7.0	7.0	4.1	4.5	0.1	0.1
C.V. (%)		8.2	26.8	3.9	4.2	3.9	2.9

*Means followed by the same letter in a column are not significantly different ($p \leq 0.05$)

Key: 1 = Control; 2 = 10 MT FYM ha^{-1};
3 = 20 MT FYM ha^{-1}; 4 = 50 kg P ha^{-1};
5 = 50 kg P ha^{-1} + 10MT FYM ha^{-1}; 6 = 50 kg P ha^{-1} + 20 MT FYM ha^{-1};
7 = 100 kg P ha^{-1}; 8 = 100 kg P ha^{-1} + 10 MT FYM ha^{-1};
9 = 100 kg P ha^{-1} + 20 MT FYM ha^{-1}

Table 11. The effect of farmyard manure, potassium and phosphorus on the yield of potatoes Psigirio 2003.

Treatment		Total Yield (MT ha^{-1})	Ware (MT ha^{-1})	Seed (MT ha^{-1})	Ware No ha^{-1} X 10^4	Seed No ha^{-1} X 10^4	Total tuber No ha^{-1} X 10^4
K = 0 Kg ha^{-1}	1	11.3jk*	2.8cdef	8. 0ij	2.1	1.6o	1.8o
	2	17.5efghij	5.5bcdef	12.0efghi	5.1	2.0lm	2.5j
	3	18.5defghi	6.9bcd	11.7efghi	5.6	2.2k	2.9g
	4	15.2fghij	3.0cdef	12.1defghi	2.1	2.8hi	2.5jk
	5	21.2bcdefg	4.6cdef	16.6abc	2.8	2.4ef	2.8hi
	6	26.6abc	10.3ab	16.3abcd	5.9	3.0b	3.6a
	7	22.2bcdef	5.7bcde	16.8abc	3.6	3.0b	3.3c
	8	25.0bcd	6.4bcde	18.0ab	4.9	2.6d	2.9fg
	9	32.7a	15.5a	17.2abc	9.5	2.3gh	3.2d
K = 833 Kg ha^{-1}	1	5.1k	0.2f	4.9j	0.1	1.5p	1.5p
	2	11.5ijk	1.7ef	9.8ghi	1.3	2.0m	2.2m
	3	15.2fghij	3.6cdef	11.9efghi	2.7	2.4fg	2.6i
	4	12.0hijk	2.8cdef	9.3hi	2.2	2.2j	2.4k
	5	12.5hij	3.1cdef	9.4hi	2.5	2.2ij	2.5jk
	6	19.0defgh	5.9bcde	13.1cdefgh	4.2	2.5e	2.9fg
	7	14.6ghij	2.5cdef	12.1defghi	1.1	2.9c	2.9fg
	8	15.9efghij	4.2cdef	11.8efghi	3.3	2.0m	2.5jk
	9	27.9ab	7.9bc	20.1a	5.2	3.4a	3.4b
K = 166 Kg ha^{-1}	1	11.8hijk	2.4def	9.5hi	1.9	2.1kl	2.3l
	2	14.9ghij	4.5cdef	10.5fghi	3.1	2.lm	2.5jk
	3	17.7efghij	4.5cdef	13.1cdefgh	3.3	2.3gh	2.7i
	4	12.5hij	3.0cdef	9.5ghi	2.2	1.8elm	2.0n
	5	18.1defghij	5.9bcde	12.2defghi	3.9	2.4fg m	2.7h
	6	20.6cdefg	7.0bcde	13.7cdefg	6.5	2.3gh	3.0f
	7	20.0cdefg	5.8bcde	14.3bcdef	3.9	2.2ij	3.1e
	8	23.1bcde	7.4bcd	15.7bcd	4.6	2.6d	3.1e
	9	20.0cdefg	5.5bcdef	14.6bcdef	2.8	2.9c	3.2d
LSD		7.2	5.5	4.2	0.9	0.1	0.9
C.V. (%)		9.3	28.5	10.1	20.8	1.6	1.4

*Means followed by the same letter in a column are not significantly different ($p \leq 0.05$)

Key: 1 = Control
2 = 10 MT FYM ha^{-1};
3 = 20 MT FYM ha^{-1};
4 = 50 kg P ha^{-1};
5 = 50 kg P ha^{-1} + 10MT FYM ha^{-1};
6 = 50 kg P ha^{-1} + 20 MT FYM ha^{-1};
7 = 100 kg P ha^{-1};
8 = 100 kg P ha^{-1} + 10 MT FYM ha^{-1};
9 = 100.2 kg P ha^{-1} + 20 MT FYM ha^{-1}

4.3.1 The effects of phosphorus and farmyard manure on total yield ware yield and seed yield

Phosphorus and farmyard manure combination had no effect on potato tuber yield in season 1 NARC Kitale. This was because the experiment was conducted in high fertile area (Table 5), so high yields were realized in plots with no fertiliser. However, in season 2 at the NARC – Kitale and Psigirio sites, phosphorus and farmyard manure combinations affected ware, seed and total tuber yield of potatoes (Table 12). It was possible that by the time the second experiment was conducted at the NARC – Kitale site, some of the soil nutrients had been mined by the first crop of potatoes that was why phosphorus and farm yard manure combinations had significant effect on potato yield.

At NARC – Kitale season 2 and Psigirio sites, the control treatments resulted to the lowest ($p \leq 0.05$) ware yield 2.9 MT ha^{-1} and 1.8 MT ha^{-1} respectively. At NARC – Kitale site season 2 and Psigirio, treatments with 100 kg P ha^{-1} + 10 MT FYM ha^{-1} and 100 P kg ha^{-1} + 20 MT FYM ha^{-1} resulted to the highest ($p \leq 0.05$) ware yield 11.8 MT ha^{-1} and 9.6 MT ha^{-1}, respectively. Fertiliser treatments had effect on potato seed yield at NARC – Kitale season 2 and Psigirio sites (Table 12). At NARC – Kitale season 2 and Psigirio sites, the control treatments resulted to the lowest ($p \leq 0.05$) seed yield 6.1 MT ha^{-1} and 7.6 MT ha^{-1}, respectively. At NARC – Kitale site season 2 and Psigirio, treatments with 100 kg P ha^{-1} + 20 MT FYM ha^{-1} and 100 P Kg ha^{-1} + 20 MT FYM ha^{-1} resulted to the highest ($p \leq 0.05$) seed yield 16.7 MT ha^{-1} and 17.3 MT ha^{-1} respectively (Table 12).

Fertiliser treatments did not affect total tuber yield at NARC – Kitale season 1, but had significant effect ($p \leq 0.05$) in season 2 (NARC – Kitale) and at Psigirio sites (Table 12). The seasonal difference at NARC – Kitale was due to soil fertility, in that the potato crop in season 1 may have mined some of the nutrients in the soil. Control treatments resulted in to the lowest ($p \leq 0.05$) total tuber yield of 9.0 MT ha^{-1} at NARC – Kitale season 2 and 9.4 MT ha^{-1} at the Psigirio site (Table 12). On the other hand the applications of 100-kg P ha^{-1} + 20 MT FYM ha^{-1} resulted to the highest total tuber yield of 25.3 MT ha^{-1} at NARC – Kitale season 2 and 26.9 at the Psigirio site. There was no significant difference between the applications of 10 MT FYM ha^{-1}, 20 MT FYM ha^{-1}, 50 kg P ha^{-1}, 50 kg P ha^{-1} + 10 MT FYM ha^{-1} and 50 kg P ha^{-1} + 20 MT FYM ha^{-1} for NARC – Kitale season 2. At any given level of P application, total tuber yield increased with increase in FYM application at both the Psigirio and NARC- Kitale sites.

