RESPONSE OF BARLEY *(Hordeum vulgare* L.) VARIETIES TO SEED AND NITROGEN RATES IN KENYA

BY

OKACHA J.S. JAIRUS

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

2014

DECLARATION

Declaration by Candidate

This thesis is my original work and has not been presented for a degree in any other University. No part of this thesis may be reproduced without the prior written permission of the author and/or University of Eldoret.

Okacha J.S. Jairus **(AGR/PGC/05/10)**

School of Agriculture and Biotechnology

Department of Seed, Crop and Horticulture Sciences

University of Eldoret **Sign..………………… Date ……………….**

Declaration by Supervisors

This thesis has been submitted with our approval as University Supervisors

Prof. Elmada O. Auma

School of Agriculture and Biotechnology

Department of Seed, Crop and Horticulture Sciences

University of Eldoret **Sign..………………… Date ……………….**

Dr. Lucas Ngode

School of Agriculture and Biotechnology

Department of Seed, Crop and Horticulture Sciences

University of Eldoret **Sign..………………… Date ……………….**

DEDICATION

This research is dedicated to my wife, Felistus and my late grandmother Monica, for their exceptional inspiration in my academic life.

ABSTRACT

There is difficulty in attaining malt grade barley since barley varieties recommended for malting must meet specific quality requirements and these demand specific agronomic practices. A study to develop appropriate agronomic packages with reference to cultivar choice, plant population density and nitrogen fertilizer rates for malting Barley was conducted in two barley growing sites, University of Eldoret farm and Mau Narok in Kenya. Three varieties; HKBL 1512-5, HKBL 1385-13 and Nguzo were combined in a 4*3*3 factorial arrangement, in a completely randomized block design (RCBD), with seed rates of 150, 200 and 250 pure germinating seeds m^{-2} and nitrogen fertilizer rates of 0, 30, 40 and 50 kg-N ha^{-1} in an experiment at each of the sites to determine the effect of seed and nitrogen fertilizer application rates on their malting quality. Grain yield components including, plant establishment, spike length, number of grains per spike, number of tillers, 1000-grain weight and grain yield; and grain quality components including grain size and grain N-content were recorded. The generated data was subjected to ANOVA using the SAS package. Mean differences were determined by Least Significant Differences; (LSD) at $\alpha = 0.05$ probability level. Test variety HKBL 1385-13 had superior grain yield than the control variety Nguzo at both the Mau Narok and University of Eldoret sites by 500 kg ha^{-1} (25%) and 1400 kg ha^{-1} (37.8%) respectively. It also had a higher number of productive tillers than the control at the UoE site, a factor that could have made it produce superior grain yields. Although test variety HKBL 1512-5 had significantly higher grain yields than the control variety Nguzo at the Mau Narok site by 400 kg ha^{-1}, it had inferior yields at the UoE site. It also had shorter spike length and a lower number of grains $spike^{-1}$. However, it had consistently heavier grains throughout the study. Test varieties HKBL 1512-5 (2.33% N) and HKBL 1385-13 (2.21% N) accumulated grain N-content beyond the acceptable level of 2.2% N at the Mau Narok site compared to 1.97% N and 1.87% N respectively at the UoE site. Although site differences were observed for the proportion of maltable grains, all test varieties produced acceptable proportions of more than 90 %. Increasing seed rate increased grain yield as expected. However, whereas higher seed rate (250 seed m^{-2}) at Mau Narok produced significant increase in yield by 500 kg ha^{-1} (11.4 %) over the control seed rate, a similar increase in seed rate at the UoE did not. This is closely related to the effect of increasing seed rate on the grain N-content. Lower seed rates produced grains with higher N-content than the acceptable level for malting of 2.2 % at the Mau Narok site. Whereas N-addition significantly increased grain yield at both sites, it led to accumulation of grain N-content beyond the acceptable level. Test variety, HKBL 1385-13 can be suitable for both sites, but its seed rate should be higher than the control to attain acceptable grain N-content. The superior grain size of test variety HKBL 1512-5 can be used to improve barley varieties with superior yields but with inferior kernel size. Nitrogen fertilizer should be used sparingly with introduced varieties or combined with higher seed rates at the Mau Narok site to retain acceptable grain N-content. These findings confirm that malting barley requires specific site, variety, seed rate and N-rate recommendations.

