EVALUATION OF NITROGEN FERTILIZER, LIME AND SOIL-WATER EFFECTS ON THE YIELD AND MALTING QUALITIES OF BARLEY (*Hordeum vulgare* L.)

BY

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DECLARATION

Declaration by Student

This research thesis is my original work and has not been presented for a degree in any other University or any other award. No part of this work should be reproduced in any form without my permission and/ or University of Eldoret.

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ABSTRACT

Barley (*Hordeum vulgare* L.) is a cereal crop that grows over a wide range of environments and in Kenya it is grown primarily for malting. Barley requires adequate nitrogen (N) for good grain yields and quality malting, but the balance between adequate and excessive N is important therefore an experiment was set up between July 2011 and July 2012 to address the problems of N fertilizer use and soil moisture effects on grain yield and malting qualities. The experiment was conducted at medium altitude at University of Eldoret (Chepkoilel) (2185m asl) and at high altitude in Mau-Narok (2740m asl). The objective was to evaluate effects of nitrogen fertilizer rates, liming and varying soil water on the grain yield and malting qualities of barley. The experiments were done in the field and in the greenhouse. For the field experiment, nitrogen as C.A.N fertilizer was applied at 5 levels 0, 30, 40, 50 and 60Kg N/ha, all at planting. Phosphorus inform of TSP at 45 Kg/ha as P_20_5, and potassium in form of muriate of potash at 35 Kg/ha as K_20, were applied both as blanket in plots with nitrogen treatments, and as a treatment. Lime was applied at 2 levels (0 & 1.5 t/ha). Split plot arrangement in RCBD design was used in the field. Two different experiments were conducted in the greenhouse; the first one being a simulation of the field experiment which had similar treatments as those in the field. The second greenhouse experiment was a split-split arrangement in CRD design, with 3 soil water contents (field capacity, 80% field capacity and 50% field capacity) applied in 4 nutrient types (nitrogen, phosphorus, lime and control having all combined) tested on the two site soils. The results indicated the soils of the two sites were acidic and deficient in phosphorus. Mau-Narok site had more soil N than University of Eldoret. The effect of Nitrogen on grain yield was highly significant ($P \leq 0.001$). Increasing N rates beyond 40Kg N/ha increased the grain protein content beyond the malting range. Effect of lime on grain yield in the field was significant at ($P \leq 0.01$) while ($P \leq 0.05$) in the greenhouse for both site soils. Lime treatments had higher grain protein contents than non-limed ones but not significantly different. Lime-nitrogen interaction on kernel weight was highly significant ($P \leq 0.001$) but not significant for grain yield. The differences in grain yield, kernel weight and biomass due to soil type were highly significant ($P \leq 0.001$).There was a significant relationship ($P \leq 0.001$) between soil moisture content and lime on barley growth. Limed treatments of both site soils utilized less water to produce mature grains compared to the un-limed ones. The effect of soil moisture levels on biomass and tillering was highly significant ($P \leq 0.001$). Application of lime in combination with N rates at 30 and 40 N Kg/ha produced best results for grain yield (>7 t/ha for both field and green house), biomass, kernel weight and grain crude protein (10-13.5 %) with soil moisture contents of between field capacity and 80% field capacity being ideal for barley growth on both soils. Nitrogen rates at 30N and 40 N Kg/ha produced highest grain yield, highest kernel weight and ideal maltable grain protein content for both site soils and therefore was recommended as optimum agronomic rates for both sites. In addition, liming was recommended for Chepkoilel while increase in phosphorus use for Mau-Narok.

DEDICATION

To God Almighty who has always guided me throughout my entire life, ever caring and watching over me. Thanks to Him (God) for having given me this special talent of easily understanding my studies.

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LIST OF ABBREVIATIONS AND ACRONYMS

Abs	Above sea level
ANOVA	Analysis of Variance
CAN	Calcium Ammonium Nitrate
DAP	Di-ammonium phosphate
EABL	East Africa Breweries limited
EAML	East Africa Malting limited
FC	Field Capacity
HI	Harvest Index
HKBL	Hybrid Kenya Breweries Limited
IMA	International Malting Association
KARI	Kenya Agricultural Research Institute
KBL	Kenya Breweries Limited
MT	Metric Tones
NUE	Nitrogen Use Efficiency
P.a	per Annum
TSP	Triple super phosphate
USDA	United States Department of Agriculture

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CHAPTER ONE

INTRODUCTION

1.1 Background

Barley (*Hordeum vulgare* L.) is the world's fourth important cereal crop after wheat, maize and rice. It is an annual grass that grows over wider environment range than any other cereal crop and probably grows in many areas unsuitable for other crops (Brink & Belay, 2006).

Barley is cultivated at medium to high altitude regions receiving between 900-1400mm of rainfall p.a. but it requires 635mm of rainfall during the growth period (KBL, 2005). The crop does well in altitudes of 1500m to 3000m asl with optimum temperatures ranging from 15-30^{o}C. Under low humid conditions, the crop can tolerate higher temperatures above 32^{o}C. The crop thrives well on coarse textured, well drained soils intolerant to water logging with pH range of 7.0 to 8.0. It is sensitive to soil acidity and the resultant aluminum toxicity than any other cereal crop.

In Kenya, barley is a medium to high altitude (1500-3000 m asl) crop. The main growing areas are the Mau escarpment, Mt. Kenya region (Timau), Nakuru district and Moiben region. Of these, the Mau escarpment contributes 60% of the total area, Timau – 20%, Moiben13% and Nakuru area 7 %. The total area under barley cultivation is 20,000 hectares against a potential area of 85,000ha (EABL, 2010). Mean annual global production between 1999 and 2003 was 136m tones grain from 54m hectares. The major world producing countries were Russia, Germany and Canada with 16.2, 12.1 and 11.4 million tons, respectively. In tropical Africa, the main producers are Ethiopia, Kenya and Eritrea.

Between 1999 to 2003 periods, Kenya produced 45000tons from 20000ha annually, (Brink & Belay, 2006). Barley yields have remained stagnant since 2001 up to date (2012) at 75 metric tones per year (USDA, 2012).

Barley grown in Kenya is primarily for malting. It is also used as feed grain to livestock, but by far, its economic value is linked to the malting industry. In other regions of the world: barley is used as a thickener in the production of starch for the food industry and as an ingredient in making Japanese alcohol. In Morocco, Ethiopia and China; barley is used as human food.

It is believed to be the most drought and salinity tolerant of the cereals. Globally, barley is grown in diverse environments that range from sub-arctic to sub-tropic. According to Chapman (1978), the crop performs well in temperate climates and high altitudes of the tropics and sub tropics.

Due to the irregularity of rainfall in growing areas in Kenya, a preplant application of nitrogen is important to adequately feed the crop through its short growing season. Top-dressing after crop establishment has been unsuccessful because it contributes more to increased protein than increased yield. This has raised many problems on the quality of the malt or beer produced (KARI Report, 2009). Once the Nitrogen application is made, managing the crop for high yield is important. Although yield is most directly related to temperatures, soil moisture and rainfall of a growing season, growers have a number of things they can do to maximize yield in any given year. High fertilizer applications does not push yield higher than environment and management factors allow; therefore, being conservative on N rates is important to maximize the odds of producing malting-grade barley.

For optimum yields and performance: the main nutrients required are, nitrogen, phosphorus, potassium and to a lesser extent copper, manganese and zinc (Australian Dept of Agriculture and Food, 2007). Sulphur deficiency has been reported to reduce the yields.

1.2 Statement of the problem and justification of the research

Barley requires adequate nitrogen for good grain yields, but grain protein in excess of malting requirements often leads to rejection of a crop while excess nitrogen leads to smaller kernel size, therefore the line between adequate and excessive nitrogen is an important issue in barley production (Franzen & Goos, 2007). Excessive grain protein lengthens steeping times, makes germination more erratic and creates undesirable qualities in grain malt leading to losses to any barley grower. In addition barley growing zones in Kenya are faced with a key problem of soil acidity limiting optimum productivity. The acid soils are characterized by high aluminium saturation with less available phosphorus which together with inadequate nitrogen contributes to low grain yield and undesirable grain malting qualities. Therefore, there is need for research to solve this problem through liming. Climate change have caused unpredictable weather conditions leading to irregular rainfall patterns, droughts and frost conditions that have resulted to total crop failure in high potential zones of Mau-Narok and Mount Kenya regions, hence need for drought tolerant and water efficient barley varieties. Malting barley yields have remained low at a national average of 2.2 tones against a potential of 5 to 7 tones per hectare and recently it has been observed that only 76% of harvested barley attained the acceptable grain nitrogen content in the year 2010 (EABL, 2011).

This shows there is need for improvement in terms of yield and grain quality. Currently, farmers in Kenya are faced with high N fertilizer prices due to hikes in both natural gas and petroleum prices which are the major ingredients in fertilizer N manufacture (Johnston *et al.,* 1991).

This has increased the cost of barley production leading to reduced profits to farmers and as result, these questions arise; how does the price of fertilizer N influence the optimum rate of N for malting barley? And how does the form (NH^+_4/NO^-_3) of fertilizer N affect the quality of malting barley?

Due to increase in demand for malting barley (EABL, 2010), malting companies need the right quality of barley grain in terms of correct protein content to produce the best beer quality for consumption. From this another question arises; what are the correct N fertilizer application rates and nitrogen form for which farmers to use to get satisfactory yields and good quality grain for malting?

To answer these questions, a study was carried out through careful manipulation of agronomic and management practices that would provide a solution to barley growers. The actual output from the study was to establish and recommend N fertilizer rates that would give optimum yields as well as good malting barley grain in terms of crude protein content and kernel weight.

1.3 Objectives

1.3.1 Major objective

- To evaluate effects of nitrogen fertilizer rates, liming and soil water on the grain yield and malting qualities (protein content, and kernel weight) of barley

1.3.2 Specific objectives

- To evaluate how soil nitrogen availability and uptake by barley crop affect its grain yield, grain protein content and kernel weight

- To evaluate effect of liming the soil on grain yield, grain protein content and kernel weight of barley
- To evaluate effect of varying soil water contents on soil nutrient release, biomass and tillering by the barley crop
- To study the combined effects of lime and soil moisture on the chemical and physical properties of soils

1.4 Research hypotheses

Varying nitrogen rates, liming and varying soil water contents have no significant effect on the grain yield and malting qualities (protein content, kernel weight) of barley ($\mathbf{H_0}$)

Liming and soil moisture have no significant effects on soil chemical and physical properties ($\mathbf{H_0}$)

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and geographical distribution

Barley is a cereal crop grown across the globe. Its synonym is *Hordeum saticum.* It is also known as barley in English, Orge (French), Cevada (Portuguese) and Shayiri in Swahili

Barley was domesticated in western Asia before 7000BC. Cultivation spread to northern Africa and moved upwards along the Nile into Ethiopia about 5000 years ago. Nowadays it is grown over a broader environmental range than any other cereal from 70^{o} N in Norway to 44^{o} S in New Zealand. In tropical Africa, barley is grown in Eastern Africa mainly Kenya and Ethiopia. In West Africa barley is grown in Nigeria and the Sahel region (Brink & Belay, 2006).

2.1.1 Barley botany

Barley is an annual grass that grows up to 120-150cm tall, and tillers freely. It has got both primary and adventitious root system. Barley comprises of 32 species. The cultivated barley has been developed from original wild populations. Fertile hybrids between wild and cultivated types are easily obtained and occur naturally (Brink & Belay, 2006).

2.1.2 Growth and development of barley

Barley seedling emerges from the soil 5-6 days after germination. Tillers are produced on the main shoot until flowering stage. Tillering in barley is a function of cultivar, plant density, cultivation and environmental factors. A single plant can develop up to 6 stems and even more at low plant densities. Barley is a long day species, flowering earlier under longer photoperiods and is cultivar sensitive (Brink & Belay, 2006).

2.2 Barley growing in Kenya

In Kenya, barley cultivation can be traced back to the 1940s when it was cultivated as a rotational crop for animal feed. Barley growing for industrial processing began in 1947 after an interest from Kenya Breweries Ltd. (KBL, 2005). To date, most barley grown in Kenya is for malting. Barley is a medium to high altitude (1500-3000 m above sea level) crop and therefore in Kenya, the main growing areas are the Mau escarpment, Mt. Kenya region (Timau), Nakuru district and Moiben region. Mau escarpment contributes 60% of the total area, Timau – 20%, Moiben 13% and Nakuru area 7 %. The total area under barley cultivation is 20,000 hectares against a potential area of more than 85,000ha. This shows that there is huge potential to increase production through increased acreage. Most barley is grown by large scale contracted farmers although 15% of the farmers are small scale. Barley farming in Kenya is important because it supports over 100,000 people directly and indirectly with billions of Kenya shillings being paid to the farmers, contractors and transporters (KBL, 2005). The Kenya government benefits from barley farming through tax levies paid by the brewing industry.

2.3 Use of fertilizers in barley production in Kenya

Fertilization of barley in Kenya has been limited to large scale farming with small holder farmers applying inadequate or no fertilizer at all. Kenya Breweries, the main consumers of malting barley have been using N rates of 40.5Kg N /ha. The main fertilizer source has been N. P.K with fertilizer grade 23:23:0 (EABL, 2010) but currently other fertilizers are being used like Mavuno, DAP 18:46:0 and NPK 17:17:0. Most small scale farmers have been using different kinds of nutrient sources including both organic and inorganic sources which always lead to varying N and protein contents of the grain. This has raised many problems on the quality of the malt or beer produced (KARI Report, 2009).

2.4 Ecological requirements of barley

2.4.1 Climatic factors

Barley grows under a wide range of photoperiod, temperature and rainfall conditions. It can withstand high temperatures in dry climates and humidity in cool climates. It is ill-adapted to hot, humid climate due to its susceptibility to diseases. The barley plant is a short season, early maturing crop found in widely varying environments globally (Australian Dept of Agriculture and Food, 2007). Cultivated barley is grown in diverse environments that range from sub-arctic to sub-tropic. However it prefers temperate areas and high altitudes of the tropics and sub tropics. Altitudes of 1500 to 3000masl are ideal for barley with optimum temperatures ranging from 15-30^{o}C. It can tolerate higher temperatures above 32^{o}C so long as humidity remains low (Chapman, 1978). Barley is adapted to an annual rainfall ranging from 200 to1000 mm. It is more droughts escaping due to its early maturity than drought tolerant. Compared to other cereal crops, barley is an efficient water user and is a crop of choice in drier areas. Nevertheless rainfall distribution in these areas should ensure adequate rains during the growth phase (Brink & Belay, 2006).

2.4.2 Soil factors

Barley perform well in course textured, well drained soils within pH range of 7.0 to 8.0. It is sensitive to soil acidity and the resultant aluminium toxicity than any other cereal crop. It is however more tolerant to soil salinity and it can be the preferred crop for sodic soils (Chapman, 1978). For successful barley production, the main nutrients required are, nitrogen, phosphorus, potassium and to a lesser extent copper, manganese and zinc (Australian Dept of Agriculture and Food, 2007). Low sulphur levels can also be a problem in areas of long history of cultivation. This raises the need for soil testing before fertilizer is used in barley production.