The above results agree with findings of Mugambi, (1979), who reported that the application of N, P, and K increased tuber yield. It also agreed with work done by Sud (1996) who reported that significant responses of potato tuber yield to P application were obtained at application rates of 22 kg ha^{-1}. Houghland (1960) reported that potatoes require large amounts of phosphorus because phosphorus is important in starch phosphorylation.

There were no significant differences between the application of 0, 10, 20 MT ha^{-1} of FYM. However there was increase in potato yield with increasing FYM. The application of FYM in combination with phosphorus resulted to the reinforcement of FYM by P application. Ahn (1993) reported similar results, that inorganic phosphate when applied in combination with FYM reinforces the generally low phosphate in FYM. Thus the yield of potatoes was directly proportional to the amount of P application. Opena and Porter (1999) observed that farmyard manure application increased root length density and LAI, which resulted to increase tuber yield with increase in P application. Farmyard manure increased the uptake of N, Fe and Zn and increase P uptake (Ranganathan and Salvseelan, 1997). Nitrogen, phosphorus and potassium uptake by plants increased with increase in FYM application (Minhas and Sood 1994). This explains why tuber yield increased with increasing FYM at any given level of P application.

Table 12. The effects of farm yard manure and phosphorus on the yield of potatoes, NARC – Kitale season 1 and 2 and Psigirio, 2003

	Ware Yield (MT ha^{-1})			Seed yield (MT ha^{-1})			Total tuber yield (MT ha^{-1})		
	NARC – Kitale			NARC – Kitale			NARC – Kitale		
Treatments	season 1	season 2	Psigirio	season 1	season 2	Psigirio	season 1	season 2	Psigirio
Control	15.0	2.9b*	1.8 b	10.3	6.1c	7.6 d	26.8	9.0c	9.4d
10MT FYM ha^{-1}	17.0	7.2ab	3.9ab	9.7	6.8c	10.7cd	31.9	14.0bc	14.6bcd
20MT FYM ha^{-1}	17.2	4.2b	5.0ab	8.8	9.3c	12.3c	25.7	13.3bc	17.1bcd
50 kg Pha^{-1}	15.6	7.7ab	2.9b	8.3	12.6ab	10.3cd	30.1	20.3ab	13.4d
50 kg P ha^{-1}+10MT FYM ha^{-1}	15.4	8.3ab	4.5ab	9.0	10.1bc	12.8abc	29.0	18.5ab	17.3bcd
50 kg P ha^{-1}+ 20MT FYM ha^{-1}	20.3	7.1ab	7.7ab	12.0	11.5b	14.3abc	28.5	18.6ab	22.1ab
100 kg P ha^{-1}	19.5	9.6ab	4.9ab	12.2	12.7ab	14.3abc	32.7	22.3a	19.0bc
100 kg P ha^{-1}+ 10MT FYM ha^{-1}	15.9	11.7a	6.0ab	12.0	12.9ab	15.3ab	28.3	24.6a	21.3ab
100 kg P ha^{-1}+ 20MT FYM ha^{-1}	18.9	8.6ab	9.6a	12.0	16.7a	17.3a	28.9	25.3a	26.9a
LSD	NS	7.5	6.0	NS	4.5	4.6	NS	9.8	7.9
C.V. (%)	18.0	26.8	28.5	15.8	3.9	10.1	9.3	8.2	9.3

*Means followed by the same letter in a column are not significantly different ($p \leq 0.05$)

4.3.2 The effects of farmyard manure and phosphorus on ware number, seed number and total tuber number of potatoes.

Phosphorus and farmyard manure had no significant effect on tuber number at NARC – Kitale season 1. However at NARC – Kitale season 2 and Psigirio site, P and FYM had significantly ($p \leq 0.05$) increased the tuber number (Table 13). At NARC – Kitale season 2, the application of 100 kg P ha^{-1} + 20 MT FYM ha^{-1} gave the highest ($p \leq 0.05$) seed number (250,000 ha^{-1}) and total tuber number (300,000 ha^{-1}), with the control treatment resulting to the lowest ($p \leq 0.05$) seed number (90,000 ha^{-1}) and the lowest total tuber number (120, 000 ha^{-1}) in season 2, (Table 13).

At Psigirio site (Table 13), the application of 100 kg P ha^{-1} + 20 MT FYM resulted to the highest ($p \leq 0.05$) seed number (290,000 ha^{-1}) whereas the control treatment resulted to the lowest ($p \leq 0.05$) seed number (170,000 ha^{-1}). At the Psigirio site, the application of 100 kg P ha^{-1} + 20 MT FYM ha^{-1} gave the ($p \leq 0.05$) highest total tuber number (330,000 ha^{-1}) compared to the rest of the treatment. The control plots showed significantly ($p \leq 0.05$) the lowest total tuber number (190,000 ha^{-1}) compared to the rest of the treatments at the Psigirio site respectively (Table 13).

At both Psigirio and NARC – Kitale season 2, high application of P (100 kg P ha^{-1}) resulted to the highest tuber number compared to no application of phosphorus. Similarly at any given level of P application, the total tuber number of potatoes, increased with increase in FYM application. This is so because the application of FYM to soil results to increase in carbon mineralization from the soil due to available carbon for microbial respiration, provision of nitrogen and phosphorus (Nyamangara et. Al., 2000). The availed nitrogen and phosphorus in the soil, are important in tuber initiation and tuber enlargement (Sikka, 1982), therefore tuber number increased with increase in phosphorus and farmyard manure application. At all levels of P application, the lowest percent of potato ware number was produced when FYM is not applied and when FYM is applied at the rate of 20 MT ha^{-1}, whereas the highest percent of ware potato is obtained when FYM is applied at 10 MT FYM ha^{-1} (Table 13). For seed the reverse is true, with the highest percent seed obtained at no application of FYM and 20 MT FYM ha^{-1} while the lowest percent was obtained at the application of 10 MT FYM ha^{-1}. At NARC – Kitale season 2 and Psigirio, the percent ware potato increased with increase in P application. These results agree with findings of Mwania (1983) who reported that increasing nitrogen and phosphorus to potatoes gave the highest number of ware potato tubers. Thus the

optimum combination for P and FYM application for seed potato production is obtained at any level of P with FYM rate of 10 MT ha^{-1}. At Psigirio (Table 13), at any given level of phosphorus application, the percent ware potatoes increased with increase in FYM application. The reverse was true for seed potatoes whose percent decreased with increase in FYM application.