TABLE OF CONTENTS

CONTENT

PAGE

LIST OF TABLES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA – Analysis of Variance

CAN – Calcium Ammonium Nitrate

CP – Crude Protein

CV – Coefficient of Variation

EABL – East African Breweries Limited

EAML – East African Malting Limited

EPZA – Export Processing Zone Authority

EU – European Union

GMS – Global Malting Society

ISTA – International Seed Testing Association

KBL – Kenya Breweries Limited

NPK – Nitrogen Phosphorus Potassium

PGS – Pure Germinating Seed

RCBD – Randomized Complete Block Design

TGW-Thousand Grain Weight

TSP – Triple Superphosphate

UoE– University of Eldoret

ACKNOWLEDGEMENT

My sincere thanks go to MU-EABL barley Research Project funded by EABL through EAML for funding field. Special thanks go to the principal scientist, Professor Julius Ochuodho for his consent for students' participation in the Barley research project. I would like to express my sincere appreciation for my University supervisors, Professor Elmada O. Auma and Dr. Lucas Ngode for their tireless guidance and input into the completion of this research. This study was made possible by my main sponsor, Bukura Agricultural College, who took the bold decision to nominate me from amongst many other deserving candidates. To Bukura agricultural college, I say thank you for the transparent training policy. Both my nuclear and extended families sacrificed a lot of their comfort and rights to enable me pursue this training. I want to particularly thank my wife, Felistus, my children; Eric, Evans, Elvis, Were and Khaabi for their patience and understanding during my absence in pursuit of this success. I send special thanks to my fellow students, particularly, Stanley Nadir, Deonice Mshida and Antony Khaenje, for their objective critique which enriched this research.

To all of you, I say; that you were there for me, when you were needed most. May the almighty God, the creator of all things and the owner of all treasures, reward you abundantly in his own exceptional ways.

Okacha Jairus.

CHAPTER ONE

INTRODUCTION

1.1 Background

1.1.1 Global barley production

Barley is one of the crops of old world agriculture and was among the first domesticated cereals (Adrian *et al.*, 2011). It is ranked fourth in the world cereal crop production after maize, wheat and rice. Globally, 136 million tonnes of barley are produced annually on about 56 million hectares (Ceccarelli and Grando, 2006; Newman& Newman, 2008). Leading global producers of barley are the European Union (EU), the Russian Federation and Canada (Akar *et al.,* 2004; EPZA, 2005). However, leading exporters are Australia, Ukraine, and the EU while the principal markets for barley are Saudi Arabia, Japan and China (Akar *et al.,* 2004; EPZA, 2005). In tropical Africa the main barley-producing country is Ethiopia, with 950,000 tonnes of grain from 870,000 hectares (Ceccarelli & Grando, 2006). Kenya is ranked second in tropical Africa with a production of 75,000 metric tonnes from 20,000 hectares (USDA, 2011), whereas Eritrea at 24,000 tonnes from 44,000 hectares is ranked number three (Ceccarelli & Grando, 2006).

1.1.2 Classification and origin

Barley, *Hordeum vulgare* L. is an annual grass growing to 60-120 cm tall and tillers freely (Australian Govt., 2008). Classification of barley may be on the basis of its botany, the number of fertile seeds per spikelet, the length of the awns, seed colour, seed cover or lack of it and geographical distribution (Ahmed *et al.,* 2011). The most common of these are the botanical and the number of fertile seeds per spikelet. Botanically, barley belongs to the genus *Hordeum* in the tribe Triticeae of the grass family, Poaceae (gramineae). There are two subspecies: *H. vulgare* L. *ssp. vulgare* otherwise called the cultivated barley, and *H. vulgare ssp. spontaneum,* also called wild barley and which is the wild progenitor of cultivated barley (Chapman and Carter, 1978). On the basis of fertile seeds per spikelet, barley can be classified as two-, four-, and six-row barley. Generally, two-row barley is preferred for malt production (Australian Govt., 2008). All the three commercially grown malt barley varieties in Kenya (Nguzo, Sabini and Karne) are two-rowed.