2.4.3 Propagation, harvesting and yield

Barley is planted through direct seeding either through drills or hand broadcasting. The distance between rows is 15-35cm with a seed rate of 50-150Kg/ha the sowing depth is 2-6cm. The land is ploughed to a depth of 10-15cm, (Brink and Belay 2006). Barley is ready for harvesting after reaching 35-40% kernel moisture. Threshing of malting and naked grain is careful done to avoid breakages. Barley grain yields vary from 0.3t/ha in dry years and up to 10t/ha in marginal environments. In Africa, average yields are 0-2.5 t/ha (Brink & Belay, 2006).

2.4.4 Diseases and Pests

The crop is affected by several viral and fungal diseases. The most important being barley yellow dwarf virus (BYDV), transmitted by various aphid species and barley stripe mosaic (BMSV). In Kenya, epidemics of African cereal streak caused by maize streak virus (MSV) and transmitted by leafhoppers (*Cicadilina* spp) have been reported. Fungal diseases in barley include; powdery mildew (*Blumeria gramins*), spot blotch (*Biopolaris sorokiniana*), scald (*Rhynchosporium secalis*), Net blotch (*Pyrenophora teres*) and barley rust (*Puccinia spp*), (Brink & Belay, 2006).

2.5 Nutrient requirement for malting barley

The main nutrients required for optimum performance of barley are; nitrogen, phosphorus, potassium and to a lesser extent copper, manganese and zinc (Australian Dept of Agriculture and Food, 2007). Sulphur deficiency has been reported to reduce the yields.

2.5.1 Nitrogen

Nitrogen is needed for early tiller development of barley. Nitrogen is also an essential part of proteins, and largely determines the protein concentration in the grain. The nitrogen required to grow a successful barley crop must be supplied from the soil or as fertilizer.

Symptoms

The older leaves turn pale green and the leaf tips pale yellow. The yellow color progresses down the leaf towards the base eventually turning pale brown. The youngest leaves remain green.

Crop requirements

The amount of nitrogen that a malting barley crop needs to maximize yield and quality depend on the growing season conditions, soil type and rotational history of the paddock, as well as the potential yield of the crop (Australian Dept of Agriculture and Food, 2007).

Yield potential

Between 40 and 54 Kg of mineral nitrogen is generally needed in the soil for each tone of barley grain produced. As the potential yield increases, extra nitrogen will have to be supplied by the soil or extra fertilizer.

2.5.2 Phosphorus

It is essential for the rapid early development of barley roots and seedlings. It is important for seed formation and a deficiency can reduce both head and grain numbers, which are established early in the development of the crop (Australian Dept of Agriculture and Food, 2007).

Symptoms

The old leaves develop a purple edge, which is more prevalent towards the tip of the leaf. Over time, the purple discoloration extends down the leaf edge and the leaf turns to dark yellow then brown color.

Management

It is recommended to apply about 4 Kg/ha of P for every tone of barley yield targeted. Apply extra P on soils that are prone to chemically locking the applied phosphorus, e.g. highly calcareous and ironstone soils. Phosphate is needed during early growth, so phosphatic fertilizers are drilled with the seed during sowing (Australian Dept of Agriculture and Food, 2007).

2.5.3 Sulphur

Sulphur deficient plants that are low in nitrogen have pale younger leaves and their growth is retarded and their maturity delayed. Where nitrogen has been applied, the sulphur symptoms appear more severe. The entire plant becomes a lemon yellow colour and the stems become red. The symptoms of nitrogen deficiency are different from sulphur deficiency in that it is the older leaves that are affected first with nitrogen deficiency (Australian Dept of Agriculture and Food, 2007).

Occurrence

Sulphur deficiencies most occur on the deeper wetter sandy soils. Deficiencies most often occur in the wetter years and they progressively become more severe with successive years when applying fertilizers with low sulphur content.

Management

Crop tests are used as guides for diagnosing sulphur deficiency. Sulphur at 0.2 per cent in younger leaf tissue is the critical level used for many crops, but often the nitrogen to sulphur ratio (N/S) is also a valuable guide. A ratio of greater than 19:1 often indicates a sulphur deficiency.

Applying a sulphur-containing phosphatic fertilizer at a rate that supplies 5 to 10 Kg of sulphur per hectare can avoid a sulphur deficiency. These sulphur-containing fertilizers should be used in rotation with DAP or triple super in a fertilizer strategy (Australian Dept of Agriculture and Food, 2007).

2.5.4 Potassium

Potassium is required in similar amounts as for nitrogen. Deficiencies can lead to poor root growth, restricted leaf development, fewer grains per head and smaller grain size affecting both yield and quality. Potassium is an essential nutrient for grain filling and a deficiency can increase the level of screenings and can reduce the tolerance of plants to environmental stresses, such as drought, frost and water logging as well as pests and diseases. Potassium deficient is more prone to foliar leaf diseases reducing grain yields (Australian Dept of Agriculture and Food, 2007).

Symptoms

Barley plants become stunted or appear drought stressed. For barley, potassium fertilizer is required when soil test potassium levels are below 50 mg/Kg in the top 10 cm. In medium and high rainfall areas, application of a potassium fertilizer should be delayed until four weeks after germination when the plants have developed a sufficient root system to take it up. Drilling the fertilizer with the seed is discouraged as it reduces establishment.

In low rainfall areas with no risk of leaching, the economic benefit from applying potassium depend on the expected yield. Application of 40 to 80 Kg/ha of muriate of potash is encouraged where potassium deficiency is diagnosed to give an economic yield increase.

2.5.5 Nitrogen uptake and utilization in barley

Barley uses nitrogen taken up from the soil as NO^-_3. This uptake results mainly from an active influx of NO^-_3, partly offset by a passive efflux of NO^-_3 back into the rooting medium. Other ions may influence this process, chloride and sulphate salts inhibit the uptake. The effect of bromide is negligible (Abrol, 1990**).** The cation calcium accelerates the absorption of NO^-_3, while NH^+_4 stimulate NO^-_3 efflux. On the other hand, barley plants in a mixed NH^+_4/NO^-_3 feeding solution show a far greater productivity (plant size and nitrogen content) than plants grown on either nitrogen source alone. Nitrate fed plants have a low nitrogen content compared with plants fed with ammonium or nitrate/ammonium. N-uptake in field grown barley shows that uptake of NH^+_4-N is delayed in comparison with uptake of NO^-_3-N. Environmental factors influence N uptake; at low temperatures, barley seedlings show preferential absorption of some organic N sources like arginine over inorganic ones. Nitrate uptake in barley during aging is low initially, reaching a maximum value around 49 days. A second (smaller) peak is found around 84 days, and a third peak appears around 118 days after sowing, (Abrol,1990**).**

2.5.6 Nitrogen application methods

Application of nitrogenous fertilizer in barley is determined by many factors. Nitrogen can be applied with the seed at planting as long as it does not exceed the limits. Some growers also use a mid-row banding of anhydrous ammonia, urea or nitrogen solutions.

Nitrogenous fertilizers like Urea, C.A.N can be applied in barley as long as the seed is separated from the fertilizer (Franzen & Goos, 2007). Adequate incorporation of urea in low-residue situations takes a one-half to three-quarters of an inch of rainfall.

Under no-tillage practices, subsurface application of urea or urea solutions is strongly recommended, as the conversion from urea to free ammonia is faster when residues are present. Deep harrowing may not be enough to cover the urea adequately with soil if there is no enough rain to dissolve the urea and move it past the residue and into the soil, (Franzen & Goos, 2007).

2.6 The effect of lime on soil properties and yield

Studies have indicated that liming the soils increases grain yields of barley. Liming the soils facilitates more nutrient availability to plants. There have continued yield increases over the years, even as far as 15 years after the initial lime application, (Http://www.Agricultural lime). It is known that lime affects both chemical and physical properties of the soils. Liming increases soil pH and reduces both aluminium and manganese toxicities. It improves biological and physic-chemical properties (Brown *et al.,* (1959). Calcium in lime improves the soil structure by binding the soil organic matter into aggregates.

2.7 Grain protein content of malting barley

The required grain protein content in malting barley should be greater than 9.0% but less than 11.5% (1.4 – 1.7% N) in two–row barley, the common barley cultivar for malting in Kenya (EABL, 2010). Grain protein content is controlled by multi-genes and is sensitive to environmental factors; especially precipitation during growing season (Zeng *et al.,* 2012) Grain protein concentration is a function of cultivar, N-fertilizer application and the interaction between cultivar and N-rate. Prediction of optimum rates of N-fertilizer application for malt barley, though difficult to predict, can be based on determination of pre-plant soil NO_3-N to estimate available N in the soil (McKenzie, 2004).

However this rate may range from 0 $Kgha^{-1}$ in sites with greater than 30ppm NO_3-N in soil to 96$Kgsha^{-1}$ in soils with 0-6ppm NO_3-N.

Protein content and grain yield will increase with increased nitrogen application, however, protein content increase at a slower rate; for example where nitrogen application doubles the grain yield, protein content increases by 1- 2 % (Hochman *et al.,* 2009).

2.8 Barley grain yield and water consumption

Barley grain yield is a function of the amount of water consumed and the N uptake by the crop. Maximum nutrient application and water utilization is needed for optimum grain yield. This generally affects the ratio of the number of plants per unit area to the number of ears per unit plant, thus affect tillering (Heyland & Werner, 1975).This can be influenced, depending on water and N supply, by application of N. It has been estimated that depending on the quantity and timing of N application, around 250 litres of water per Kg grain yield are required by barley crop (Heyland & Werner, 1975).

2.9 Simulation model for predicting barley N-fertilizer requirement and yield

A methodology to quantify N fertilizer requirement for a barley crop was proposed (Galvis-Spinola *et al.,* 1998). The method consists of establishing a relationship between barley N demand (DEM) and an index of soil N supply (NS). NS values are obtained by adding the inorganic N, i.e., (N-NO^-_3 + N-NH^+_4), measured just before planting in the soil to an index of soil organic N mineralization. In this model, soil N supply values are related to both grain yield (Y) and N accumulated in shoot biomass of barley grown under greenhouse conditions giving rise to a linear relationship which is used to extrapolate the greenhouse results to field conditions. Optimum possible barley yields depend on N demand and soil N mineralization especially in tropical highland climates like Kenya.

CHAPTER THREE

MATERIALS AND METHODS

Field experiments were conducted at two sites; University of Eldoret (Chepkoilel) and Mau Narok while green house experiments, using soils from the two sites were carried out at the University of Eldoret. The experiments were conducted between, July 2011 and December 2012, a period of one year.

3.1 Study sites

3.1.1 University of Eldoret Farm (Medium Altitude)

It is situated 9 km North of Eldoret town. The site is located at latitude 0^0 30' E and longitude 35^0 15' E; at an elevation of 2185m above sea level. Its ecological zone is Lower Highlands - (LH_3) (Jaetzold, 2006) with average rainfall of 900 – 1100 mm p.a. The area experiences both long and short rains. The area is characterized by highly weathered and well drained red soils with Oxic B layer (rhodic Ferralsols). The soils are acidic with $_P$H 4.7. This site was chosen to represent the medium altitude barley growing areas

3.1.2 Mau Narok, Purko Farm (High Altitude)

The site is at Purko farm located 70km south of Nakuru town and positioned as (0^o 20'S, 35^o 35'E). Its elevation is 2740m above level. The area is in the agro eco-zone UH3 (Jeatzold, 2006) and lies along the Mau escarpment. The climate at this site is cool with mean temperatures of 15- 19^oC and an average annual precipitation of 1200 – 1400mm p.a. The site is characterized by deep fertile and well drained soils that are prone to erosion and copper deficiencies known as andosols with $_P$H 4.7 (Jeatzold, 2006). The Mau-Narok site represented the high altitude barley growing areas in Kenya in this research experiment.

3.2 Land use of the experimental fields

3.2.1 University of Eldoret

The experiment was set up on the university research farm in July 2011 which had been under barley and maize cultivation the previous two seasons 2009 and 2010. The farm was largely mechanized with heavy use of mineral fertilizers (DAP, urea and CAN) before the onset of this study experiment.

3.2.2 Purko Farm (Mau Narok)

The experiment was done on land which had been left fallow for one cropping season. The land was currently under livestock grazing. The field was gently rolling but situated on a slope. Previously, the land was under barley and wheat field trials.

3.3 Description of Lime, fertilizer and varieties used

3.3.1 Lime

Lime with calcium carbonate as the active ingredient was sourced from the Koru Mining Company with the following contents on average Ca 30%, Mg 5%, K 0.23%, and S 0.11%.

3.3.2 Calcium Ammonium Nitrate (CAN)

Calcium ammonium nitrate (CAN) contain 26-27 % N and 20 % CaO. Nitrogen is half in the nitrate form and half in ammoniacal form. The granulation of this fertilizer ensures a quick and exact dosing. Calcium ammonium nitrate has 2 - 5 mm large whitish and light brown colored granules. The fertilizer has excellent physico-mechanical properties and properties for storage.

Ammonium Nitrate is near-neutral in its effect on soil pH and therefore can be used on soils that have a low pH without lowering the pH further. CAN is a nitrogen fertilizer which contains equal parts of fast acting Nitrate-Nitrogen and longer lasting Ammonium-Nitrogen.

This ensures a more continuous nitrogen supply to the crop and thus better nitrogen use efficiency by plants.

3.3.3 Triple Super Phosphate (TSP) Ca (H_2P0_4)$_2$

Triple Super Phosphate is made by the action of phosphoric acid on raw rock phosphate [apatite]. It typically contains 46% P_2O_5, soluble in neutral ammonium citrate and water. Of this, 90% is soluble in water. It contains 12-14% calcium.

3.3.4 Muriate of Potash (KCl)

Muriate of Potash contains 60% K_2O (potash). Potassium is important because it helps the plant to; produce vegetative matter like straw and stalk, produce reproductive matter like seeds and increases drought resistance.

3.3.5 Barley varieties

HKBL1512-5, barley variety was tested in this study experiments. The variety is one of those developed in Kenya by East African Breweries Limited (EABL, 2011) breeding programme. The variety a hybrid developed and it was still under study before being officially released to farmers.

3.4 Field Experiments: To evaluate how varying nitrogen fertilizer rates and liming affect grain yield, grain protein content and kernel weight

The experiment was also used to study effects of lime on nutrient release and nutrient utilization by barley crop. In addition; lime effects on physic-chemical properties of the soils were studied

3.4.1 Land preparation and planting

The conventional tillage system was used during land cultivation. The land was ploughed, and then harrowed to a fine tilth (20 cm depth) using a tractor.

Row planting was done using a planter. All fertilizers were applied at planting together with the seeds.