Table 13. The effects of FarmYard Manure and Phosphorus on tuber number NARC – Kitale season 1 and 2, and Psigirio 2003

	Ware (no ha^{-1}) X 10^4			Seed yield (no ha^{-1}) X 10^5			Total tuber (no ha^{-1}) X 10^5		
	NARC - Kitale			NARC - Kitale			NARC - Kitale		
Treatments	season 1	season 2	Psigirio	season 1	season 2	Psigirio	season 1	season 2	Psigirio
Control	5.7	2.3d	0.1e	1.6	0.9e	1.7g	1.7	1.2f	1.9f
10MT FYM ha^{-1}	7.8	2.0d	3.4bc	1.4	1.0e	2.0f	2.2	1.2f	2.4e
20MT FYM ha^{-1}	6.1	2.6d	3.9bc	1.0	1.6d	2.3de	1.6	1.8e	2.7cd
50 kg Pha^{-1}	6.7	2.8d	2.2de	1.3	2.3b	2.1f	2.0	2.5b	2.3e
50 kg P ha^{-1}+ 10MT FYM ha^{-1}	7.9	3.6c	3.1cd	1.1	1.5d	2.3de	1.91	1.8e	2.6d
50 kg P ha^{-1}+ 20MT FYM ha^{-1}	8.0	4.6b	5.5a	1.2	1.5d	2.6c	2.0	2.0d	3.1 b
100 kg P ha^{-1}	8.1	4.8b	3.2c	1.1	2.0c	2.7b	2.2	2.4bc	3.1b
100 kg P ha^{-1}+ 10MT FYM ha^{-1}	6.7	4.9b	4.3b	1.4	1.9c	2.4d	2.1	2.4c	2.8 c
100 kg P ha^{-1}+ 20MT FYM ha^{-1}	7.3	5.3a	5.8a	1.2	2.5a	2.9a	1.9	3.0a	3.3a
C.V. (%)	11.4	4.2	10.1	3.0	1.8	2.0	2.6	2.9	1.4
LSD	NS	1.0	1.0	NS	0.1	0.1	NS	0.1	0.1

*Means followed by the same letter in a column are not significantly different ($p \leq 0.05$)

4.4 The effect of potassium on the chipping and crisping quality of potatoes

Potassium levels showed significant ($p \leq 0.05$) difference at varying levels of K application at NARC – Kitale, season 1 and 2 and Psigirio site (Table 14). All levels of P and FYM did not affect the chipping and crisping quality at the two sites. The application of K at 166-kg K ha^{-1} resulted into potatoes with higher chipping and crisping quality compared to treatments with without potassium. There was no difference in quality of potatoes at the application of 166-kg K ha^{-1} and 83-kg K ha^{-1}. Likewise there were no differences between the application of 83-kg K ha^{-1} and no application of potassium.

The results from the study show that potato chipping and crisping quality increases with increase in K application. These findings agree with (Wilcox, 1953), who reported that potato chips made from tubers grown without potassium application were dark brown and of inferior quality. Also Hill (1953) reported that potatoes grown with potassium application were less mealy than those grown without potassium. However potatoes grown with potassium were whiter after cooking than those grown without potassium application. Increasing potassium supply to plants improves potato quality because increasing the application of potassium to plants decrease the tendency of raw macerated tubers to darken. With increasing application of potassium to plants, sugars, polyphenol oxidase activity and amino acids (except glutamic and aspartic) decrease in tubers (Welte and Muller, 1966).

Table 14. The effect of potassium on chipping and crisping quality NARC-Kitale seasons 1 and 2 and Psigirio, 2003

Potassium (Kg ha^{-1})	Chipping quality scale (1 = extremely disliked; 6 = extremely liked)			Crisping quality scale (1 = extremely disliked; 6 = extremely liked)		
	NARC - Kitale			NARC - Kitale		
	Season 1	Season 2	Psigirio	Season 1	Season 2	Psigirio
0	3.24b*	3.0b	3.0b	2.8b	2.4c	3.0b
83	3.8ab	3.1b	3.1b	4.3a	3.9b	3.7a
166	4.3a	4.0a	4.1a	4.3a	4.21a	4.1a
LSD (0.05)	0.70	0.3	0.7	1.0	0.2	0.6
C.V.(%)	14.4	3.6	5.6	10.8	2.8	5.0

*Means followed by the same letter in a column are not significantly different ($p \leq 0.05$)

4.5 Economic Analysis

Economic analysis (Cost-Benefit-Ratio) was done to assess the profitability of various fertiliser combinations {as computed by (Upton 1987)}. The Cost Benefit Ratio (CBR) was calculated using the formula: CBR = (Gross income – Variable Cost)/Variable cost (Upton 1987). Partial budget was performed in order to ascertain the net income of the treatments. The summaries of the CBR at varying levels of fertiliser application are shown in Tables 18, 19 and 20. The following assumptions were made: -

50 kg TSP cost Ksh. 1,250

1 ton FYM cost Ksh. 1,000

1 ton potato seed sells @ Ksh.10, 000

100-kg potato seed @ Ksh. 2,000

earthing up cost Ksh. 4,000 ha^{-1}

50-kg MOP cost Ksh. 1,300

ploughing cost Ksh. 3,000 ha^{-1}

Ridging cost Ksh. 1,250 ha^{-1}

planting cost Ksh. 5,000 ha^{-1}

At NARC - Kitale season 1 trial, the highest CBR was realized at the application of 100 P kg ha^{-1} (without K and FYM) and the lowest at the application of 83 kg K ha^{-1} + 100 P kg ha^{-1} +10MT FYM ha^{-1} (Table 115). At the NARC - Kitale season 2, the highest CBR was realized at the application of 166 K kg ha^{-1} + 100 P kg ha^{-1} + 10 MT FYM ha^{-1} and the lowest CBR was realized in the control treatment (Table 16). At the Psigirio site, the highest CBR was realized at the application of 100 P kg ha^{-1} 10 MT FYM ha^{-1} with no application of K and the lowest in the control treatment (Table7).

In the second season (NARC - Kitale) and the Psigirio site, at all levels of K application, treatments without phosphorus and FYM, showed the lowest CBR. Though less amounts of money was used in cases where no fertiliser is applied, low yields are realized which is translated to lower monetary gain hence low cost benefit ratios realized. The high costs experienced at higher levels of fertiliser applications are nullified by high income realized.

Table 15. Economic Analysis NARC - Kitale season 1, 2003

Treatment		Yield	Gross income	Variable cost	Net benefit	
Main plot	Sub plot	(MT ha^{-1})	(Ksh.)	(Ksh.)	(Ksh.)	CBR
0 kg K ha^{-1}	1	27.3	272,600	50,000	222,600	4.5
	2	32.8	327,700	60,000	267,700	4.5
	3	28.2	281,500	70,000	211,500	3.0
	4	33.3	333,000	56,250	276,750	4.9
	5	32.6	326,100	66,250	259,850	3.9
	6	35.9	358,500	76,250	282,250	3.7
	7	43.3	433,300	62,500	370,800	5.9
	8	34.5	345,000	72,500	272,500	3.8
	9	28.6	286,400	82,500	203,900	2.5
83 kg K ha^{-1}	1	26.8	268,700	56,500	212,200	3.8
	2	30.2	302,100	66,500	235,600	3.5
	3	28.0	280,300	76,500	203,800	2.7
	4	31.4	314,400	62,750	251,650	4.0
	5	25.4	253,600	72,750	180,850	2.5
	6	27.3	273,200	82,750	190,450	2.3
	7	30.7	307,100	69,000	238,100	3.5
	8	26.2	262,200	79,000	183,200	2.3
	9	36.2	361,800	89,000	272,800	3.1
166 kg K ha^{-1}	1	26.3	263,400	63,000	200,400	3.2
	2	32.8	328,200	73,000	255,200	3.5
	3	20.9	209,000	83,000	126,000	1.5
	4	25.5	254,800	69,250	185,550	2.7
	5	28.9	289,300	79,250	210,050	2.7
	6	22.4	223,600	89,250	134,350	1.5
	7	24.1	241,400	75,500	165,900	2.2
	8	24.2	242,000	85,500	156,500	1.8
	9	22.0	220,200	95,500	124,700	1.3