The genus *Hordeum* has its centre of origin in Abyssinia alongside wheat- *Triticum* spp and sorghum (*Sorghum spp)* (Akar *et al.*, 2004; Ceccarelli and Grando, 2006). However its centres of diversity are in central and south western Asia, Western North America, South America the Mediterranean and Morocco (Australia Govt., 2008; Ahmed *et al*., 2011). Barley was first domesticated from its wild relative, in the fertile crescent of Middle East over 10,000 years ago (Ceccarelli and Grando, 2006; Ahmed *et al*., 2011).

1.1.3 Barley and its utilization

Upon domestication, barley has evolved from largely a food grain to a feed and malting grain (Baik and Ullrich, 2008). Globally, up to 85% of barley is for feeding animals as rolled, ground or flaked kernel. The second most important use of barley is for malt, an ingredient mostly in beer but also in hard liquors, malted milk and flavorings in a variety of foods. Malt can also be used in manufacture of biscuits, bread, cakes, and desserts (Akar *et al.*, 2004). As a human food, barley is still important in regions where other cereals do not grow well due to abiotic stresses like rainfall and salinity. Such regions include India, China, Morocco and parts of Asia, where barley is used to make flat bread and porridge (Baik and Ullrich, 2008, Akar *et* *al.,* 2004). In developed economies it is used in flours for bread and other specialties such as baby foods, health foods and thickeners (Newman & Newman, 2008).

Other uses of barley are the production of starch for the food industry as a thickener or binder and making Japanese alcohol. Important bye products of barley production are straw which is used for animal beddings in the western world but can be used as livestock feed in low input agriculture systems of the developing economies (Adrian *et al.,* 2011). Brewer's and distiller grains and sprouts from malting barley have desirable protein content for animal diets (Akar *et al.,* 2004; Ceccarelli &Grando, 2006).

1.1.4 Environmental requirements for barley growing

The barley plant is a short season, early maturing crop found in widely varying environments globally (Australian Govt., 2008). Cultivated barley is grown in diverse environments that range from sub-arctic to sub-tropic (Newman and Newman, 2008). However, it prefers temperate areas and high altitudes of the tropics and sub-tropics. Altitudes of 1500 to 3000 metres above sea level are ideal for barley with optimum temperatures ranging from 15-30^{o}C., but it can tolerate higher temperatures above 32^{0}C as long as humidity remains low (Chapman and Carter, 1978).

Barley will perform well in course textured, well drained soils within a pH range of 7.0 to 8.0 (Chapman and Carter, 1978). On this basis barley is more sensitive to soil acidity and the resultant aluminum 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 and Carter, 1978). For successful barley production, the main nutrients required are; nitrogen, phosphorus, potassium, copper, manganese and zinc (Western Australian

Dept. of Agriculture and Food, 2007). Low sulphur levels can also be a problem in areas with long history of cultivation and di-ammonium phosphate use (Western Australian Dept. of Agriculture and Food, 2007). This raises the need for soil testing before fertilizer is used in barley production.

Compared to other cereal crops, barley is an efficient water user and is a crop of choice in drier areas (Ceccarelli and Grando, 2006). Nevertheless, rainfall distribution in these areas should ensure adequate rains during the growth phase. In Kenya, barley is gown in medium to high altitude areas receiving between 900 and 1400mm of rainfall per annum, but it requires 635mm of precipitation during growth (EPZA, 2005). Barley does not tolerate water logging and drought is an important abiotic stress to its cultivation (Australian Govt., 2008).