3.4.2 Treatments

Nitrogen as C.A.N fertilizer was applied at 5 levels; 0, 30, 40, 50, 60Kg N/ha all at planting. Phosphorus inform of TSP fertilizer at (45Kg $P_2 0_5$/ha) and Potassium (muriate of potash) at (35Kg $K_2 0$/ha) were applied both as a blanket in plots with Nitrogen treatments, and as a treatment. Lime was applied at 2 levels; 0, and 1.5t/ha.

3.4.3 Experimental design and layout

At each site, split plot design was adopted. Lime was taken as the main treatment and applied in the main plot. Nitrogen treatment was split into 5 levels i.e. 0, 30, 40, 50 and 60Kg N/ha in each of the two blocks created from lime application (no lime block and the one with lime). Treatments in each block were randomly located. Each experimental site had 3 replicates making a total of 36 plots for each block (Fig 1).

Main plot											
LIME (1.5t)						**NO LIME (0t)**					
N1 30Kg N	N2 40Kg N	N3 50Kg N	N4 60Kg N	N0+P 0N+20P	CTRL	N1 30Kg N	N2 40Kg N	N3 50Kg N	N4 60Kg N	N0 +P 0N+20 P	CTR L

Figure 1: Arrangement of the main plot and sub-plots in the field

3.4.4 Statistical model (split plot)

General Linear Model was used

Yijkl = μ + Pi + Lj + αij + Nk +LNjk + βijk.

Where –

Pi - main plot Effect

Lj – Lime Effect

αij – Main plot Error

Nk – Nitrogen Rates

LNjk – Lime * Nitrogen Rates

βijk – Split Plot Error

Table 1: ANOVA table showing treatments and degrees of freedom

Source of variation		**Degrees of freedom**
Blocks(r) r-1	3-1	2
Lime (v) v – 1	2–1	1
Error (a) (b-1) (v-1)	2*1	2
Nitrogen (Rates) (n-1)	5–1	4
Nitrogen * Lime (n-1) (v-1)	4*1	4
Nitrogen* Lime * site (n-1) (v-1) (a-1)	4*1*1	4
Error (b)		17
Total (van) 3 – 1	(2*5)2–1	19

3.4.5 Treatment applications

3.4.5.1 Lime

Lime was applied in the rows 7 days before sowing of the seeds. Application was limited to the top soil in the plots i.e. 15cm depth. This was to increase the effectiveness of lime in the rooting zone of the young plants. Lime was applied at 1.5t/ha.

3.4.5.2 Lime requirements calculation

Incubation method was used to determine the quantity of lime application as per Okalebo *et al.*, (2002). Soil samples of top soil layer at Field Capacity were incubated with increasing amounts of lime i.e. 0.5t, 1t, 1.5t and 1.5t/ha for 3 weeks.

Soil pH measurements during the 3 week period were used to determine the lime requirements. Lime required was to at least to raise soil pH to (pH 6.5).

3.4.5.3 Fertilizer application

All fertilizers were applied at planting time. The fertilizers were applied in the rows together with the barley seed grain.

3.4.6 Plant Population and Spacing

Plants per pot and field were established from the recommended seeding rate of 200plants/m^2, 5 plants were used in each pot.The blanket recommendation for seeding rates for all the barley varieties in Kenya is 84 $Kgha^{-1}$which corresponds to 200plants/m^2 (EABL, 2011). This was based on measured 1000-kernel weights, pure seed germination percentage and an assumption of 5% seedling mortality (Mckenzie, 2004). Each plot unit measured 1.5 by 3m with row to row spacing of 20cm

3.4.7 Harvesting and yield measurements

The crop was harvested after reaching harvest maturity with the grains having a moisture content of less than 15%. The grains were weighed immediately but then dried further till moisture reached 13% when final yield measurements were done. This followed EABL (2011), and ISTA screening procedures for malting.

3.4.8 Sampling for soil and plant materials for analysis

3.4.8.1 Soil sampling and analyses

Soil samples in the treatment plots were randomly taken to a depth of 20cm down the profile using a soil auger. In each treatment plot, 3 samples of about 1 Kg each were taken from which a composite sample of 500g was drawn for various laboratory analyses.

The soil samples were analysed for total N, available phosphorus, organic carbon and soil pH before planting. In addition, soil total N, pH and soil available phosphorus were determined after grain formation and at harvest maturity of the crop.

3.4.8.2 Plant tissue sampling and analyses

Five healthy plants were randomly taken from the experimental plots for analyzing total N and total p in the straw and protein content in the grain just after grain filling stage. The crop was harvested by the combine harvester from which plant straws and grain were separately sampled and analyzed for both total N and total P. All procedures for plant tissue analyses were taken from Okalebo *et al.,* (2002).

3.4.9 Laboratory procedures for soil and plant tissue analysis

Total N was determined by colorimetric method following the procedure outlined in Okalebo *et al.,* (2002). Soil organic carbon determination followed Walkley-Black method (Okalebo *et al.,* 2002). Soil pH was determined using water as per Okalebo *et al.,* (2002). Total P and soil available P (Olsen method) were determined as outlined in Okalebo *et al.,* (2002)

3.4.10 Determination of grain protein content

Protein content in the grain was determined just after grain formation and after harvest. Total N determination procedures and methods as per Okalebo *et al.,* (2002) were used to calculate the protein contents by multiplying by a factor of 6.25, (Mariotti *et al.,* 2008.)

3.4.11 Determination of kernel weight

A total of 1000 mature barley grains from each treatment were counted and their weights determined. The procedures followed were from ISTA, (1996) as per EABL, (2011) laboratory and screening procedures for determining malting qualities.

3.4.12 Determination of Agronomic Nitrogen use efficiencies

Calculation and determination of nitrogen use efficiency followed the procedures given in Okalebo *et al.,* (2002); whereby the difference in nutrient uptake between control and the treatment are divided by the nutrient input in the treatment.

NUE (%) = (grain yield / nitrogen applied) x 100.................Equation 1

NUE (%) = $[(YU_T - NU_C) / YA_T]$ x 100......................... .....Equation 2

Where; YU_T is yield measured in plants receiving nitrogen input treatments, YU_C is the yield measured in the control without nutrient inputs and NA_T are the total amount of nitrogen applied as inputs.

3.4.13 Determination of nutrient harvest index (HI)

Harvest index which is the ratio of harvested grain to total shoot dry matter (grain crops) was used as a measure of reproductive efficiency. It was determined by dividing the harvested grain weights with total shoot dry matter weights (straw and grain combined).

3.4.14 Data analysis and interpretation

Data analyzed involved analysis of variance to ascertain the effect of N rates, lime and soil type on yield, biomass and grain protein content and kernel weight. Data analysis was done using SAS 9.1 for Windows 2012 statistical package. Multiple comparisons on N rates was analyzed while Mean separation on means of different N rates was by Least Significance Difference (LSD) and Duncan Multiple Range Test (DNMRT) at 5% level of significance respectively, (Gomez & Gomez, 1984).

3.5 Green-house experiments

3.5.1 Experiment one: To evaluate how varying Nitrogen fertilizer rates and liming affect grain yield, grain protein content and kernel weight.

3.5.1.1 Treatments

The experiment had five levels of nitrogen; control, Phosphorus (45Kg P_20_5/ha), 30N/Kg, 40N/Kg and 60N/Kg with lime at 2 levels i.e. 0, and 1.5t/ha as soils from 2 sites (Eldoret, Mau Narok) were sampled for the experiments. The combined effects of soil moisture and lime were studied. In addition, the effect of lime on soil reaction (pH) and availability of N, P, was studied. Lastly, both water and Nitrogen use efficiencies were evaluated.

3.5.1.2 Experimental design and model

The experiment was a split-split arrangement laid out in a CRD design.

$$Yijkl = \mu + Pi + Lj + \alpha ij + Sk + LSjk + \beta ijk + Nl + NLjl + NSkl + NSLikl + \lambda ijkl$$

Where - Pi is main plot Effect

Lj – Lime Effect

αij – Main plot Error

Sk – Effect of Different soils

LSjk – Lme * Different soils

βijk – Split Plot Error

Nl – Nitrogen Effect (Rates)

NLjl – Nitrogen * Lime Interaction

NSjk – Nitrogen (Rates) * Different soils (site)

NSLikl – Nitrogen* Different soils (site) * Lime Interaction

$\lambda ijkl$ – Split Split Plot Error

3.5.1.3 Soil sampling and pretreatment for the experiments

Soil samples that were randomly taken to a depth of 20cm in the experimental fields were pretreated and used for the experiments. Soil pretreatment involved; air drying for 1 week and sieving to remove litter materials. Exactly 3 Kg of pretreated soil from each field experimental site was put in plastic pots having 15cm diameter and 25cm height that were used for the two experiments.

3.5.1.4 Soil and plant tissue laboratory analyses

All soil and plant tissue analyses were similar to those done in the field experiment part above since the soils used for greenhouse experiments came from the filed experimental plots

Table 2: Split-split plot arrangement in CRD design

Main plot	Split plot	split split
LIME	CHEP SOIL	N1
		N2
		N3
		N4
		N0+P
		CONTROL
	MAU	
		N1
		N2
		N3
		N4
		N0+P
		CONTROL
NO LIME	CHEP SOIL	N1
		N2
		N3
		N4
		N0+P
		CONTROL
	MAU	
		N1
		N2
		N3
		N4
		N0+P
		CONTROL

3.5.1.5 Source of the nutrients

CAN (27:0:0) fertilizer was the source of **N** as it has both Nitrate and Ammonium N components necessary for barley. TSP (0:45:0) (Triple superphosphate) provided P while potassium chloride (KCL, 0:0:60) provided K. Lime as CaO was sourced from Koru mining company. It contains on average Ca 30%, Mg 5%, K 0.23%, and S 0.11%.

3.5.1.6 Lime requirements calculation and application

Calculation of lime required was similar to the field experiment. Lime was applied 7 days before sowing of the seeds.

Application was limited to the top soil in the pots i.e. 5cm depth and uniformly mixed with the soil. Water was sprinkled on top of the soil but the entire soil in the pots was wetted from below through capillarity. This was to increase the effectiveness of lime in the rooting zone of the young plants. Lime was applied at 1.5t/ha.

3.5.1.7 Fertilizer application

This was done immediately after germination (2 days after germination). All the nutrients were applied in solution. The fertilizer materials were crushed and dissolved in water and equally distributed to plant root zones using a pipette. This was followed by slight sprinkle of water on top soil for 2 weeks to increase nutrient uptake.

3.5.1.8 Irrigation and application of water to barley plants

Watering of the plants followed the plant water requirements depending on the evaporation rates in the Green-house. The soil was watered to Field Capacity by refilling the water lost due to evapo-transpiration.

3.5.1.9 Plant population

Plants per pot were established from the recommended seeding rate of 200plants/m^2. Five (5) plants were planted in each pot. The blanket recommendation for seeding rates for all the barley varieties in Kenya is 84 Kg/ha which corresponds to 200plants/m^2 (EABL, 2011). This was based on measured 1000- kernel weights, pure seed germination percentage and an assumption of 5% seedling mortality (McKenzie, 2004).

3.5.1.10 Harvesting and yield measurements

The crop was harvested after reaching harvest maturity. The procedures were similar as in the field experiment mentioned earlier in this study.

3.5.2 Experiment two: To evaluate effect of varying soil water contents on soil nutrient release, biomass and tillering by the barley crop

3.5.2.1 Treatments

The experiment had four nutrient treatments; Lime, Phosphorus (TSP), Nitrogen (CAN) and the control with all 3 combined (Lime, phosphorus and nitrogen) were applied to 2 different soil types (Eldoret and Mau soils) Different water contents (Field Capacity FC, 80% Field Capacity and 50% Field Capacity) were applied to each of the treatments mentioned above to evaluate the effect of water or moisture on the nutrient release and utilization by the crop and the soil water characteristic curve for barley. Fresh weight, dry weights and tillering were determined to evaluate the effect of water deficit on barley growth. The crop was harvested at heading stage where, numbers of tillers and above ground dry weight were measured for each nutrient treatment and soil moisture level.

Table 3: Split-split arrangement in CRD design and layout

Main plot	**Split plot**	**split split**		
CHEP SOIL	Lime	fc	80%fc	50%fc
	Nitrogen	fc	80%fc	50%fc
	Phosphorus	fc	80%fc	50%fc
	Control(NPL)	fc	80%fc	50%fc
MAU SOIL	Lime	fc	80%fc	50%fc
	Nitrogen	fc	80%fc	50%fc
	Phosphorus	fc	80%fc	50%fc
	Control(NPL)	fc	80%fc	50%fc

3.5.2.2 Model

$Yijkl = \mu + Pi + Lj + \alpha ij + Sk + LSjk + \beta ijk + Nl + NLjl + NSkl + NSLikl + \lambda ijkl$

Where - Pi is main plot Effect

Lj – Soil type (site) Effect

αij – Main plot Error

Sk – Effect of Different Nutrients

$LSjk$ – Different nutrients * soil type

βijk – Split Plot Error

Nl – soil moisture content (Levels)

$NLjl$ – Soil moisture content * soil type Interaction

$NSjk$ –Soil moisture content * Different nutrients

$NSLikl$ – Soil moisture content * soil type (site) * different nutrient Interaction

$\lambda ijkl$ – Split Split Plot Error

3.5.2.3 ANOVA table showing treatments and degrees of freedom

Source of variation		Degrees of freedom
Replicate (r) r-1	3-1	2
Moisture level (v) v – 1	3-1	2
Error (a) (b-1) (v-1)	2*2	2
Site (type of soil) (A) a– 1	2-1	1
Site * moisture level (a –1) (v-1)	1*2	2
Error (b) v (a – 1) (v – 1)	2*1*1	2
Nutrient (type) (n-1)	4–1	3
Nutrient * moisture levels (n-1) (v-1)	3*2	6
Nutrient* site (n-1) (a-1)	3 *1	3
Nutrient* moisture * site (n-1) (v-1) (a-1)	3*2*1	6
Error (c)		20
Total (van) 3 – 1	(2*2*4) 3 – 1	47

Interaction effect = (r*v*a) + (r*v) +(r*a) + (a*v)

Treatments = 4 Nutrient types* 3 moisture levels * 2 soil types = 4 * 3 * 2

3.5.2.4 Description of soil moisture contents

Determination and description of Field capacity (FC)

Field capacity and water holding capacities were determined following procedures by Anderson and Ingram (1993) and Okalebo *et al.,* (2002)The field capacity is often estimated to be the water content at a soil matric potential of about -0.03Mpa. The field capacity might be measured as 5% of water per unit volume of bulk soil for sand, and might be measured as 50% per unit of soil for heavy clay. In many soils, it is considered after rain or irrigation, where the soil will drain and after 1-2 days, the water content in the soil will reach a nearly constant for a particular depth in question. This arbitrary value of water constant, expressed as a percentage is the Field capacity, Arntzen, (1994).
www.store.elsevier.com/Encyclopedia of Agricultural Science.