Key: 1 = Control; 2 = 10 MT FYM ha^{-1}; 3 = 20 MT FYM ha^{-1}; 4 = 50 kg P ha^{-1}; 5 = 50 kg P ha^{-1}; 6 = 50 kg P ha^{-1} + 20 MT FYM ha^{-1}; 7 = 100 kg P ha^{-1}; 8 = 100 kg P ha^{-1} + 10 MT FYM ha^{-1}; 9 = 100.2 kg P ha^{-1} + 20 MT FYM ha^{-1}

Table 16. Economic Analysis season 2, NARC - Kitale, 2003

Treatment		Yield	Gross	Variable	Net benefit	
Main plot	Sub plot	(MT ha^{-1})	income	cost (Ksh)	(Ksh.)	CBR
0 kg K ha^{-1}	1	8.2	81,500	50,000	31,500	0.6
	2	8.8	88,300	60,000	28,300	0.5
	3	10.9	109,500	70,000	39,500	0.6
	4	16.3	163,300	56,250	107,050	1.9
	5	18.2	181,600	66,250	115,350	1.7
	6	19.1	190,500	76,250	114,250	1.5
	7	17.9	178,500	62,500	116,000	1.9
	8	19.0	189,700	72,500	117,200	1.6
	9	24.2	241,600	82,500	159,100	1.9
83 kg K ha^{-1}	1	9.6	96,000	56,500	39,500	0.7
	2	12.7	127,100	66,500	60,600	0.9
	3	12.0	120,000	76,500	43,500	0.6
	4	22.6	225,600	62,750	162,850	2.6
	5	12.9	129,300	72,750	56,550	0.8
	6	12.2	121,900	82,750	39,150	0.5
	7	21.2	211,500	69,000	142,500	2.1
	8	23.9	238,500	79,000	159,500	2.0
	9	22.1	221,100	89,000	132,100	1.5
166 kg K ha^{-1}	1	9.4	93,600	63,000	30,600	0.5
	2	20.4	203,800	73,000	130,800	1.8
	3	17.0	170,000	83,000	87,000	1.0
	4	22.1	221,300	69,250	152,050	2.2
	5	24.4	243,700	79,250	164,450	2.1
	6	24.6	246,400	89,250	157,150	1.8
	7	28.0	279,900	75,500	204,400	2.7
	8	31.0	310,300	85,500	224,800	2.6
	9	29.6	295,700	95,500	200,200	2.1

Key: 1 = Control 2 = 10 MT FYM ha^{-1}

3 = 20 MT FYM ha^{-1} 4 = 50 kg P ha^{-1}

5 = 50 kg P ha^{-1} 6 = 50 kg Pha^{-1} + 20 MT FYM ha^{-1}

7 = 100 kg P ha^{-1} 8 = 100 kg Pha^{-1} + 10MT FYM ha^{-1}

9 = 100.2 kg P ha^{-1} + 20 MT FYM ha^{-1}

Table 17. Economic Analysis Psigirio 2003

Treatment		Yield	Gross	Variable	Net benefit	
Main plot	Sub plot	(MT ha^{-1})	income	cost (Ksh)	(Ksh.)	CBR
0 kg K ha^{-1}	1	11.3	112,600	50,000	62,600	1.3
	2	17.2	171,800	60,000	111,800	1.9
	3	18.5	185,200	70,000	115,200	1.6
	4	15.2	152,300	56,250	96,050	1.7
	5	21.2	211,600	66,250	145,350	2.2
	6	26.6	265,500	76,250	189,250	2.5
	7	22.2	222,400	62,500	159,900	2.6
	8	25.0	250,200	72,500	177,700	2.5
	9	32.7	327,100	82,500	244,600	3.0
83 kg K ha^{-1}	1	5.1	50,700	56,500	-5,800	-0.1
	2	11.5	114,800	66,500	48,300	0.7
	3	15.2	152,300	76,500	75,800	1.0
	4	12.0	120,300	62,750	57,550	0.9
	5	12.5	125,000	72,750	52,250	0.7
	6	19.0	190,100	82,750	107,350	1.3
	7	14.6	146,200	69,000	77,200	1.1
	8	15.9	159,300	79,000	80,300	1.0
	9	27.9	279,100	89,000	190,100	2.1
166 kg K ha^{-1}	1	11.8	118,400	63,000	55,400	0.9
	2	14.9	149,300	73,000	76,300	1.0
	3	17.7	176,600	83,000	93,600	1.1
	4	12.5	125,000	69,250	55,750	0.8
	5	18.1	181,000	79,250	101,750	1.3
	6	20.6	206,200	89,250	116,950	1.3
	7	20.0	200,400	75,500	124,900	1.7
	8	23.1	230,800	85,500	145,300	1.7
	9	20.0	200,400	95,500	104,900	1.1

Key: 1 = Control 2 = 10 MT FYM ha^{-1}

3 = 20 MT FYM ha^{-1} 4 = 50 kg P ha^{-1}

5 = 50 kg P ha^{-1} 6 = 50 kg P ha^{-1} + 20 MT FYM ha^{-1}

7 = 100 kg P ha^{-1} 8 = 100 kg P ha^{-1} + 10 MT FYM ha^{-1}

9 = 100 kg P ha^{-1} + 20 MT FYM ha^{-1}

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Potassium had no influence on plant growth and development but had great influence on potato tuber quality. Increasing potassium (from 0 kg ha^{-1} to 166 kg ha^{-1}) supply to potatoes resulted in to improvement of potato quality. However, phosphorus and FYM had no effect on tuber quality. Contrary to the above, phosphorus and FYM had significant effect on potato plant growth as indicated by their effects on plant height, tuber and shoot dry weights and potato tuber yield, which increased with increase in phosphorus and FYM application.

The best cost benefit ratio (CBR) and the net returns were realized in treatments having 0 kg K ha^{-1} + 100 P kg ha^{-1} + 10MT FYM ha^{-1} for the NARC - Kitale season 1, 0 K kg ha^{-1} + 50 Kg P ha^{-1} + 20MT FYM ha^{-1} for NARC - Kitale season 2 and finally the application of 83 kg K ha^{-1} + 50 kg P ha^{-1} + 0 MT FYM ha^{-1} at Psigirio site.

Finally combined use of inorganic fertilizer and manure is a feasible option for soil fertility improvement for production of high yields and good quality potatoes.

Recommendations

FYM alone cannot be used in the production high quality and high yields in potato production without additional potassium, phosphorus and FYM. Inorganic phosphate when applied in combination with FYM reinforces the generally low phosphate in FYM. Thus the application of small quantities of FYM in combination with low quantities of phosphorus and potassium is recommended for production of good quality potatoes. The optimum combination for P and FYM application for seed potato production is obtained at any level of P with FYM rate of 10 MT ha^{-1}. But for high ware potato production it is recommended to combine FYM with P without FYM or FYM at 20MT ha^{-1}. From the economic analysis done, the combination of small quantities of potassium, FYM and phosphorus is recommended for production high yields and good quality potatoes.