1.1.5 Barley growing in Kenya

In Kenya, barley growing can be traced back to the 1940s when it was grown as a rotational crop for animal feed (Chapman and Carter, 1978). Farming barley for processing started in 1947 when Kenya Breweries Ltd. (KBL) took interest in locally grown barley with good brewing qualities (EPZA, 2005). To date all barley grown in Kenya is for malting. Barley is a medium to high altitude (1500-3000m 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. Of these, the Mau Escarpment contributes 60% of the total area, Timau 20%, Moiben 13% and Nakuru area 7% (Chapman and Carter, 1978). The total area under barley cultivation is 20,000 hectares against a potential area of 85,000 ha, (EPZA, 2005). This shows that there is potential to increase production through increase in area under cultivation.

Most barley is grown by large scale contracted farmers, although up to 15% of the farmers are small scale (EPZA, 2005).

1.1.6 Yield and malting qualities of barley

Yield is a primary purpose of both crop production and research. A number of crop growth and development components contribute to yield either positively or negatively. These components of yield include, plant population density, leaf area index, tillering (in small cereals), spikes per unit area, grains per unit area, spike length, number of grains per spike, biomass, harvest index, grain yield and kernel weight (Zadoks *et al.*, 1974).

Malting qualities include purity of grain, uniform grain that is plump and of bright colour, dryness, maturity and high and uniform germination percentage. However, the most important quality for malting barley is the protein content of the grain which has a big influence on the final product, beer (Chapman and Carter, 1978). Grain protein content should be within the range of 11.5 – 13.5 % in six-row barley and 10 – 12.0 % in two row barley (Newman and Newman, 2008). Lower grain protein content leads to low enzyme activity for breaking down carbohydrates into simple sugars whereas higher protein content leads to fizzing in the final product (Chapman and Carter, 1978).

The attainment of these qualities requires more vigorous management of the barley crop; particularly the agronomic practices involved in its production, compared to ordinary grain and feed barley. These include prudent management of plant population, nitrogen fertilizer and all other practices that will ensure there is no water stress on the barley plant while in the growth phase.

Malting barley yields in Kenya have remained low at a national average of 2.2 t ha^{-1} against a potential of 7 t ha^{-1} (EPZA, 2005). Besides, not all the harvested barley attains the required grain protein content. For example, in the 2010 – 2011 crop years, only 76 % of harvested barley attained the acceptable grain protein content of 10-12 %, with the rest being used as feed barley (Mumbi M., personal communication, March, 2011). This leaves a big gap for improvement in agronomic practices in barley production in order to increase yield and the proportion of harvested barley that attains the grain protein content requirement.

This study investigated how different barley varieties, seed rates and nitrogen application rates affected the yield components of plant establishment, number of productive tillers per plant, spike length, number of grains per spike; grain yield and grain test weight and the malting qualities of kernel size (proportion of maltable grain) and grain protein content.

1.2 Problem Statement

There is difficulty in attaining malt grade barley, not only in Kenya but globally, since barley varieties recommended for malting must meet specific quality requirements. These quality requirements demand specific agronomic practices. Research into newer varieties of malt barley that are high yielding, early maturing and having resistance to lodging, diseases and sprouting is on – going. Breeding programmes in this research have targeted some of the agronomic requirements by breeding barley varieties that adapt best to the agro-ecological zones suited for barley growing. Eight malt barley varieties have been released for further evaluation on disease resistance by the research arm of East African Malting Limited (EAML), a subsidiary company of East African Breweries Limited (EABL) (EPZA, 2005). Many other potential varieties have also been sourced from Global Malting Services (GMS) of Australia and Syngenta for trials in Kenya (Mumbi M., Personal Communication, March, 2011). These potential barley varieties are being evaluated for possible release for commercial cultivation by farmers in Kenya. Upon release, there are no variety specific agronomic practices, particularly with reference to seed rate and nitrogen fertilizer rates, instead, these potentially good varieties are cultivated using blanket recommendations. For these new varieties to perform optimally, variety specific agronomic packages with reference to seed rate and nitrogen fertilizer rates should be developed.

1.3 Justification

Many potential introductions from Global Malting Services (GMS) and Syngenta are under evaluation with the aim of releasing more variety options for the barley farmers. Currently there are over 300 entries from USA on rust selection. Eight new potential varieties from Syngenta and another 8 from GMS are also under evaluation (Mumbi M., personal communication, March 2011). After release, an appropriate agronomic package will be required for each new release.