3.5.2.7 Irrigation and application of water to plants

Watering of the plants followed the 3 soil moisture treatments (Field Capacity FC, 80% Field Capacity and 50% Field Capacity). The field capacities of both soils used were determined in laboratory as mentioned above.

3.5.2.8 Laboratory procedures for soil physical analyses

The physical properties investigated were; particle size for texture class, changes in bulk density, water evaporation rates and the water holding capacities. The physical properties were determined at the start and after the experiment. Soil samples from the experimental pots were used for laboratory analysis.

Particle size analysis was by the Hydrometer method (Okalebo *et al.,* 2002). Bulk density, field capacity and water holding capacities were determined following procedures by

Anderson & Ingram (1993) and Okalebo *et al.,* (2002). Evaporation or water loss was determined by measuring the soil water content by gravimetric method.

3.5.2.8 Lime and fertilizer application

Application of lime and fertilizer nutrients was similar to experiment one mentioned earlier. Both of them were applied at planting time.

3.5.2.9 Measurement of biomass and counting of tillers

The crop was harvested just after heading after tillers had been counted per plant and per experimental pot. Fresh weights were taken per pot for each treatment. Fresh plants were then air dried in the greenhouse for 7 days after which dry weights were measured.

3.5.2.10 Measurement of barley water consumption and modelling

The amount of water used to produce mature grain was measured throughout growing period (Green house experiment 1) which was used to calculate water use efficiency (WUE), a quantitative measurement of how much grain biomass produced over a growing season with the amount of water used. Measurement of water use by barley was done by weighing and refilling of the soil to field capacity levels depending on the evaporation rates of water from the experimental pots. Total amount of water used for refilling for the growing season were divided with the grain yield harvested for each treatment to give water consumption values per unit grain yield produced.

Barley-water modeling involved drawing a water characteristic curve for different soil water contents and both biomass and number of tillers produced for each treatment (Green house experiment 2).

3.5.2.11 Data analysis and interpretation

Data analysis involved analysis of variance on dry weight biomass and the number of tillers as affected by different soil moisture content. It also involved analyzing the relationship between different nutrients, lime and soil moisture levels and how it affects barley growth and development. Genstat Edition 12, 2012 statistical package was used for analysis. Mean separation was by Duncan Multiple Range Test (DNMRT) at 5% level of significance, (Gomez & Gomez, 1984).

CHAPTER FOUR

RESULTS

4.1 Site characterization and Nutrient deficiencies

4.1.1 Soil fertility status

Initial soil results of both experimental sites indicated that both sites had acidic soils, with low levels of available phosphorus. The University of Eldoret site was deficient in both nitrogen and phosphorus coupled with high acidity i.e. low pH. The results are given below (Table 4).

Table 4: Initial top-soil (0-20cm depth) characterization of the sites

Chepkoilel 2011		Mau-Narok 2011
pH H_20	4.75	5.4
P (ppm)	8.62	12.75
Total %N	0.03	0.16
%OC	1.93	2.14
Bulk density	1.5g/cm	1.65g/cm
Field capacity	43%v/v	40.7%v/v

The soils used had the following chemical and physical properties**.** Both experimental sites had similar texture class of sand loams with 61% and 71% sand, 14% and 8% clay and 25% and 21% silt respectively.

According to Okalebo *et al.,* (2002), it was evident that nitrogen and phosphorus were deficient basing on the critical soil nutrient concentrations (Appendix 10). Both sites were acidic hence the choice for liming that resulted to significant effects. Mau-Narok site had adequate soil nitrogen which led to no response of it to yield unlike University of Eldoret site which had a positive response to nitrogen.

4.1.2 Weather patterns during the experimental period

Both sites received well distributed rainfall throughout the cropping period although annual rainfall totals were much less than the normal yearly long term means. Growth period temperatures were recorded (Table 5) with Mau-Narok site experiencing frost incidences during October and November 2011 but the crop was not affected.

Table 5: Weather patterns during the experimental period

	Temp(^{o}c)				**Rainfall(mm)**	
	Eldoret		**Mau**		**Eldoret**	**Mau**
2011	Min	Max	min	Max		
AUG	10	22	12	24	123	97
SEP	10	23	11	26	51	73
OCT	11	24	11	25	36	83
NOV	12	23	12	24	50	100
DEC	11	23	11	26	20	61
2012						
JAN	11	24	11	27	35	30
FEB	10	25	11	28	21	30
MAR	11	25	12	28	63	62
APRIL	12	24	13	26	105	119
MAY	11	23	13	25	85	106
JUNE	11	22	12	24	91	73
JULY	10	22	12	24	147	83
	10.83	**23.33**	**11.72**	**25.58**	**827**	**917**

4.1.3 Green-house weather conditions

The rate of water loss by the soil in pots in the green house ranged from 100-300mm for every two days measured during entire growing period. Growth period temperatures were recorded (Table 6)

Table 6: Green house growth mean monthly temperatures

	Temperature ^{o}c	
Month	min	max
Nov	14	27
Dec	17	29
Jan	17	34
Feb	16	35
Mar	15	32
April	13	26
May	13	27
June	12	25
July	13	26

4.2 FIELD EXPERIMENT RESULTS

4.2.1.5 The effect of nitrogen rates and lime on the yield of Barley

Mau-Narok site

Application of lime significantly increased the yields ($P \leq 0.01$). The mean yield difference between lime plots (4.94t/ha) and absolute control plots (3.625t/ha) was 1.31t/ha in Mau Narok. Effect of N rates on yield was highly significant ($P \leq 0.001$). Effect of lime on yield was significant ($P \leq 0.01$), (Appendix 1). The combined effect of lime and N rates on yield was not significant at 95% level of significance (Appendix 1).

The differences between absolute control and N treatments were highly significant. There were no significant differences among the different N rates except the treatment with P alone with no N added (Table 7).

Table 7: Effect of nitrogen rates and lime on barley yield (Field results after harvest)

Treatments	Mau site lime	no lime	Chep site no lime	lime
Control	4.95a	3.62a	2.62a	3.19a
PN0	6.87bc	6.04c	3.37ab	4.20bcd
30N	7.02c	5.80b	3.87b	4.17cd
40N	7.05c	6.11c	4.07b	4.88d
50N	6.76b	6.16c	3.44ab	4.84ab
60N	6.90bc	6.16c	3.4ab	3.94abc
mean	6.59	5.65	3.46	4.20
CV%	8.54			
SED	0.09	0.10	0.40	0.37
LSD	0.21	0.21	0.88	0.80

A mean value followed by the same letter do not differ significantly from each other at 5% level of significance according to Duncan's New Multiple Range Test (DNMRT)

4.2.3 Effect of nitrogen rates and lime on grain protein content of barley

Increase in N rates increased grain protein content. Liming the soil increased the protein content. Grain protein content at physiological maturity was lower than at harvest maturity, (Table 8). Grain protein content at harvest ranged between 8.3% and 12.3% for the field experiment while 8.4% to 14% for the Greenhouse experiments.

Table 8: Effect of N rates, lime on protein content (Field results after harvest)

	Mau site		Chep site	
Treatment	no lime	lime	no lime	lime
Control	9.17a	10.04a	9.80a	10.44a
PN0	8.30b	10.11a	10.43ab	9.63a
30N	10.01c	10.44a	11.33b	12.50bc
40N	9.82c	10.22a	11.63b	12.17b
50N	10.36c	10.85a	13.17c	13.37bc
60N	11.07d	12.23b	13.10c	13.73b
Mean	10.65	9.79	11.58	11.97

		SED	LSD
N rates		0.45	0.90
N rates*lime		0.64	1.28
CV%	10.10		

A mean value followed by the same letter do not differ significantly from each other at 5% level of significance according to Duncan's New Multiple Range Test (DNMRT)

4.2.4 The effect of Nitrogen and lime on the kernel weight of barley

Kernel weight differences were highly significant ($P \leq 0.001$). The effects of lime and N rates on Kernel weight were highly significant, $P \leq 0.001$and $P \leq 0.001$ respectively. The interaction effect of lime and N rates was significant at 95% ($P \leq 0.05$), (Appendix 4). Multiple comparisons of N rates indicated N1 being significantly different from N2 and absolute control being different from N treatments, (Appendix 12). Use of lime increased the kernel weight (Table 3).

Table 9: Effect of N rates and lime on kernel weight (Field results after harvest)

	Mau site		Chep site	
Treatment	no lime	lime	no lime	lime
Control	40.47a	45.34a	40.88a	46.20b
PN0	44.69b	45.26a	46.42c	51.43cd
30N	44.28b	46.61b	46.73c	49.21c
40N	43.00b	46.61ab	49.67d	52.36d
50N	43.77b	46.61b	42.60ab	43.07a
60N	45.35b	46.61b	44.30b	44.57ab
Mean	43.59	45.96	45.10	47.84
CV%	9.70			
SED	0.92	1.07	0.90	1.06
LSD	2.01	2.33	1.97	2.32

A mean value followed by the same letter do not differ significantly from each other at 5% level of significance according to Duncan's New Multiple Range Test (DNMRT)

4.2.5 Agronomic Nitrogen Use Efficiency (NUE)

Both N and lime reduced Nitrogen Use efficiency. Agronomic Nitrogen Use Efficiency showed an inverse relationship with N rates i.e. NUE reduced with increase in N rates. Liming reduced the N use efficiency (Table 10).

Table 10: Nitrogen use efficiencies (Mau-Narok Field)

Treatment	60N	50N	40N	30N	mean
NO LIME					
Yield(grain/ha)	6.16	6.22	6.11	5.80	6.07
NUE	42.40	51.91	62.20	72.52	57.25
LIME					
Yield(grain t/ha	6.90	6.76	7.05	7.02	6.93
NUE	32.62	36.35	52.67	69.45	47.70
Mean	22.02	25.31	32.01	38.69	29.50

4.2.6 Effect of nitrogen and lime on soil chemical properties

(Soil pH and soil phosphorus)

Treatments with no lime had decreased soil pH over the growing the season (Table 11). Liming increased soil pH (Table 11). Application of Lime increased the available phosphorus in the soils. Soil available P after grain formation and after harvest was much higher than initial levels before planting in the limed treatments (Figures 2 and 3).

Table 11: Effect of liming on soil pH (Field)

	Mau site				Chep site			
Treatment	Initial PH	6 WKS	Harvest	mean	Initial PH	6 WKS	Harvest	mean
Control	5.20	5.14	5.05	5.13	4.80	4.73	4.65	4.72
L0+P	5.40	5.31	5.19	5.30	4.60	4.56	4.59	4.58
L0+30N	5.50	5.33	5.31	5.38	4.60	4.40	4.47	4.49
L0+40N	5.30	5.2	5.06	5.18	4.75	4.63	4.50	4.62
L0+50N	5.40	5.23	5.10	5.24	4.65	4.55	4.64	4.61
L0+60N	5.30	5.17	5.11	5.19	4.71	4.60	4.61	4.64
Lime(L1)	5.34	6.14	6.02	5.83	4.60	6.62	6.52	5.91
L1+P	5.60	6.30	6.19	6.03	4.70	6.35	6.21	5.75
L1+30N	5.30	6.41	6.11	5.94	4.72	6.31	6.19	5.74
L1+40N	5.36	6.35	6.05	5.92	4.80	6.46	6.25	5.83
L1+50N	5.40	6.25	6.09	5.91	4.85	6.35	6.15	5.78
L1+60N	5.25	6.29	6.12	5.88	4.71	6.40	6.33	5.81
mean	5.36	5.76	5.61	5.57	4.70	5.49	5.42	5.21
S. Error	0.03	0.16	0.14		0.02	0.27	0.25	

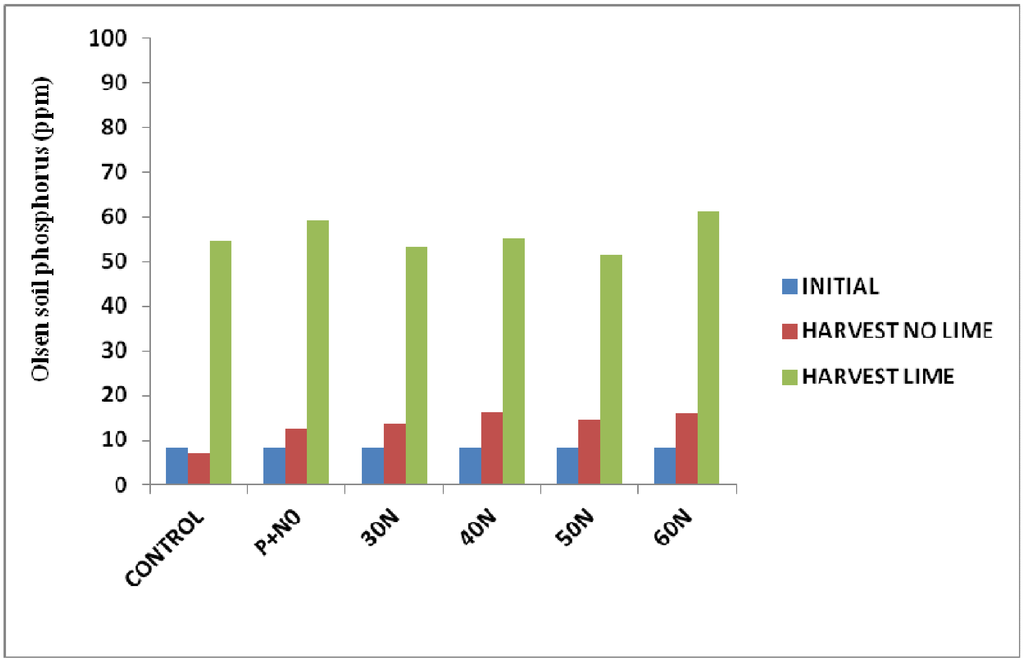

Figure 2: Effect of Liming on Olsen soil phosphorus (Chepkoilel Field)

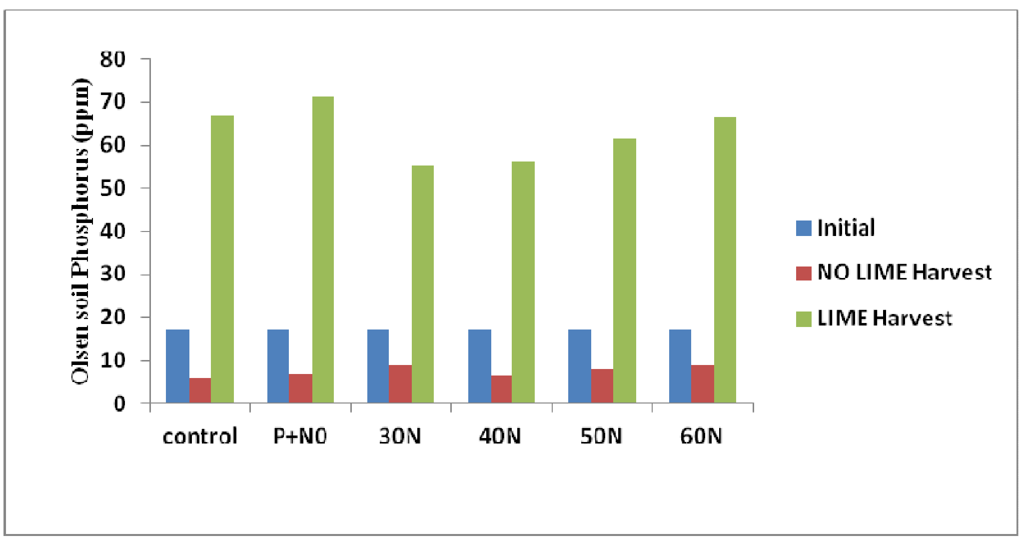

Figure 3: Effect of liming on Olsen soil phosphorus (Mau Field)

4.3 GREENHOUSE RESULTS

Experiment one

4.3.1 The effect of nitrogen rates and lime on the yield of barley

The effect of N rates on the yield of barley differed greatly with the two different experimental soils, (Mau and Chepkoilel), (Table 12). Increasing the N rates increased yields proportionately for Chepkoilel soils. For Mau Narok soils, a linear relationship occurs at low N rates but then yield reduced as N increased. Greenhouse experiment had mean yield for lime treatment (2.67t/ha) and absolute control (0.83t/ha) for Chepkoilel soil while lime treatments (7.67t/ha) and absolute control (6.67t/ha) for Mau-Narok soils. The yield differences due to site (type of soil) was highly significant ($P \leq 0.001$). Increasing N rates affected yield significantly (95%) ($P \leq 0.05$).The effect of lime on the yield was evident but not significant ($P \leq 0.0516$) at 95% level of significance. The combined effect of lime and Nitrogen on yield was not significant. Differences between absolute controls and N treatments were highly significant, (Appendix 5). There were no significant differences among the N rates except the treatment with P alone which had no N, (Appendix 12).