Appendix I. Chemical composition of soil samples from plots, NARC - Kitale season 2, after harvesting, 2003

Treatment	Depth of sampling cm)	pH	Na me %	K me %	Ca me %	Mg me %	Mn me %	P ppm	N %	C %
1	0 – 15	5.5	1.2	1.2	4.7	1.8	0.9	62.5	20	2.0
	15 – 30	5.5	0.7	0.9	3.9	1.6	0.9	45.5	14	1.4
2	0 – 15	5.3	0.7	1.0	3.9	2.3	0.9	70.0	15	1.5
	15 – 30	5.4	0.6	1.0	4.3	1.9	0.8	58.5	13	1.3
3	0 – 15	5.5	0.6	1.6	5.5	2.4	0.8	48.5	15	1.5
	15 – 30	5.7	0.8	1.2	4.3	2.2	0.8	41.5	13	1.3
4	0 – 15	5.6	0.6	1.3	5.1	1.9	0.9	53.5	14	1.4
	15 – 30	5.5	0.6	0.8	3.6	1.8	1.0	35.5	14	1.4
5	0 – 15	5.4	0.9	1.0	3.9	1.9	0.9	50.0	14	1.4
	15 – 30	5.5	0.9	0.9	3.9	1.6	0.9	43.0	14	1.4
6	0 – 15	5.7	0.7	1.3	5.5	2.2	0.9	50.0	14	1.4
	15 – 30	5.7	0.7	1.0	4.3	2.0	0.9	41.5	14	1.4
7	0 – 15	5.6	0.7	1.0	5.9	2.5	0.9	41.3	14	1.4
	15 – 30	5.7	0.7	1.4	3.9	2.4	0.8	35.5	13	1.3
8	0 – 15	5.7	0.6	1.0	3.6	1.8	0.9	43.0	14	1.4
	15 – 30	5.6	0.8	0.8	4.7	1.8	1.0	40.5	13	1.3
9	0 – 15	5.8	0.7	1.2	4.7	1.6	0.8	43.0	14	1.4
	15 – 30	5.6	0.8	1.0	3.9	1.5	1.0	39.0	14	1.4
10	0 – 15	5.6	1.0	1.2	4.3	2.4	0.9	82.5	15	1.5
	15 – 30	5.5	1.0	1.2	4.7	2.1	0.8	53.0	13	1.3
11	0 – 15	5.7	0.8	0.9	3.9	2.1	0.8	58.5	17	1.7
	15 – 30	5.5	0.9	1.3	5.1	2.0	0.7	51.5	15	1.5
12	0 – 15	5.7	0.6	0.8	3.6	2.3	0.9	48.0	14	1.4
	15 – 30	5.5	0.7	0.8	3.6	2.0	0.8	36.5	14	1.4
13	0 – 15	0.6	0.6	0.8	3.6	1.9	0.7	46.5	14	1.4
	15 – 30	5.7	0.6	0.7	3.6	1.8	0.8	39.0	13	1.3

14	0 – 15	5.6	0.8	0.8	3.9	1.8	0.8	46.5	15	1.5
	15 – 30	5.6	0.7	0.5	3.7	1.7	0.6	40.5	13	1.3
15	0 – 15	5.5	0.8	1.1	3.9	2.3	0.7	42.5	15	1.5
	15 – 30	5.5	0.8	1.1	3.9	2.3	0.7	38.0	13	1.3
16	0 – 15	5.5	0.9	0.9	4.2	2.8	0.8	48.0	13	1.3
	15 – 30	5.3	0.8	1.0	3.8	2.7	0.8	43.5	13	1.3
17	0 – 15	5.6	0.9	1.1	4.2	2.0	0.9	56.5	14	1.4
	15 – 30	5.6	0.7	0.9	3.6	1.7	0.8	42.3	15	1.5
18	0 – 15	5.8	0.9	0.9	3.8	2.5	1.0	38.2	14	1.4
	15 – 30	5.4	0.9	0.9	3.5	2.2	0.9	37.4	14	1.4
19	0 – 15	5.8	0.8	1.1	3.5	2.6	1.0	42.0	15	1.5
	15 – 30	5.8	0.7	1.1	3.7	2.3	0.9	41.0	13	1.3
20	0 – 15	5.7	0.9	1.0	4.3	2.4	0.8	45.3	15	1.5
	15 – 30	5.7	0.9	0.9	4.0	2.2	0.8	42.3	14	1.4
21	0 – 15	5.8	1.0	1.1	3.9	1.9	1.2	44.3	16	1.6
	15 – 30	5.7	1.0	1.0	3.8	1.8	1.0	40.5	14	1.4
22	0 – 15	5.8	0.9	1.0	4.1	2.1	1.0	42.3	16	1.6
	15 – 30	5.5	0.92	0.9	3.8	1.9	0.9	38.9	15	1.5
23	0 – 15	5.8	0.94	1.1	3.2	2.2	0.9	39.3	15	1.5
	15 – 30	5.7	0.95	1.1	3.0	2.1	0.8	36.8	14	1.4
24	0 – 15	5.6	0.82	0.9	3.6	2.5	0.9	42.2	11	1.1
	15 – 30	5.5	0.76	0.9	3.2	2.0	0.8	41.0	14	1.4
25	0 – 15	5.5	0.76	1.1	3.5	2.3	0.9	44.3	14	1.4
	15 – 30	5.6	0.76	1.0	3.7	2.1	0.9	43.2	14	1.4
26	0 – 15	5.6	0.85	1.1	3.8	1.9	0.9	53.0	14	1.4
	15 – 30	5.5	0.82	1.1	3.7	1.7	0.8	48.9	14	1.4
27	0 – 15	5.7	0.66	1.1	4.2	1.6	0.9	45.3	13	1.3
	15 – 30	5.6	0.65	0.9	4.0	1.2	0.8	42.4	13	1.3

Appendix II. Chemical composition of soil samples from Psigirio after harvesting, 2003