There is a limited varietal base for barley farmers in Kenya. Only three varieties; Nguzo, Karne and Sabini are being cultivated in barley growing areas of Kenya (EPZA, 2005). Sabini is reported to have succumbed to the barley yellow dwarf virus disease, leaving only two options. However, there are 8 local barley varieties but these will need disease and pesticide evaluation and development of appropriate agronomic packages (Mumbi M., personnel communication, March, 2011).

EAML expects to increase current barley production from 75,000 metric tonnes by 35%, hence the need to develop agronomic practices that will increase yield while retaining malting quality (Mumbi M., personal communication, March 2011). This expectation will be achieved through adoption of best practices in the barley crop management.

Area specific recommendations for variety, fertilizer rates and types and plant population densities are lacking in Kenya today. One blanket recommendation is given for all areas. Consequently, there is a big gap between the yield potential of the released varieties and the actual yields. For example, while the yield potential of released varieties is 7.0 tonnes ha^{-1}, the national average yield in Kenya is 2.2 tonnes (EPZA, 2005). Agronomic practices are suspected to be the cause of this gap, especially, regional fertilizer and varietal recommendations (Mumbi M., personal communication, March, 2011). Barley as a crop is important in the Kenyan economy because it supports over 100,000 people both directly and indirectly (EPZA, 2005).

1.4 Objectives

1.4.1 Broad objective

The broad objective of this study was to determine appropriate agronomic packages for potential malting barley varieties in medium and high altitude barley growing areas of Kenya.

1.4.2 Specific Objectives

The specific objectives of the study were to;

i) Determine optimum plant population densities for potential malting barley varieties,

ii) Determine appropriate Nitrogen applications rates for potential malting barley varieties

1.5 Research hypotheses

H_{a1} – Potential malting barley varieties require varietal-specific seed rates

H_{a2} - Potential malting barley varieties require varietal-specific nitrogen application rates

CHAPTER TWO

LITERATURE REVIEW

2.1 Importance of barley

Worldwide, barley is the most important grain in producing high quality beer (Jason *et al.*, 2001). It is estimated that, about 30% of all the barley produced worldwide is grown for malt while the rest is grown for livestock feed, human food and seed (Australian Govt., 2008; Akar *et al.*, 2004). Malting barley grains are soaked (steeped) in water for at least 40 hours and allowed to germinate until the roots and shoots are roughly the length of the kernel (Chapman and Carter, 1978). At this point the process is stopped, the kernels dried and heated or cured to produce the desired colour and flavour needed for producing beer. This process involves the conversion of starch in the grain endosperm into simple sugars that are subsequently used in the fermentation process to produce alcohol (Chapman and Carter, 1978).

Malting barley has much higher quality requirements when compared to food or feed barley. Many farmers have difficulty achieving malting grade; for example in Kenya 76% of all barley delivered to the maltisters in the 2010-2011 crop year achieved the grade (Mumbi, personal communication, 2011). In Western Canada only 25% of the malting barley grown is accepted for malting. Similar difficulty is reported by French farmers (O'Donovan *et al.,* 2012). This difficulty is associated with unfavourable climatic conditions but suboptimal agronomic practices may also be a factor. It is for this reason that malting barley fetches 50% more income per unit weight than the other types of barley (Jason *et al.,* 2001). Therefore, regardless of the type or variety grown, malting barley must meet specific quality standards to quality for the higher price. This can only be achieved if specific environments and agronomic practices are determined for each of the evolving newer varieties. In Kenya, barley is exclusively grown for malt production and the industry supports upwards of 100,000 people either directly or indirectly (EPZA, 2005). Choice of appropriate environments and appropriate agronomic practices will enable these farmers to achieve higher proportions of malt grade barley.