Table 12: Effect of nitrogen rates and lime on barley yield (greenhouse)

Treatment	Mau soil no lime	lime	Chep soil no lime	Lime
Control	5.87a	7.71a	0.85a	2.56a
P+N0	7.09a	8.02ab	1.34ab	3.36b
30N	6.17a	9.67c	1.70bc	3.35b
40N	6.08a	8.17ab	2.02c	4.33c
60N	6.02a	8.85bc	2.56d	5.33d
Mean	6.25	8.49	1.70	3.79
SED	0.57	0.41	0.31	0.27
LSD	1.28	0.92	0.70	0.60
CV%	22.2			

A mean value followed by the same letter do not differ significantly from each other at 5% level of significance according to Duncan's New Multiple Range Test (DNMRT)

4.3.2 Effect of nitrogen rates and lime on grain protein content of barley

Lime treatments had higher grain protein contents than non-limed treatments. Increasing the N application rates increased the protein content. There was a relationship between N rates and protein contents though not perfect but statistically different.

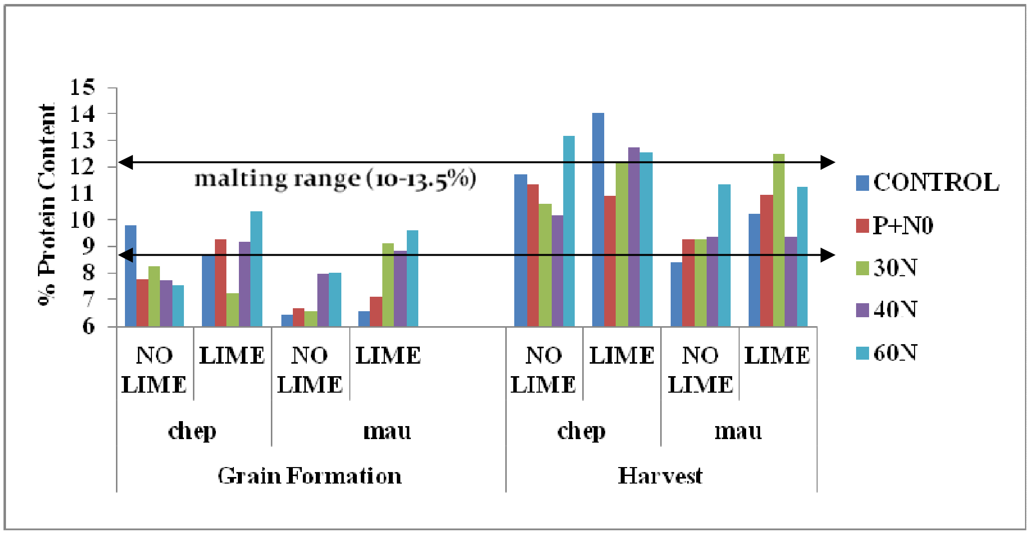

Figure 4: Effect of N rates and Lime on protein content (greenhouse)

4.3.3The effect of nitrogen and lime on the kernel weight of barley

Site (different soils) differences were highly significant ($P \leq 0.001$). Nitrogen effect on kernel weight was highly significant ($P \leq 0.001$). Lime-Nitrogen interaction on kernel weight was highly significant ($P \leq 0.001$), (Table 13). The combined effect of site, lime and Nitrogen on kernel weight was highly significant ($P \leq 0.001$), (Appendix 7). Lime effect on kernel weight was not significant at 95% ($P \leq 0.05$). Differences in N rates affected kernel weight significantly (Appendix 14). Limed treatments had more grain yields than treatments with no lime (Table 13).

Table 13: Effect of N rates and Lime on kernel weight (greenhouse)

Treatment	Chep soil no lime	lime	Mau soil no lime	lime
Control	53.01a	55.04a	35.13a	49.01ab
P+N0	54.20a	64.09c	46.04c	45.10a
30N	61.01b	60.04bc	42.06b	48.10ab
40N	54.05a	54.05a	41.11b	50.09b
60N	56.08a	56.08ab	50.04d	51.04b
Mean	55.67	57.86	42.88	48.67
CV%	5.61			
SED	1.93	1.90	1.78	1.83
LSD	4.31	4.24	3.97	4.07

A mean value followed by the same letter do not differ significantly from each other at 5% level of significance according to Duncan's New Multiple Range Test (DNMRT)

4.3.4 The effect of nitrogen rates and Lime on nutrient use efficiency and harvest index

Agronomic Nitrogen Use Efficiency showed an inverse relationship with N rates. Increase in N rates led to reduction in Nitrogen Use efficiency. The relationship between N rates and NUE was similar in both lime and non-limed plots but NUE values in lime plots were less (Table 14).

Table 14: Nitrogen use Efficiencies (Greenhouse)

	No lime (L0)				Lime (L1)			
	30N	40N	60N	Mean	30N	40N	60N	Mean
Chep soil								
YIELD(t)	1.66	2.00	2.50	2.05	3.33	4.33	5.33	4.33
NUE	27.70	29.16	27.7	28.18	22.20	41.60	44.40	36.06
Mau-Narok soil								
YIELD(t)	6.16	6.00	6.00	6.05	9.60	8.16	8.83	8.86
NUE	11.11	4.16	2.77	6.01	66.60	12.50	19.40	32.83
	11.65	10.33	9.74	10.57	25.43	16.64	19.49	20.52

Harvest Index (HI)

Generally, Harvest index of limed treatments was slightly higher than the un-limed treatments for both soils studied. HI values for Mau soils were higher than that of Chepkoilel soils, (Table 15).

Table 15: Harvest Index (Greenhouse)

	No lime (L0)						Lime (L1)					
Treatment	Control	L0+P	30N	40N	60N	Mean	Control	L0+P	30N	40N	60N	Mean
Chep soil												
YIELD(t)	0.83	1.33	1.67	2.00	2.50	1.66	2.67	3.33	3.33	4.33	5.33	3.79
Harvest index	0.32	0.33	0.41	0.35	0.29	0.34	0.40	0.40	0.39	0.41	0.35	0.39
Mau-Narok soil												
YIELD(t)	6.67	7.00	6.17	6.00	5.83	6.33	7.67	8.00	9.67	8.17	8.83	8.46
Harvest index	0.48	0.49	0.47	0.45	0.42	0.46	0.49	0.486	0.50	0.47	0.45	0.47
Mean	2.75	2.28	2.18	2.20	2.26	2.20	2.80	3.05	3.47	3.35	3.74	3.28

4.3.5 Effect of nitrogen and lime on soil chemical properties (soil pH and soil phosphorus)

Treatments with no lime had a decreasing trend in soil pH over the growing the season (Table 16).The effect of lime on soil pH was clearly evident as the pH of all treatments increased as indicated by the graph (Table 16). Application of Lime increased the available phosphorus in the soils. Soil available P after grain formation and after harvest was much higher than initial levels before planting in the limed treatments (Figure 5).

Table 16: Effect of liming on soil pH (Green house Expt 1)

Mau soil					Chep soil					
Treatment	initial	3 wks	6 wks	harvest	mean	initial	3 wks	6 wks	harvest	mean
Control	5.20	4.65	4.80	5.25	4.97	4.80	4.30	4.33	4.50	4.48
L0+P	5.40	4.60	4.61	5.48	5.02	4.60	4.40	4.36	4.55	4.47
L0+30N	5.50	4.61	4.58	5.35	5.01	4.60	4.33	4.34	4.57	4.46
L0+40N	5.30	4.70	4.65	5.36	5.00	4.75	4.25	4.09	4.45	4.38
L0+60N	5.40	4.62	4.63	5.36	5.00	4.65	4.55	4.51	4.70	4.60
Lime(L1)	5.20	7.02	6.40	6.62	6.31	4.60	7.00	6.23	6.55	6.09
L1+P	5.60	7.10	6.30	6.60	6.40	4.70	6.80	6.30	6.45	6.06
L1+30N	5.30	7.20	6.60	6.70	6.45	4.72	6.80	6.10	6.33	5.98
L1+40N	5.30	7.22	6.77	6.60	6.47	4.80	7.00	6.02	6.16	5.99
L1+60N	5.40	7.21	6.65	6.50	6.44	4.85	6.90	6.05	6.15	5.98
mean	5.36	5.89	5.59	5.98		4.71	5.63	5.23	5.44	
S. Error	0.04	0.41	0.31	0.20		0.02	0.42	0.30	0.29	

Soil Phosphorus (Olsen P)

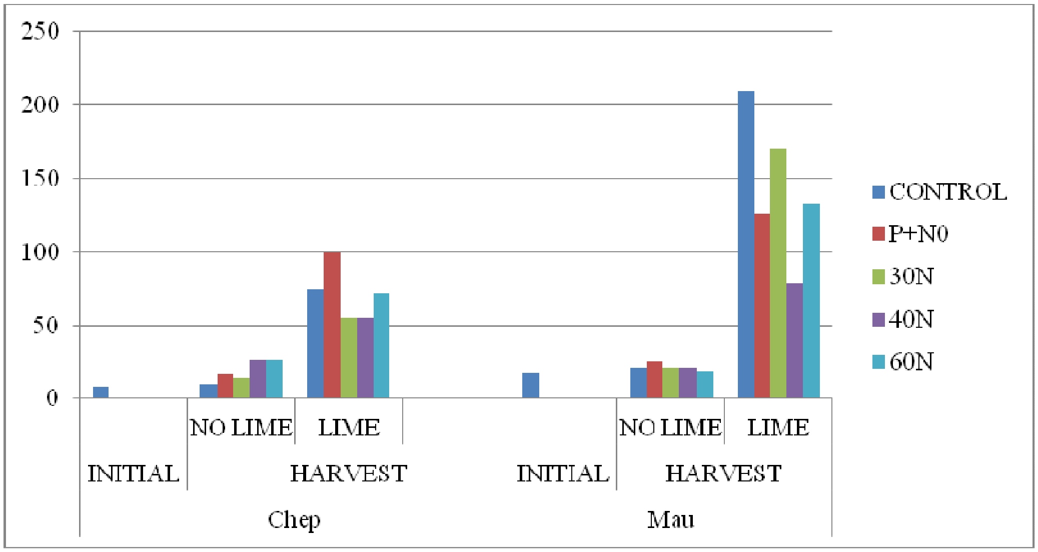

Figure 5: Effect of liming on Olsen soil phosphorus (greenhouse)

4.4 Experiment two

4.4.1 Effect of varying soil moisture levels and lime on barley growth (tillers and biomass)

The effects of reducing soil moisture levels on biomass and tillering was highly significant ($P \leq 001$).The combined effects of different nutrients and water deficits on biomass and tillering were highly significant ($P \leq 0.001$) (Appendix 2). Also there was a combined interaction of water deficits, different nutrient levels and site soils which together affected biomass and tillering significantly ($P \leq 0.001$). The mean differences due to different water contents were significant both for biomass and tillers ($P \leq 0.05$) with the differences between 50%FC and FC being large (Appendix 15). Mean differences between FC and 80%FC were not so large perhaps due to soil water contents not being so much different.

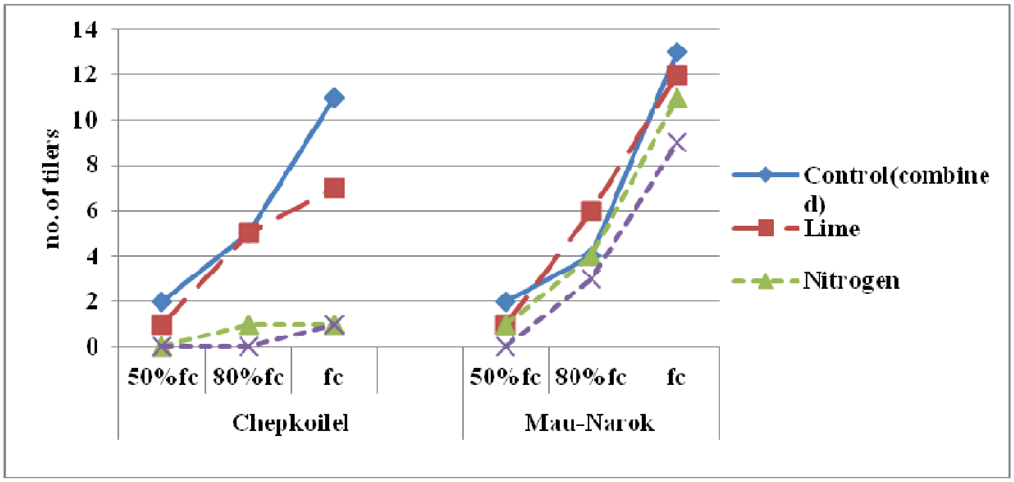

Figure 6: Effects of varying soil moisture and nutrients on barley tillering

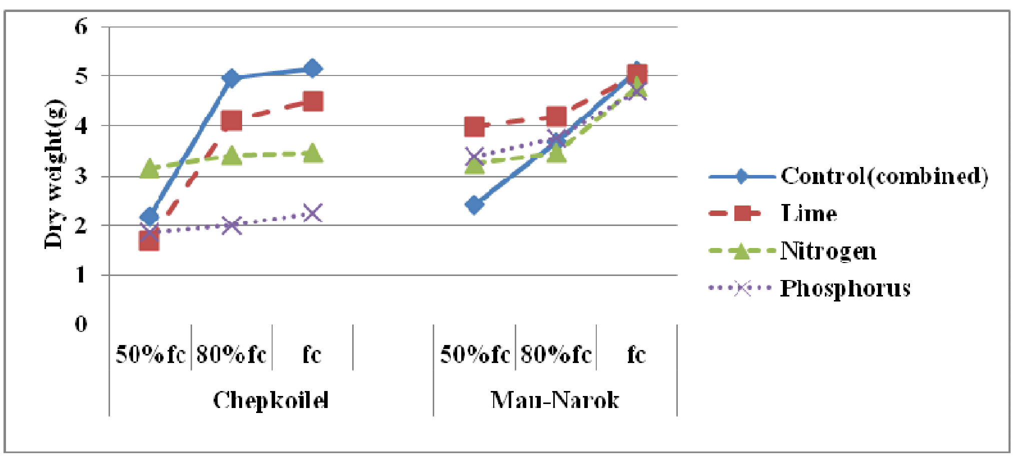

Figure 7: Effects of varying soil moisture and nutrients on barley tillering

4.4.2 Effect of lime and nitrogen on barley water use efficiency

Mau Narok soil used less water to reach harvest maturity compared to Chepkoilel soils. Limed treatments of both soil sites utilized less water to produce mature grains compared to the unlimed treatments (Figure 8).