Treatment	Depth of sampling (cm)	p H	Na me %	K me %	Ca me %	Mg me %	Mn me %	P ppm	N %	C %
1	0 – 15	5.8	0.7	0.4	2.4	1.9	0.4	68.0	12.0	1.2
	15 – 30	5.3	1.0	0.3	2.0	1.9	0.4	2.2	10.0	1.0
2	0 – 15	5.8	0.7	0.6	3.0	2.4	0.4	20.0	13.0	1.3
	15 – 30	5.7	0.7	0.2	1.6	1.7	0.4	12.5	11.0	1.1
3	0 – 15	5.4	0.8	0.5	2.8	2.2	0.5	20.0	12.0	1.2
	15 – 30	5.3	0.8	0.4	2.4	2.0	0.5	15.0	12.0	1.2
4	0 – 15	5.2	0.6	0.5	2.8	2.2	0.6	16.0	12.0	1.2
	15 – 30	5.2	0.8	0.3	1.8	2.0	0.5	14.0	12.0	1.2
5	0 – 15	5.6	0.7	0.7	4.0	3.1	0.5	31.0	15.0	1.5
	15 – 30	5.4	1.0	0.4	2.6	2.6	0.5	15.0	14.0	1.4
6	0 – 15	5.6	0.8	0.7	4.4	3.2	0.5	25.0	17.0	1.7
	15 – 30	5.8	1.0	0.4	2.4	2.2	0.5	14.0	13.0	1.3
7	0 – 15	5.8	0.8	0.8	4.4	2.1	5.2	18.0	17.0	1.7
	15 – 30	5.4	0.7	0.3	2.2	2.5	0.5	12.5	13.0	1.3
8	0 – 15	5.4	0.6	0.6	3.2	2.1	0.5	22.5	13.0	1.3
	15 – 30	5.3	0.7	0.3	1.6	2.1	0.4	14.0	13.0	1.3
9	0 – 15	5.5	0.6	0.6	3.2	2.2	0.4	18.5	14.0	1.4
	15 – 30	5.3	0.6	0.5	2.4	1.8	0.3	12.5	12.0	1.2
10	0 – 15	5.5	0.5	0.6	3.2	2.0	0.4	18.5	11.0	1.1
	15 – 30	5.3	0.9	0.4	2.0	2.0	0.3	16.0	13.0	1.3
11	0 – 15	5.3	0.5	0.8	3.6	1.8	0.4	16.0	13.0	1.3
	15 – 30	5.2	0.6	0.3	2.0	1.5	0.4	14.0	11.0	1.1
12	0 – 15	5.3	0.6	0.5	2.6	1.4	0.4	38.5	1.40	1.2
	15 – 30	5.3	0.5	0.5	2.4	1.6	0.3	15.0	13.0	1.3
13	0 – 15	5.3	0.4	0.5	2.6	1.4	0.4	15.0	11.0	1.1
	15 – 30	5.2	0.8	0.6	2.8	1.5	0.4	18.0	11.0	1.1

14	0 – 15	5.4	0.6	0.6	3.0	1.8	0.4	32.5	13.0	1.3
	15 – 30	5.2	0.6	0.4	2.4	1.7	0.3	10.0	11.0	1.1
15	0 – 15	5.4	0.8	0.4	2.8	2.6	0.3	18.5	14.0	1.4
	15 – 30	5.2	0.8	0.4	2.2	2.2	0.3	8.5	11.0	1.1
16	0 – 15	5.4	0.7	0.8	3.6	2.7	0.4	13.0	11.0	1.1
	15 – 30	5.3	0.6	0.5	2.4	2.2	0.3	8.5	12.0	1.2
17	0 – 15	5.2	0.7	0.6	3.0	2.0	0.4	16.5	14.0	1.4
	15 – 30	5.2	1.0	0.5	2.4	1.8	0.5	20.5	12.0	1.2
18	0 – 15	5.7	0.8	0.9	4.4	3.4	0.5	34.5	15.0	1.5
	15 – 30	5.7	0.8	0.6	3.0	2.2	0.4	23.0	14.0	1.4
19	0 – 15	5.4	0.7	0.7	4.0	3.2	0.5	33.0	18.0	1.8
	15 – 30	5.4	0.4	0.4	2.4	2.1	0.5	13.0	15.0	1.5
20	0 – 15	5.5	0.5	0.8	4.4	3.7	0.6	20.5	20.0	2.0
	15 – 30	5.8	0.9	0.5	3.2	2.5	0.5	10.0	17.0	1.7
21	0 – 15	5.5	1.2	0.7	4.0	3.1	0.6	46.5	20.0	2.0
	15 – 30	5.5	0.7	0.4	2.2	3.4	0.6	10.0	17.0	1.7
22	0 – 15	5.6	0.7	0.7	3.2	3.8	0.8	15.0	20.0	2.0
	15 – 30	5.4	0.7	0.4	2.0	2.8	0.6	9.0	16.0	1.6
23	0 – 15	5.7	0.8	0.8	4.0	4.2	0.7	31.6	21.0	2.1
	15 – 30	5.5	0.8	0.5	2.4	3.3	0.7	11.5	17.0	1.7
24	0 – 15	5.8	0.7	1.1	5.4	5.2	0.8	51.5	24.0	2.4
	15 – 30	5.5	0.5	0.5	2.4	3.4	0.8	11.5	18.0	1.8
25	0 – 15	5.8	0.9	1.0	4.8	4.2	0.8	18.5	23.0	2.3
	15 – 30	5.8	0.7	0.4	2.4	2.8	0.8	15.5	19.0	1.9
26	0 – 15	5.7	0.7	0.8	3.6	3.5	0.9	36.5	20.0	2.0
	15 – 30	5.8	0.7	0.4	2.2	3.0	0.8	10.0	17.0	1.7
27	0 – 15	5.6	0.8	0.9	4.0	4.4	0.9	39.0	19.0	1.9
	15 – 30	5.4	1.0	0.5	2.2	5.6	0.5	47.0	14.0	1.4

REFERENCES

Aggarwal G.G., A.S Sidhu, N.K. Sekhom, K.S. Sardhu and H.S. Sur. 1995. Puddling and Management effects on crop response in a rice wheat cropping system. Soil and Tillage. 36(3/4):129-139

Ahn P.M. 1993. Manure fertiliser and use. Tropical soils and fertiliser use, Intermediate Tropical Agriculture series, Longman Group, UK Ltd, England pp. 147-148

AIC (Agricultural Information Centre). 1981. Major Crops Technical Handbook. Ministry of Agriculture, Livestock Development and Marketing, Nairobi, Kenya.

Amberger, A. 1983. Ways to control availability turnover and losses of mineral Fertiliser N in soils. Development in plant and soil Sciences Vol. 10. Efficient use of fertilisers in agriculture, United Nation Commission for Europe. Martinus Nijhoff, United nations New York. pp.145 –167.

Bicudo, J.R., L.M. Safley Jr. and P.W. Westerman. 1999. Nutrient content and sludge Volumes in single cell recycle anaerobic swine lagoons in North Carolina. Transactions of the ASAE. 9.42 (4):1087-1093.

Biotechnology Trust Africa. 2001. Guidelines for Tissue culture potato cultivation, published by biotechnology trust Africa, family Plaza, Nairobi, Kenya. pp 11.

Brady, N. C. 1990. Practical management of soil nitrogen. The manure and properties of Soils. Mac millan publishing company, New York . pp. 336–338.

Braun, H. and R.N. Roy. 1983. Maximizing the efficiency of mineral fertiliser. Development in plant and soil Sciences Vol. 10. Efficient use of fertilisers in agriculture, United Nation Commission for Europe, Martinus Nijhoff, United nations New York pp. 251.

Buchner 1951. In ORA Smith. 1977. Potatoes Production, storing and Processing 2nd edition, The AVI publishing company, INC West Port, Conecticut.

Burton, W. G. 1966. The potato. A Survey of its History and of the factors influencing its Yield, Nutritive value, Quality and Storage Second edition.Wagenigen, The Netherlands, 382pp.

CAB International, 2000. Crop protection campedium, Global Module, 2nd edition. Wallingford, UK: CAB International.

Chambers, B.J., K.A. Smith and B.F. Pain. 2000. Strategies to encourage better use of nitrogen in animal manure. British Society of Soil science Journal. Soil use and land management.16:157–161.

Cees, L., N. Roling and G.Bruin. 1998. Can the farmer field school replace the T & V of extension in sub – Saharan Africa? Paper for the 15th International Symposium of the association for Farming System Research–Extension, Pretoria South Africa 30th November – 4th December, 1998.

Chivenge, P.P., H.K. Murwira and K.E. Giller. 2000. Effect of soil organic matter fraction methods on soils of different texture under similar management. The Tropical Soil Biology and Fertility, TSBF, Report 1997–1998, pp. 48.

Cook, G.W., 1967. Organic manure. The control of soil fertility, London, pp. 143.

Drechsel, P and B. Reck. 1997. Composted shrub prunings and other organic manure for smallholder farming systems in southern Rwanda, agro forestry system Journal. 39 (1): 1 – 12.

Esilaba, A. O., J.B. Byalebeka, A. Nakgandu, S. Mubiru, R.J. Dalve, H. Ssali, and M. Mbulule, 2001. Integrated nutrient management strategies in eastern Uganda. A paper presented to PRIAM working group meeting held in Kisii, Kenya 5th – 7th November 2001.

Fischer, M. and C.S. Wortmann. 1999. Green manure for maize bean systems in Eastern Uganda: agronomic performance and farmers perceptions, Agro forestry Systems journal. 9:47(1/3):123–38.

Flirt, E.V., J. Pontius and N. Roling. 1996. Searching for strategies to replicate a successful extension approach: Training if IPM trainers in Indonesia. European Journal of agricultural education and Extension volume 1 no. 4. pp 44.

Gathungu, G.K., S.I. Shibairo, S.M Githiri, M.W.K.Mburu, P.S. Ojiambo and H.M. Kindanemariam 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.

Gomez, K.A., and A.A. Gomez. 1984. Statistical procedures for agricultural research, 2nd edition. John willey and sons New York. pp 304-308.

Hagedorn, F., K.G.Stainer, L. Sekayange and W. Zech. 1997. Effect of rainfall pattern on nitrogen mineralization on leaching in green manure experiments in south Rwanda. Plant and soil journal. 195 (2) 365–375.

Hill, H., 1953. In ORA Smith 1977. Potatoes Production, storing and Processing 2nd edition, The AVI publishing company, INC West Port, Conecticut.

Hind, G. 1995. Thylakoid components and processes. In: Photosynthesis and production in a changing environment. A field and laboratory manual.

Hittab, K.O., K. Natarajan, and A. Gapalaswam i. 1998. Influence of different organic manures on yield and N- use efficiency of rice. Journal of Indian Society of Soil Science. 46(2) 239–242.

Houghland, G.V.C. 1960. The influence of phosphorus on the growth and physiology of the potato plant . American potato Journal. 37: 127-138.

Irungu, J.W., L.M. Muriithi and S. Amboga. 2000. Integrated use of organic and inorganic soil nutrient resources for soil fertility improvement in potato (*Solanum tuberosum*) production

Jacob, A. 1963. Fertiliser use, Nutrition and manuring of tropical crops, 3 edition, Hannover, Germany 617pp.

Jaetzold, R. and Schmidt, H. 1983. Farm management handbook of Kenya Vol. II/B, Central Kenya (Rift valley and Central Provinces). Published by Ministry of Agriculture Kenya, in cooperation with German agricultural team (GAT) of the German agency for Technical cooperation (GTZ). pp 188 – 202.

James, D.W., R.L.Hurst, D.J. Westermann and T.A. Tinall. 1994. Nitrogen and potassium fertilization of potatoes: Evaluating nutrient element interaction in petiole with response surfaces. America Potato Journal. 7(4): 249- 265.

Jones, M.J. and A. Wild. 1975. Soils of the West African savanna: The maintenances and improvement of their fertility. Tech. Com. No. 55, Comm. Bur. of soils harpenden. Ahmadu Bello University, Nigeria, 44pp.

Kirhhof, G. and F.K. Salako. 2000. Residual tillage and bush fallow effects on soil properties and maize inter-cropped with legumes on a tropical alfisol. British Society of Soil science Journal. Soil use and land management 16:166-188.

Macdicken, K.G., K. Hairiah, K. Otsamo, B. Bukuma and W.M. Majid. 1996. Shade based control of Imparata calendar; tree falloffs and cover crops, Agrosystems. 36(1/3):131–149.

Martin, C., P.Demo, D.Njualem, T. Gas and C. Ntonifor. 1995. Late blight resistant varieties for Cameroon. America Potato Journal. 72(9): 513- 522.

Martinez and Pell, P. 2000. Nutrient fluxes from a soil treatment process for pig slurry.British Society of Soil science Journal. Soil use and land management. 16:100–107.

Maier N.A., A.P. Dahlenburg, C.M.J. Williams. 1994. Effects of nitrogen, phosphorus, and potassium on yield, specific gravity, crisp colour, and tuber chemical composition of potato (*Solanum tuberosum L.*) cv. Kennebec. Australian Journal of Experimental Agriculture. 34 (6). 813-824.

Minhas, R.S. and S. Gulap. 1998. Utilization of weed plants alone or in conjunction with fertilisers in a wheat–maize cropping sequence on Hapludalf in hilly region of Himachel Pradesh. Journal of the Indian Society of Soil science. 46 (1). 50–54.

Minhas, R.S. and A.Sood. 1994. Effects of in organics and organics on the yield and nutrient uptake by three crops in a rotation of an acid Alfisol. Journal of the Indian Society of Soil Science. 42 (2): 257- 260.

Misra, R.D., V.K.Gupta and D.S. Pandey. 1996. Managing crop residues in rice, Inter rice research notes Journal.21 (2/3): 71 –72.

MOA & R.D. 2000. Annual Report (Unpublished)

MOA & R.D. 2000. West Pokot District annual Report on crop production for year (Unpublished)

Mubonderi, I., I. Mariga, L. Mugwira, and O. Chivenge, 1999. Maize response to method and rate of manure application. Afr. Crop Sci. J. 9.7(4): 407-413

Mugambi, M. Susan. 1979. Manure and fertiliser requirements of potatoes on acid soils. E. Afr. Agric. For. J. 1979. 44(4): 178-278.

Mutuo, P.K., J.B.Mukalama, J.Agunda, S. Kobare, C.A.Palm, B. Jama, J. kanyangi, S. Amdalo and A. Niang. 2000. On farm testing of organic and inorganic phosphorus sources on maize in western Kenya. The Tropical Soil Biology and Fertility, TSBF, Report 1997 – 1998, pp. 22 – 23.

Mwale, M., 2000. Effect of timing of application of *S. sesban* prunings on maize yields. The Tropical Soil Biology and Fertility (TSBF) Report 1997 – 1998, pp. 38.

Mwania, N.M.M. 1983. The influence of nitrogen and phosphate fertiliser on growth, development and yield of potatoes (*Solanum tuberosum L.*). Msc. Thesis University of Nairobi, Kenya.

Mweri, B.A.M. 2001. Exposition Psigirioer Field School Methodology (Unpublished).

Nandasaba, J., C.M. Lusweti, C. Nkonge, E. Wanjekeche and D.J. Rees, 1999. Participatory evaluation of potato varieties for increased yields and cash generation. KARI/DFID NARP II Project end of conference 23rd-26th March 1999 Nairobi Kenya. Sutterland eds.

Nhamo, N. and H.K. Murwira. 2000. Use of manure in combination with inorganic fertilisers on sandy soils in Murewa, Zimbabwe. The Tropical Soil Biology and Fertility (TSBF) Report 1997 – 1998, pp. 29.