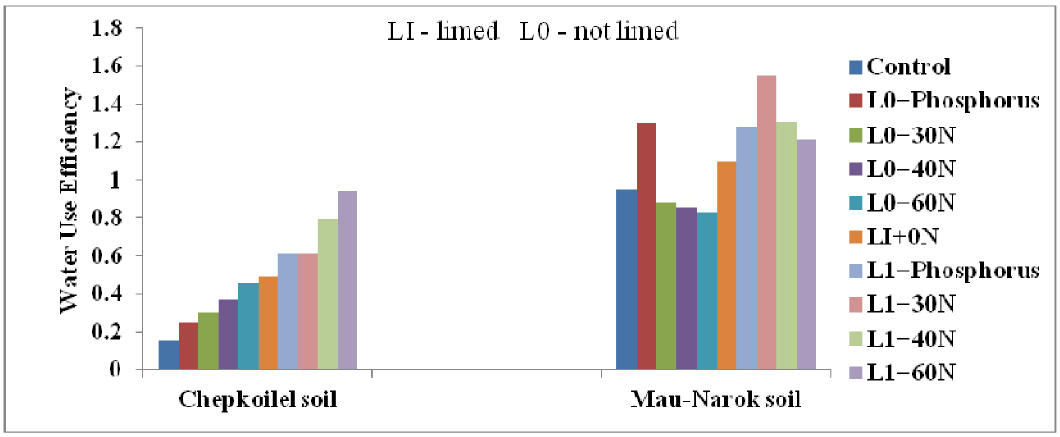

Figure 8: Water use efficiency

4.4.3 Effect of lime on the soil physical properties

Bulk density seemed to decrease statistically significant after liming the soil (Figure 9).

Lime increased the content of sand from 61%-69% but decreased both clay and silt contents from 14% and 25% to 10% and 21% respectively. For Mau soils, this was different. Sand decreased from 71%to 65%. Clay and silt increased from 8% and 21% to 10% and 25% respectively (Figure 10).

The limed treatments recoded higher evaporation rates i.e. the rate of water loss was much higher compared to treatments with no lime (Figure 11).

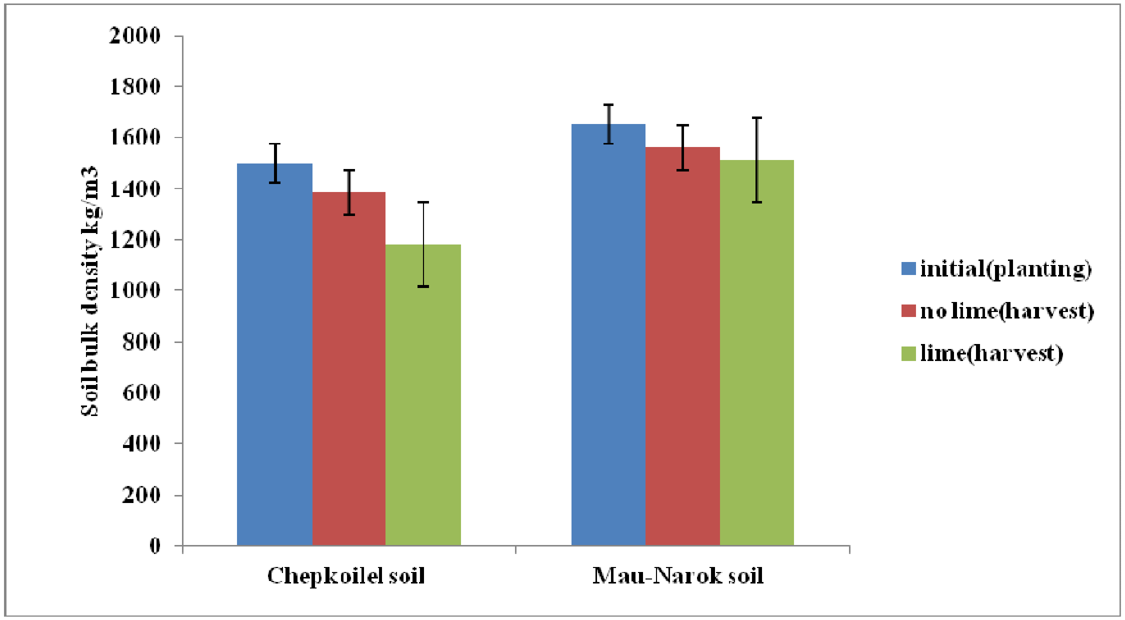

Figure 9: Effect of liming on soil bulk density

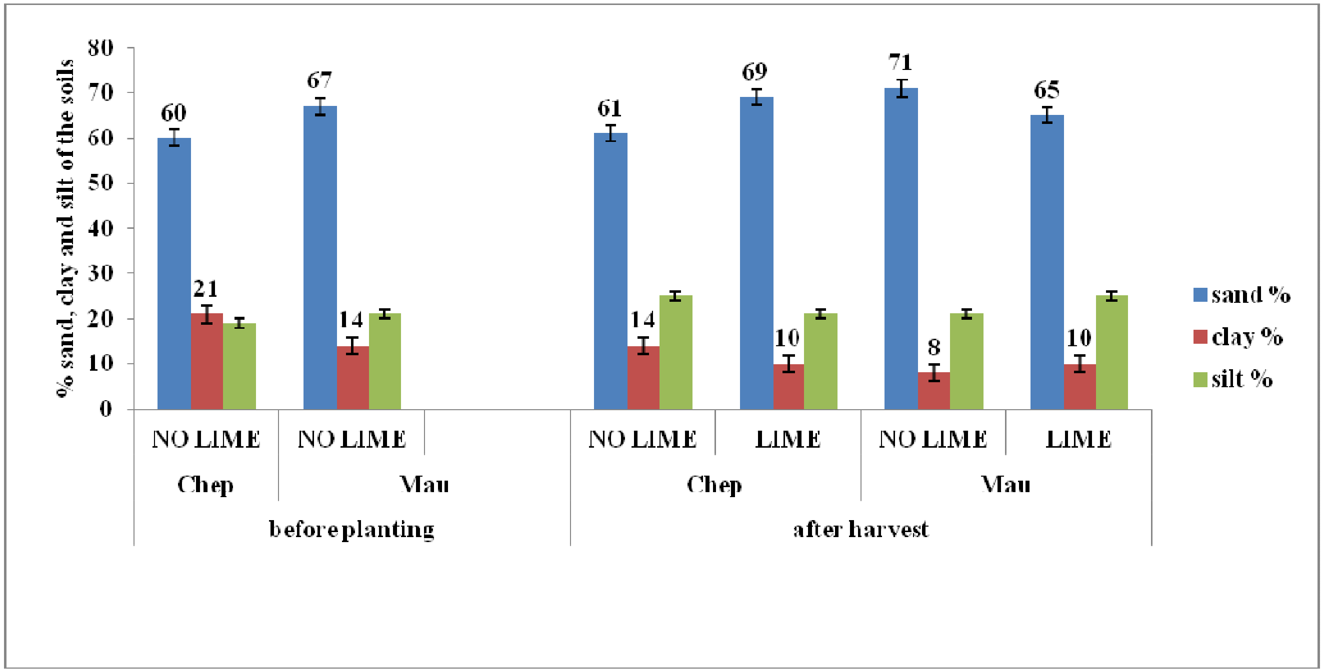

Figure 10: Effect of lime on soil texture (sand, clay and silt proportions)

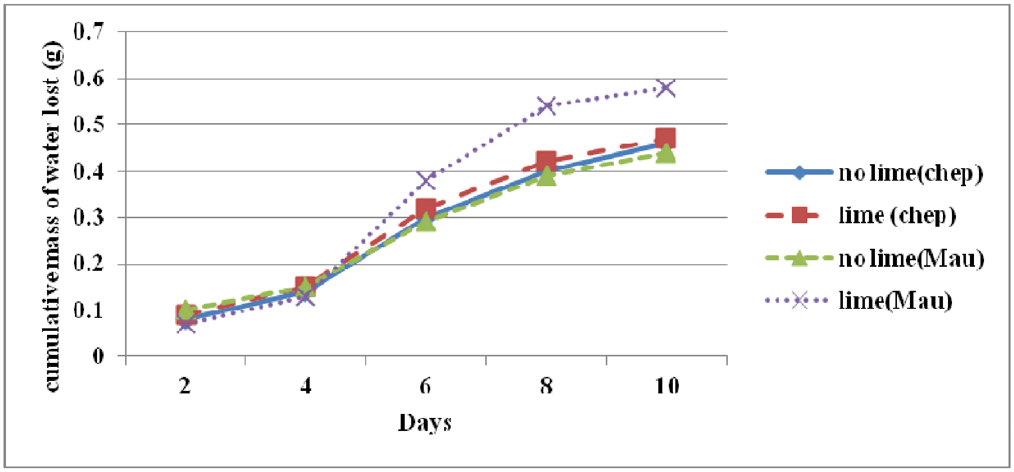

Figure 11: Effect of lime on the amount of soil water lost due to evaporation

CHAPTER FIVE

DISCUSSION

5.1 The effect of nitrogen rates and lime on the yield of barley

Increase in nitrogen rates was not proportional to yield increase. At low rates of nitrogen, grain yield increased with increase in nitrogen amounts but there was no yield response at higher rates. Basing on the initial soil analysis it was clear that Mau-Narok soil had adequate N for barley growth. Therefore at higher N rates, nitrogen applied was not assimilated to grain but to other parts like shoot biomass (harvest index, Table 15). Both field and the greenhouse yield results from this study were in agreement with those of Abrol (1990) who indicated that in favorable conditions, increasing applications of fertilizer nitrogen increase dry matter production and grain yield. However, the application of fertilizer nitrogen beyond a certain level causes a decline in grain yield that is primarily due to lodging. A correlation between fertilizer supply and yield, though imperfect, is reported in barley except at a high nitrogen level, (Abrol, 1990). Grain yield increased significantly by applying lime in pot experiment while it was non-significant but positive effect in the field experiment (Adhikari *et al.,* 2010). Jankovic *et al.,* (2011) reported a significant increase in grain yield with optimal plant nutrition being achieved by applying 50 Kg N ha^{-1}. By further increasing nitrogen amounts, the grain yield increased but the differences were not significant. Stern and Wright (1962) found a highly significant joint effect of lime and superphosphate on enzyme activity but no direct effects of lime on yield were established. According to McKenzie (2004) grain yield was strongly affected by rate of N fertilizer application. Phosphorus fertilizer applied at relatively low rates generally increases yield although the magnitude and frequency of response is much less than for N addition.

According to White & Wilson, (2006), fertilizer N, soil N and variety significantly affected yield, and the responses of the varieties varied significantly with fertilizer N rate.

Similar results in barley have been reported (Clancy *et al.,* 1991). Alam (2005) reported similar results in Bangladesh while investigating the effects of sowing time and nitrogen fertilizer on barley. Barley uses different forms of nitrogen in the soil hence fertilizers that provide both NH^{+}_{4}/NO^{-}_{3} forms should be identified for growing barley (Abrol, 1990). Prediction of optimum rates of N fertilizer application for malt barley production is difficult due to the uncertainty in estimates of available soil N and N demand (McKenzie, 2004).

From the results, lime treatments produced more grain yield compared to un-limed treatments for different site soils. This shows that lime alone has the capacity to increase yield by facilitation of nutrient availability to the crop by changing the soil pH. Lime raised soil pH that increased availability of soil P by unlocking the soil fixed P into available P for crop use. Lime increases availability of other nutrient elements mostly basic cations essential to crop use especially calcium which forms plant structure. Lime with N rates at 40 Kg N/ha produced the highest yields. Such results on lime and barley have been reported in Australia, 2004, (Http://www.Agricultural lime) whereby yield increases of 0.19 and 2.5 were realized with application of agricultural lime at 2.5 and 5.0 t/ha respectively during the first year of application. (Http://www.Agricultural lime).

5.2 Effect of nitrogen rates and lime on grain protein content of barley

Lime had an effect on the grain protein content. Lime treatments had higher grain protein contents than non-limed ones. Increasing the nitrogen application rates increased the protein content beyond malting range. All treatments except control and 60 N/Kg had acceptable or required grain protein contents recommended for International Malting Association (IMA) which is 9-11.5 % protein (Abrol, 1990) and Protein content of 11 to 12.5 % for Brewing and Malting Barley Research Institute (BMBRI), (Recksiedler *et al.,* 2010). This was also consistent with the East Africa Malting Limited (EABL) protein ranges of 10 -13.5 % (EABL, 2011). Grain protein content at harvest ranged from 8.3% to 12.3% for the field experiment while 8.4% to 14% for the greenhouse experiments. Absolute controls (no N applied) for Mau had very low protein values not suitable for malting. This was similar for both Mau field experiment and Mau green-house soil studies (8.3% for field and 8.4% for greenhouse). For the greenhouse experiment, Chepkoilel treatments recorded higher protein values compared to Mau treatments. This was because the Chepkoilel soils had a critical N deficient that led to rapid absorption and utilization of the applied N. This was hugely supported by the high nitrogen use efficiencies of Chepkoilel soils (Table 5). It was evident lime had an effect on grain protein although statistically not significant. It is well known that lime affects P availability in the soil which then affects protein synthesis in the plant. Lime also increases availability of cations like Ca, Mg which acts as catalysts in protein synthesis. Stern & Wright (1962) found a highly significant joint effect of lime and superphosphate on enzyme activity which explains the high rate of superphosphate, with lime, producing a decrease in total ß-amylase in barley. Protein content obtained just after physiological maturity stage was lower than those determined after harvest.