Nkandu, J., M. Magambo and J.Y.K. Zake. 1999. Effect of farmyard manure on the growth of onion (*Allium cepa*). Soil Science Society of East Africa, Conference Proceedings from 6th to 10th Sep.1999 and pp. 355–359 Kampala, Uganda.

Novak, B. 1983. Integrated plant nutrition systems; Development in plant and Soil Sciences. Efficient use of fertilisers in agriculture, United Nation Commission for Europe. Martinus Nijhoff, United nations New York. pp 67–69.

Novak, B. 1983. Integrated plant nutrient systems. Efficient use of fertilisers in agriculture pp. United Nation Commission for Europe. Martinus Nijhoff, United nations New York . pp.76.

Nyamangara, J., H. Kirchman and M.I. Phila. 2000. Carbon and nitrogen turn over soil amendment with aerobically decomposed cattle manure an N fertilisers. Tropical Soil Biology and Fertility, TSBF, Report 1997–1998, pp. 34–37.

Nzuma, J.K. and H.K. Murwira. 2000. Effect of management on changes in manure nitrogen during storage. The Tropical Soil Biology and Fertility, TSBF, Report 1997 – 1998 pp. 26 – 29.

Opena, G.B. and G.A. Porter. 1999. Soil management and supplemental irrigation effects on potato: II. Root growth. Agronomy Journal. 9.91 (3): 426-431.

Palm, C.A., K.E. Giller and M.J. Swift. 2000. Soil organic matter. The Biology and Fertility of tropical soils, TSBF, Report 1997-1998, pp. 46.

Palm, C.A., R.J.K. Myers, and S.M. Nandwa. 1997. Combined use of organic and inorganic nutrient source for soil fertility maintenance and replenishment. In: Bursh, R,J.Sanchez, P.A. and Calhoum, F. (eds), Replenishing soil fertility in Africa. SSSA special publication No. 51. Wisconsin, USA. Pp. 193-102.

Panique, E., K.A. Kelling, E.E. Schulte, D.E. Hero, W.R. Stevenson and R.V. James. 1997. Potassium rate and source effect on potato, yield, and quality and disease interaction. America Potato Journal. 7(6):379-398.

Panjek, F. and B. Jelanic. 1983. Effect of the organic mineral fertiliser "Homofertil" on the maintenance and increase of soil fertility and on the prevention of underground and water pollution. Development in plant and Soil Sciences Vol. 10. Efficient use of fertilisers in agriculture, United Nation Commission for Europe, Martinus Nijhoff, United Nations New York. pp. 325–330.

Peter, E.H. 1983. Modified stability analysis of farmer managed, on farm trials. Agronomy Journal.76:271 –274.

Porter, G. A., G.B. Opena, W.B. Bradbury, J.C. Mc Burnie and J.A. Sisson. 1999. Soil management and supplemental irrigation effects on potato: I. Soil properties, tuber yield and quality. Agronomy Journal. 9. 91 (3): 416-425.

Poulsen, H.D. 2000. Phosphorus utilization and excretion in pig production. Journal of environmental quality. 29 (1): 12–27.

Quizon, J., G. Feder and R. Murgai. 2000. A note on sustainability of the farmer field school approach to Agricultural Extension. Development economics group. The World Bank, USA.

Ranganathan, D.S.and D.A. Salvseelan. 1997. The effect of mushroom spent compost in combination with fertiliser application on nutrient uptake by potato in an Ultic Tropudalf. Journal of the Indian society of soil science. 45 (3): 515–519.

Rola, A.C., Z.S. Provido, M.O. Olanday, F.J. Paraguas, A.S. Sirue, M.A. Espadon and S.P. Hupeda eds. 1998. Making Farmers better Decision – makers Through the Farmer Field Schools.

Roy H.F, S.M. Larry, L.D. Roy. 1981, Fertilisers and soil amendments, New, Delhi, India. 465pp.

Roy, R.N. and R. Braun. 1983. Integrated plant nutrition systems. Efficient use of Fertiliser systems in agriculture, Martinus Nijhoff, United nations New York, pp. 235.

Russell, E.J.1921. Manuring for higher crop production pp. 1, Crop production, 3rd edition, Cambridge University press, 94 pp.

Schleich, K. 1986. The use of cattle dung in agriculture. Natural resource and resource development 23: 53-87

Sharma, M.P., S.V. Bali and D.K. Gupta. 2000. Crop yield and properties of inceptisol as influenced by residue management under rice – wheat cropping sequence. Journal of the Indian Society of Soil Science. 48 (3): 506-509.

Sharma, P.K., T.S. Verma and R.M. Bhaget. 1995. Soil structural improvements with addition of *Lantana camara* biomass in rice wheat cropping. British Society of Soil Science Journal. Soil use and land management 11 (4):199-209.

Shewel, C., David and Charles. 1972. Compost gardening Tom Stacey, London, 197pp.

Sikka, L. 1982. Fertiliser and manure requirement of potato. Potato seed production for Africa. Nganga and shideler, F. edds. International potato center, pp. 93.

Smith, K.A., A.J. Brewer, A. Dauven and D.W. Wilson. 2000. A survey of production and use of animal manure in England and Wales. British Society of Soil science Journal. Soil use and land management. 16:124 -132.

Soil Management Project annual report 1995 (unpublished).

Soil Management Project annual report Annual Report 2000 (unpublished)

Sud, K. C. 1996. Effect of phosphorus and sulphur on potato nutrition in Shima hills. Journal of the Indian Society of Soil Science. 44 (3): 440-444

Upton, M. 1987. African farm management. Cambridge University Press. pp. 190

Van Faassan, H.G. and H. Van Dijk. 1987. Manure as a source of Nitrogen and Phosphorus in soils. Animal manure on grassland and fodder crops. Fertiliser or waste? vad de Meer eds. pp. 27 – 45.

Wanjekeche, E., T. Mwangi, M.P. Powon and J. Khaemba, 1999, survey of Management practices of boma manure and it's nutrients in west Pokot District of Kenya, Soil Science Society of East Africa, Conference Proceedings from 6th to 10th Sep.1999, and pp. 355–359 Kampala, Uganda.

Ward, G.M. 1959. Potassium in plant metabolism. II. Effect of potassium upon the carbohydrate and mineral composition of potato plants. Canad. J. Plant Sci. 39:246-252

Welte, E and Muller, K. 1966. The influence of potassium manuring on the darkening of raw potato pulp. Eur. Potato J. 9: 38-37

Westermann, D.J., D.W. James, T.A. Tinall and R.L. Hurst. 1994. Nitrogen and potassium fertilization of potatoes: sugars and starch; America Potato Journal. 71(7): 433- 453.

Wilcox, G. E. 1961. Effect of sulfate and chloride sources and rates of potassium on potato growth and tuber quality. America Potato Journal. 38: 215-420.

Whyte, W.F. and R. Boynton. 1983. Human systems for agriculture Cornell University press, Itheca , New York.

Woomer, P.L., N.K. Karanja and J.R. Okalebo. 1999. Opportunities for improving integrated nutrient management by small holder farmers in Central Highlands of Kenya. Afr. Crop. Sci. J. 7(4): 441-454

EGERTON UNIVERSITY LIBRARY