This could be explained by the fact that at grain filling stage the plants were still actively absorbing nitrogen from the soil. Also the nitrate reductase (NR) activity responsible for nitrogen translocation in the plant was still active (Abrol, 1990).

Grain protein levels in barley are a function of amount of available nitrogen plus growing season moisture and temperature conditions. High rates of nitrogen and/or limited growing-season moisture result in protein content above acceptable malting levels (Abrol, 1990). An increase in nitrogen above 1.6% makes the grain unsuitable for malting. Grains with 2.0 to 2.6%N may be preferred for highly enzymatic malts. Therefore, for malting barley one should apply moderate amounts of nitrogen fertilizer at pre-sowing or seedling stage, (Abrol, 1990). Jankovic *et al.,* (2011) found grain quality decreasing by increasing nitrogen rates. Barley studies by Minale *et al.,* (2011) showed that grain protein content increased with higher N application rates. Grain protein content ranged from 8.9% with the application of 46 Kg N/ ha to 11.8% at the highest N rate (115 Kg N ha-1). According to McKenzie (2004), grain protein concentration is affected by cultivar, N fertilizer application and the interaction of cultivar and N rate. Abrol (1990) reports that on soils with low N supplies, malting barley responds well to N fertilizer, exhibiting increases in yield and protein content. However, too much nitrogen can increase protein beyond levels not acceptable to the malting industry standards. Excessive grain protein lengthens steeping times, makes germination more erratic, and creates undesirable qualities in malt. Besides over application of N, excessively high grain protein levels can also arise from low rainfall and high temperatures after anthesis (Johnston *et al.,* 1991). Therefore, malting barley grower must address field management and environmental uncertainties to produce profitable crops.

5.3 The effect of nitrogen and lime on the kernel weight of barley

Application of lime had a positive effect on the grain weight. Grain weight increased with N rates up to a certain point and then reduced. These results were in agreement with those of Jankovic *et al.,* (2011); where different nitrogen rates showed a significant effect on the absolute grain weight and volume grain weight. Studies by Minale (2011) revealed high N application rate significantly increases grain yield, grain protein and grain N content, and decreases kernel weight and kernel plumpness. As the N application rate increased, a thousand-kernel weight increased. In 2004 McKenzie reported higher N rates generally reduced kernel size. The proportion of kernels plumpness was affected by cultivar, Kernel size is less responsive to N fertility, but may be reduced with increasing N fertility (Clancy *et al.,* 1991)**.** Liming also had a positive effect as it increased the kernel weight whereby lime treatments produced grains with higher weights than those without lime. Stern & Wright (1962) reported that lime caused a 12% reduction in the percentage of husk.

5.4 The effect of nitrogen rates and lime on nitrogen use efficiency (NUE) and harvest index (HI)

5.4.1 Agronomic nitrogen use efficiency

Agronomic nitrogen use efficiency showed an inverse relationship with N rates. Increase in N rates led to reduction in nitrogen use efficiency. At low N rates, the barley plant absorbed and utilized N more efficiently because N levels were still deficient (Table 14). At high N rates the crop absorbs more than it needs hence wastage. The over absorbed N ends up in other plant organs like leaves hence increasing shoot biomass but not the grain (Harvest Index, Table 15). The relationship between N rates and NUE was similar in both lime and non-limed plots but NUE values in lime plots were less. This might have been due to the effect of lime in helping to release other nutrients that reduced NUE. Such results have been found by Minale *et al.,* (2011); who indicated that increase in N application rate, reduced N use efficiency. Results of Nitrogen use efficiencies of spring barley grown under varying nitrogen conditions in the field and growth chamber showed similar growth and NUE characteristics across field and growth-chamber tests (Beatty *et al.,* 2010). Increased nitrogen levels were also found to increase straw nitrogen uptake and grain nitrogen uptake. This was in agreement with findings of Gouis *et al.,* (1999). It has been reported that the N-use efficiency of a crop is enhanced as a result of important soil factors that may affect available P, soil moisture and the nature and amount of clay in the soil. Nutrient use efficiency (NUE) is used to evaluate the effectiveness of soil fertility management options. It is a function of the crop and its genotype, soil factors, types, method and time of application of the nutrient and environmental differences, (Okalebo *et al.,*2002).

Agronomic use efficiency which is an estimate of production efficiency and calculated in units of yield increase per units of nutrient applied helps to answer questions such as "How much productivity was gained as a result of fertilizer application?"(Snyder & Bruulsema, 2007). Agronomic efficiencies for N in a well-managed system will usually exceed 25, with the typical range averaging 10 to 30 units of yield increase per unit of N input, (Dobermann, 2007). The values by Dobermann (2007) are in agreement with those found in this study. Typical values for Recovery Efficiency (RE) of N in cereal crop production fall between 0.3 and 0.8, with well-managed systems usually having an RE greater than 0.5, (Dobermann, 2007). Estimation of Nutrient Use efficiencies is a good way for identifying leaks in the cropping system that may require attention. However, high NUE does not necessarily indicate that the cropping system is operating most efficiently. Practices implemented to increase NUE must always be evaluated in the context of the total cropping system and its ability to meet production needs for the world's growing population (Dobermann, 2007).

5.4.2 Harvest Index (HI)

Generally, the harvest index (HI) of limed treatments was higher than the un-limed treatments for both soils studied. The HI values for Mau soils were higher than that of Chepkoilel soils (Table 6), perhaps due to the fertility differences. Harvest index seemed to have an expo-linear relationship with N rates whereby the values increased from absolute controls up to N1 (40 N/Kg) then started decreasing. At high N rates, HI reduced. This meant that the rate of conversion of shoot biomass to grain biomass was less at high rates of N, whereby barley plant absorbed excess N most of which ended up in the shoot tissues but not the grain hence wastage. From this, it could be concluded that increased N led to increased shoot biomass but not the intended grain biomass therefore undesirable.

In addition, the HI values seemed to have the same trend like that of NUE. Lime increased HI as shown in (Table 6). This meant that lime increased the rate of conversion of shoot biomass to yield and therefore lime enhanced barley reproductive efficiency. Harvest index also increased with increase in N rates, the differences in the HI were not tested statistically hence it cannot be concluded that they were similar. Alam *et al.,* (2005) observed that the effects of nitrogen fertilizer levels were more or less similar for NHI (Nutrient Harvest Index) except control.

Similar results were reported by Pettersson (1989) and Boonchoo *et al.,* (1998). Accumulation of dry matter increased with higher doses of nitrogen but nitrogen use efficiency reduced. Harvest index was more or less similar except for control. In addition, fertilizer N and variety, but not soil N, significantly affected harvest index, with no interactions amongst the factors. Harvest Index, which is the ratio of harvested grain to total shoot dry matter (grain crops), it is used as a measure of reproductive efficiency. Factors that influence crop HI include the energy and protein content of seeds, breeding, and extreme (either hot or cold) temperatures during crop reproductive development. Crop husbandry can also influence HI, especially delayed sowing, which shortens the length of the vegetative phase and increases HI, (Unkovich, 2010).

5.5 Effect of nitrogen and lime on soil chemical properties (Soil pH and soil phosphorus)

5.5.1 Soil pH

Treatments with no lime had a decreasing trend in soil pH over the growing the season while the limed treatments had pH increasing to maximum point and decreased exponentially. This could be attributed to high rainfall during the growing season that affected the soil chemical properties resulting from the leaching of basic cations leaving the top soil more acidic than before planting. The decreasing trends in pH were proportional in all treatments including the absolute control. The effect of lime on soil pH was clearly evident as the pH of all treatments increased as indicated by table 16. The presence of calcium which is a cation would have been the key factor in the pH rise. Although the pH rose initially after 6 weeks after planting, it took a decreasing trend before reaching a nearly stabilized range. The decreasing trend would still be a factor of leaching of basic cations present in the soil especially calcium as witnessed in the treatments with no lime. In addition, the chemical reactions and interactions of different fertilizers used would have been another contributing factor for final pH decrease. These results were to some extend in agreement with studies done on response of wheat to levels and time of lime applications in Nepal (Adhikari *et al.,* 2010) which indicated that the pH before sowing of wheat in the pot and field experiments was higher than pH obtained after the harvest of the crop. Liming had significant positive effect in decreasing soil acidity. Lime raised soil pH from 4.5 to 5.5 and 6.7 in the field and pot soils, respectively. Studies in Australia in 2004 also reported significant effect of lime on soil reaction where; topsoil pH rose from 4.7 to 5.5 and 6.1 with lime application at 2.5and 5.0t/ha respectively in the first season. (Http://www.Agricultural lime)

5.5.2 Soil Available Phosphorus (Olsen P)

Application of lime increased the available phosphorus in the soils. Soil available P after grain formation and after harvest was much higher than initial levels before planting in the limed treatments. Increase in soil available P was also supported by the increase in soil pH after lime application. Adhikari *et al.,* (2010) observed that limestone treatments increased C.E.C, P_2O_5 and Ca content of the soil, but the lime application had no significant effects on available K_2O and bulk density of the topsoil. Adhikari *et al.,* (2003) also suggested that the liming under the pot conditions influenced more to the response variables as compared to the liming under the field conditions. This supported the significant effects of liming on grain and straw yields, effective tillers, harvest index and days to heading in pot experiments, where as the significant effects of liming were only limited to days to heading and plant height under field conditions which were to some extend in agreement with this study. The increase in soil pH resulting from the application of lime provides a more favorable environment for soil microbiological activity which increases the rate of release of plant nutrients, particularly nitrogen. Reduced acidity due liming increased the availability of other plant nutrients mostly phosphorus. It is estimated that about 20 per cent of fertilizer phosphorus is taken up by a crop in the year of application while the remainder is fixed in the soil in various degrees of availability to succeeding crops. On acid soils (pH less 6.0) the fixed phosphorus is retained in less available forms than on slightly acid to neutral soils (pH 6.1 to 7.5). Therefore the key benefits of liming acid soils are the increased utilization of residual fertilizer phosphorus by crops. Liming also improves physical properties of some soils like; reduced soil crusting, improved emergence of small seeded crops and reduced power requirements for tillage. Lime increases microbial growth due to calcium influencing nutrient availability (Glinsiki, *et al.,* 2011)

5.6 Effect of lime and nitrogen on barley water use

Mau Narok soil treatments used less water to reach harvest maturity compared to Chepkoilel soils meaning that less amount of water utilized to produce mature grains. Limed treatments of both sites utilized less water to produce mature grains compared to the unlimed treatments. In addition, there seemed to be a relationship between increasing N with the amount of water used to produce mature grains. Increase in N rates reduced the amount of water utilized per mature grain formed. It was not clear to explain the combined effect of Lime and Nitrogen on the water utilization by barley, but since lime increases the availability of other soil nutrients like P and Ca which speeds up growth hence reaches harvest maturity in a shorter time hence saving water. Absolute control (no nutrient added) of Chepkoilel soil took a longer time to mature yet it had very little yield. The effect of Lime in enhancing the water use efficiency is also based on its effect on the physical properties of the soil. Lime is known to increase porosity of a given soil hence increasing water movement in the soil hence better water absorption. Bole & Pittman (1980) found that N rates greater than 100 Kg N ha^{-1} could be used if available soil water was greater than 150 mm, but only 20 to 50 Kg N ha^{-1} could be applied if available soil water was less than 100 mm due to excessive protein concentrations.

Liming reduced the amount of water needed by the plant to produce grain to physiological maturity. This was evident as non-limed treatments utilized more water to produce grain at physiological maturity compared to limed ones. This means that limed soil needs less quantity of water to produce barley grain at both physiological and harvest maturity than non-limed soil perhaps due to improved water movement in the soil. These results would be useful in growing seasons with less rainfall or under irrigation.

5.7 Effect of varying soil water levels and lime on barley growth (tillers and biomass)

Water deficits or reducing soil water levels had a significant effect on barley growth. Biomass and tillering were greatly affected by reducing soil water (Figures 6 and 7). Lime was found to have a major effect on the soil water deficits. A strong relationship between soil moisture content and lime was realized where by the combined effect on the two on barley growth was significant. The growth attributes that were greatly affected were; number of tillers per plant, plant height and dry matter biomass.

The difference between the two soils (Chepkoilel and Mau) was evident; the effect of nitrogen and soil moisture was seen in Mau Narok soils only. Nearly all N and P treatments for Chepkoilel soils with varying soil moisture levels had no tillered plants and the biomass was more less the same. There was a strong relationship between soil fertility and soil moisture whereby control treatment (lime, N and P) had all plants tillered and with highest biomass at different soil moisture levels. In all treatments (different nutrients), soil moisture levels of Field capacity (FC) produced the highest number of tillers , followed by 80% Field capacity and then 50% Field capacity. This is because at FC, most of soil nutrients are in solution form hence available to plant. Soil moisture at 50% FC produced less biomass with little tillers per plant, the simple reason being less water in the soil to bring all nutrients into solution for plant absorption. Such studies on the effect of soil moisture on plant growth attributes have been reported by (Hsiao, 1973) who found a decreasing trend in maize leaf length, but not leaf width, with decreasing soil water potentials.

He also observed that reduction in leaf length by a short period of water deficit can prolong to certain duration. Thus, total leaf area was decreased through reduced leaf expansion and increased senescence rate. Barley is characterized by being relatively high drought tolerance, where it can grow with lesser soil irrigation (Mishra & Shivakumar, 2000). Barley plant's tolerance to moderate levels of water is useful because of the pressure of saving irrigation water. Reducing soil moisture in barley growth could reduce final yield due to incomplete development of grains (El-seidy & Khattab, 2000). Barley yield was reduced by up to 15% when last irrigation was skipped, (Ouda *et al.,* 2005). The reduction in barley grain yield under water stress could be attributed to the reduction in number of spikes/m^2, number of grains/spike and grain weight. Moreover, under water stress conditions, mobilization of stem nonstructural reserve increases occurs (McMaster, 1997) due to stomata closure and reduction of carbon exchange rate for photosynthesis.

Thus, it is important to identify barley genotypes with high yield potential and with high yield stability under reduced soil moisture or drought stress (El-Bawab, 2000). Predicting the impact and extend of imposing water stress or reducing soil moisture during barley growing season is very important because it helps to avoid significant crop performance and yield losses.

5.8 Effect of soil moisture deficits on phosphorus and nitrogen deficiency

There was a marked response of phosphorus deficiency to reducing soil moisture levels especially at 50% FC moisture where plants were stunted and developed purple stems. This was observed in the Control treatments of both site soils at 50% FC and both in nitrogen and phosphorus treatments. Both FC and 80% FC did not show any marked P deficiencies in Control treatments. Lime treatments did not show any visual P deficiency symptoms except at 50%FC moisture level. This could be due to the fact that both soils used are associated with less available phosphorus content due to fixation as a result of acidity. Since the P utilized by plants is in solution form, the water stress (50%) reduced solution P to forms not utilized readily by plants.

5.9 Effect of lime on the soil physical properties

5.9.1 Bulk density, Soil texture and the rate of water loss due evaporation

Bulk density decreased after liming the soil. Mau soils had a higher bulk density and a greater change after harvest lower than before planting. The changes were statistically different but it was clear that effect of lime on bulk density was different for each soil type. Lime is known to improve soil structure and resistance to pulverizing during cultivation (Glinsiki, *et al.,* 2011).

The presence of calcium in lime causes flocculation of the soil particles due its larger atomic radius when wet. This result to formation of stable soil aggregates hence soil structure improvement.

There were no changes in the textural classes of the different soils studied after liming but the contents or separates of each specific soil were greatly changed. Both soils had a textural class of sand loams which never changed after liming at harvest time. The contents of sand changed from 61%-69% but a decrease for both clay and silt contents from 14% and 25% to 10% and 21% respectively. For Mau soils, this was different. Sand decreased from 71% to 65%. Clay and silt increased from 8% and 21% to 10% and 25% respectively.

The limed treatments recoded higher evaporation rates i.e. the rate of water loss was much higher compared to treatments with no lime. Due to this effect, the soil treatments with lime dried much faster. Mau soil had higher rate of water loss per day than the Chepkoilel soils.

This could be partly be explained by the fact that Mau soils had a more sand content and due to large pore space for sand then water loss is high. In addition, Lime addition in soil leads to improvement in the physical conditions like permeability of a soil and the hydraulic conductivity (Brown, *et al* 1959).

Adhikari *et al.,* (2010) observed that limestone increased Ca content of the soil but had no significant effects on bulk density of the topsoil. Studies made on the effect massive applications of lime on physical properties of soils in California ((Brown, *et al* 1959) indicated that lime had an effect on modulus of rupture of different soils and on their Hydraulic conductivities. The two parameters indicate an improvement in the physical conditions of any given soils. Modulus of rupture is the force per square centimetre required to break a specially formed briquette of soil and is correlated with the crusting tendency or hardness of a soil (Brown, *et al* 1959).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Increasing the amount of Nitrogen (rates) increased the yields proportionately for Chepkoilel site and soils but no response for Mau-Narok soils

Nitrogen rates at 30N and 40 N Kg/ha produced highest grain yield, highest kernel weight and maltable grain protein content for both site soils.

Lime with Nitrogen rates at 30N and 40 N Kg/ha produced highest grain yield, highest kernel weight and maltable grain protein content both site soils.

Reducing soil water content beyond Field Capacity significantly affected tillering and biomass. In addition, reducing soil water levels accelerated onset of phosphorus deficiency.

Lime seemed to reduce the negative effect of water stress on barley growth and development by reducing the amount of water needed by the plant and soil to produce grain at both physiological and harvest maturity hence increased water use efficiency.

Lime affected both soil physical & chemical properties; reducing soil bulk density, increased the rate of soil-water loss (evaporation) with no change in soil textural class. Soil pH and available phosphorus increased.

6.2 Recommendations

1) For Chepkoilel site and its environments; liming should be given priority as the key soil amendment to reduce acidity, increase P availability and to enhance efficient water use (increase porosity). This will lead to sustainability in barley production in the region (sustainable yields and soil fertility). Apply N at 40 N Kg/ha rates for better yields and grain quality. N is critically deficient.

2) For Mau Narok; Apply 30 N Kg/ha (nitrogen not deficient). Increase rates of phosphorus for quality grain. Use organic matter to maintain fertility & reduce acidity (andosols).

6.3 The way forward for research

- More research to evaluate the residual effect of lime on soil fertility and the economic analysis of using lime in barley production
- More research should be done to exactly determine the optimum site specific lime rates that can be used in combinations with the P and N fertilizers for increased yields and best barley grain quality
- Increase breeding for genotypes with enhanced nitrogen-fertilizer and water efficiency and modification of cultural practices to improve grain quality

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APPENDICES

Appendix I: ANOVA for the effects of lime and N rates on barley yield (Mau-Narok Field)

Source of variation	DF	Type III SS	Mean Square	F Value	Pr> F
Block	2	0.02702973	0.01351486	0.05	0.9524
Lime	1	3.44497106	3.44497106	12.45	0.0020
Block*Lime	2	0.04559838	0.02279919	0.08	0.9212
Nitrogen rates	5	16.72101894	3.34420379	12.09	<.0001
Lime*Nitrogen	4	1.87702395	0.46925599	1.70	0.1886

Appendix II: ANOVA for the effect of varying soil moisture levels, different nutrients and lime on barley biomass

Source of Variation	d.f	s.s	m.s	v.r	Fpr
Nutrients*moisture level*Units* stratum					
Soil moisture levels	2	21.40474	10.70237	140.58	<.001
Nutrients*moisture level	6	6.82620	1.13770	14.94	<.001
Nutrient*moisture*Site	12	25.59352	2.13279	28.01	<.001
Residual	24	1.82715	0.07613		
Total	47	85.33958			

Appendix III: ANOVA for the effect of varying soil moisture levels, different nutrients and lime on barley tillering

Source of Variation	d.f	ss	m.s	v.r	Fpr
Nutrients.moisture level*Units* stratum					
Soil moisture levels	2	775.542	387.771	204.54	<.001
Nutrient*mosture levels	6	169.458	28.243	14.90	<.001
Nutrient*moisture*Site1	2	173.250	14.438	7.62	<.001
Residual	24	45.500	1.896		
Total	47	1610.979			

Appendix IV: ANOVA for the effects of lime and N rates on barley kernel weight (Field)

Source of variation	DF	Type III SS	Mean Square	F Value	Pr> F
Block	2	2.38888889	1.19444444	0.96	0.4009
Lime	1	70.57973684	70.57973684	56.43	<.0001
Block*Lime	2	6.96222222	3.48111111	2.78	0.0847
N rates	5	52.73600000	10.54720000	8.43	0.0002
Lime*N rates	4	15.04666667	3.76166667	3.01	0.0415

Appendix V: ANOVA for the effects of lime and N rates on barley yield (green house)

Source of variation	DF	Type III SS	Mean Square	F Value	Pr> F
Block	2	0.50971648	0.25485824	0.19	0.8251
Site	1	51.15544192	51.15544192	38.79	<.0001
Block*Site	2	0.91094511	0.45547256	0.35	0.7103
Lime1	2	0.92232578	2.92232578	2.22	0.1455
Site*Lime1	2	0.86561346	2.86561346	2.17	0.1494
Block*Site*Lime	4	1.55014216	0.38753554	0.29	0.8800
Nitrogen rates	5	17.89306529	3.57861306	2.71	0.0357
Lime*N rates	5	1.60217386	0.32043477	0.24	0.9405
Site*lime* N rates	3	7.86000869	2.62000290	1.99	0.1339

Appendix VI: ANOVA for the effects of lime and N rates on barley biomass (DW)

Source of variation	DF	Type III SS	Mean Square	F Value	Pr> F
Block	2	1.75828550	0.87914275	0.75	0.4810
Site	1	34.01842346	34.01842346	28.92	<.0001
Block*Site	2	0.24680649	0.12340325	0.10	0.9007
Lime	1	40.83441513	4.83441513	4.11	0.0503
Site*Lime	1	7.49750842	7.49750842	6.37	0.0163
Block*Site*Lime	4	1.05379115	0.26344779	0.22	0.9232
Nitrogen rates	5	89.21847301	17.84369460	15.17	<.0001
Lime*N Rates	5	1.49637461	0.29927492	0.25	0.9347
Site*Lime*N rates	3	12.71015047	4.23671682	3.60	0.0228

Appendix VII: ANOVA for the effects of lime and N rates on barley kernel weight (green house)

Source of Variation	DF	Type III SS	Mean Square	F Value	Pr> F
Block	2	15.8819267	7.9409633	0.96	0.3926
Site	1	348.6428525	348.6428525	42.17	<.0001
Block*Site	2	15.0244606	7.5122303	0.91	0.4124
Lime	1	0.4316241	0.4316241	0.05	0.8206
Site*Lime	1	0.2001031	0.2001031	0.02	0.8773
Block*Site*Lime	4	8.8901379	2.2225345	0.27	0.8960
Nitrogen rates	5	391.6498364	78.3299673	9.47	<.0001
Lime*N rates	5	241.6929267	48.3385853	5.85	0.0005
Site*Lime*Nitrates	3	184.0489215	61.3496405	7.42	0.0006

Appendix VIII: Grain protein content after grain formation and after harvest (greenhouse)

	Grain Formation				Harvest			
	Chep		Mau		Chep		Mau	
	No LIME	LIME	NO LIME	LIME	NO LIME	LIME	NO LIME	LIME
Control	9.82	8.67	6.45	6.60	11.73	14.06	8.41	10.21
PN0	7.77	9.25	6.67	7.11	11.35	10.88	9.26	10.96
30N	8.29	7.25	6.60	9.12	10.61	12.16	9.27	12.50
40N	7.71	9.17	7.99	8.85	10.16	12.76	9.35	9.35
60N	7.55	10.36	8.03	9.62	13.17	12.59	11.35	11.28

Appendix IX: Soil available phosphorus (ppm) after harvest (greenhouse)

	Chepkoilel			Mau		
	INITIAL	HARVEST		INITIAL	HARVEST	
		NO LIME	LIME		NO LIME	LIME
CONTROL	8.30	10.87	74.52	17.1	21.66	209.28
PN0	8.30	16.58	99.28	17.1	25.31	125.47
30N	8.30	13.57	55.15	17.1	21.34	170.39
40N	8.30	26.26	55.15	17.1	21.66	79.28
60N	8.30	26.11	71.50	17.1	18.96	132.77

Appendix X: Critical soil nutrient concentrations for tropical soils according to Okalebo *et al.,* (2002)

Organic C (%)	> 3.0	High
	1.5-3.0	Moderate
	0.5-1.5	Low
	< 0.5	Very low
Total N (%)	> 0.25	High
	0.12-0.25	Moderate
	0.05-0.12	Low
	< 0.05	Very low
P (ppm)	< 10	Critical
pH H20	< 6.5	Acidic

Appendix XI: Mean separation for N rates and lime on grain yield of barley

(Mau-Narok field)

Treatment	no lime	lime	mean
Control	3.62a	4.95a	4.29
PN0	6.04c	6.87bc	6.46
N1	5.80b	7.02c	6.42
N2	6.11c	7.05c	6.58
N3	6.16c	6.76b	6.47
N4	6.16c	6.90bc	6.54
mean	5.66	6.59	
CV%	8.54		
	SED	LSD	
N rates	0.09	0.21	
Lime	0.10	0.21	

A mean value followed by the same letter do not differ significantly from each other at 5% level of significance according to Duncan's New Multiple Range Test (DNMRT)

Appendix XII: Effect of nitrogen rates and lime on kernel weight of barley (Mau- Narok field)

Treatment	no lime	lime	mean
Control	40.47 a	45.34 a	42.91
PN0	44.69 b	45.26 a	44.98
N1	44.28 b	46.61 b	45.45
N2	43.00 b	46.61 ab	44.81
N3	43.77 b	46.61 b	45.98
N4	45.35 b	46.61 b	45.98
mean	43.59	45.96	
CV%	2.7		
	SED	LSD	
N rates	0.92	2.01	
Lime	1.07	2.33	

A mean value followed by the same letter do not differ significantly from each other at 5% level of significance according to Duncan's New Multiple Range Test (DNMRT)

Appendix XIII: Mean separation for nitrogen rates and lime on grain yield of barley (green house)

	Chep soil			Mau soil		
Treatment	no lime	lime	mean	no lime	lime	mean
Control	0.85a	2.56a	1.71	5.87a	7.71a	6.70
PN0	1.34ab	3.36b	2.35	7.09a	8.02ab	7.55
N1	1.70bc	3.35b	2.53	6.17a	9.67c	7.92
N2	2.02c	4.33c	3.18	6.08 a	8.17ab	7.12
N3	2.56d	5.33d	3.95	6.028a	8.85bc	7.44
mean	1.70	3.79		6.25	8.49	
CV%	22.2					
	SED	LSD		SED	LSD	
N rates	0.31	0.70		0.57	1.28	
Lime	0.27	0.60		0.41	0.92	

A mean value followed by the same letter do not differ significantly from each other at 5% level of significance according to Duncan's New Multiple Range Test (DNMRT

Appendix XIV: Mean separation for nitrogen rates and lime on kernel weight of barley (green house)

	Chep soil			Mau soil		
Treatment	no lime	lime	mean	no lime	lime	mean
Control	53.01 a	55.04 a	54.04	35.13 a	49.01 ab	42.07
PN0	54.2 a	64.09 c	59.15	46.04 c	45.1 a	45.57
N1	61.01 b	60.04 bc	60.53	42.06 b	48.1 ab	45.08
N2	54.05 a	54.05 a	54.05	41.11 b	50.09 b	45.6
N3	56.08 a	56.08 ab	56.08	50.04 d	51.04 b	50.54
mean	55.67	57.86		42.88	48.67	
CV%	5.61					
	SED	LSD		SED	LSD	
N rates	1.93	4.31		1.78	3.97	
Lime	1.90	4.24		1.83	4.07	

A mean value followed by the same letter do not differ significantly from each other at 5% level of significance according to Duncan's New Multiple Range Test (DNMRT)

Appendix XV: Mean separation for different soil moisture contents and different nutrient sources on the number of tillers and biomass of barley

Treatments		Chepkoilel soil		Mau-Narok soil	
Nutrients	soil moisture	tillers	biomass	tillers	biomass
Control	50%fc	2a	2.17a	2a	2.42a
	80%fc	5b	4.99b	4b	3.67a
	fc	12c	5.16b	14c	5.12ab
Lime	50%fc	1a	1.69a	2a	3.98a
	80%fc	5b	4.11b	6b	4.20a
	fc	11c	4.5b	12c	5.03ab
Nitrogen	50%fc	1a	3.15a	1a	3.24a
	80%fc	1a	3.41a	3a	3.47a
	fc	1a	3.46a	11b	4.80ab
Phosphorus	50%fc	1a	1.85a	1a	3.38a
	80%fc	1a	2.00a	2a	3.75a
	fc	1a	2.25a	9b	4.70a
	mean	3.47	3.23	5.53	3.98

	CV%	SED
soil moisture	7.40	2.55
soil moisture*nutrients	23	2.71
soil type*soil moisture	4.30	2.10

A mean value followed by the same letter do not differ significantly from each other at 5% level of significance according to Duncan's New Multiple Range Test (DNMRT)