2.2 Small cereal crop growth and development

Small cereal crop development can be split into vegetative and reproductive categories. To change from vegetative to reproductive category, length of day and temperature play a role. Longer days that are warmer hasten the changeover (FAO, 2003). For plants to grow, they absorb carbon dioxide from the atmosphere which (CO_2) is built into sugars using solar energy (photosynthesis). These sugars, in different forms and combinations with inorganic nutrients extracted from the soil become the components from which the plant is build. Some of the sugars are stored in stalks for later use, particularly for grain filling.

As long as the crop has enough sunlight, CO_2, water and inorganic nutrients, and it is warm enough, all organs will grow to their full potential. Water is a major drawback to this process of photosynthesis. It is therefore necessary that the plant retains adequate water, or is able to extract water from the drying soil to be able to continue with growth and development.

The amount of sunlight that the crop can absorb to drive photosynthesis is dependent on the leaf area index, since this will determine the amount of sunshine that can be intercepted (FAO, 2003). Further, the crop can produce many tillers, although this will depend on the substrate available in the soil. If the plant is short of the substrate, like in times of drought, low light or shortage of nitrogen, the tillers remain dormant or may not grow (FAO, 2003).

In summary, the crop continuously senses its environment and adjusts its size, shape and type of components to match the constraints. Efforts should be made to ensure that the crops composition leads to the best yield within the constraints. Other reproductive parts like ears, spikes, florets and grains are subject to similar rules (FAO, 2003).

2.3 Relationship between barley varieties and yield and malting qualities

Many studies have been conducted on the relationship between barley varieties and their yield and malting qualities. The yield and quality specifications of a given malting barley variety are determined by its genetic makeup and the physical conditions during growth, harvesting and storage (Fettel *et. al.,* 1999; Glen *et al.,* 2006; Australian Govt., 2008). In a study involving farmers in Northern Ethiopia, malting barley genotypes were selected by farmers on the basis of differences in the agronomic traits of crop stand establishment, number of tillers per plant, spike length, number of kernels per spike, and 1000 kernel weight (Aynewa *et al.,* 2013; Soudabeh *et al.,* 2013). Subsequent statistical analysis in this study confirmed that, these traits were indeed different across genotypes (Aynewa *et al.*, 2013).

Genotype will influence the germination percentage due to differences in kernel and dormancy characteristics among cultivars (Fettel *et al.,* 1999; Glen *et al.,* 2006; Australian Govt., 2008). This will subsequently determine the plant stand establishment which is an important yield component in barley and which varies with variety (Mackenzie *et al.,* 2005). However, in similar studies, no genotypic differences were observed for plant stand establishment (Aynewa *et al.*, 2013). This contrast may indicate a weak relationship between genotype and plant stand establishment.

The number of fertile tillers per plant is influenced by the plant stand establishment and the genetics of the variety as well as by environmental factors. Differences of up to 20% in fertile tiller numbers per plant have been observed (Tambussi *et al.*, 2005). However, other studies show that environment has a lower influence on barley tillering and that genetics has more influence due to its low variability across different environments (Tamm, 2003). O'Donovan *et al.,* (2011) did not find cultivar differences with respect to barley tillering, indicating a weak relationship between genotype and number of productive tillers per plant.

Genotypic differences in the number of grains per spike are associated with its relatively higher heritability of 98% when compared to other yield components (Rao *et al.*, 2012). Genetic effect on grain size was found to be greater than environmental effect even when experimental sites suffered terminal moisture stress, with retention (on 2.5 mm screen) value of 88 to 96% (Glen *et al.,* 2006). Similar studies also found a very high heritability value for 1000 kernel weight of 99.9% (Nanak, *et al.,* 2008) per plant.

Large differences in grain yield between varieties have been observed by many studies but the yield stability across different weather conditions was high (Tamm 2003). However, other studies found highly significant differences among genotypes, environment and genotype by environment interaction, although the ranking across environments was not consistent, showing varying stability among genotypes with respect to grain yield (O'Donovan *et al.*, 2011). This large differences could be associated with the relatively high heritability of 96 % (Rao *et al.,* 2012), although other studies show a lower heritability of 52.4% for grain yield, but with a high correlation between grain yield and productive tillers per plant and number of kernels per spike. Newer barley varieties are higher yielders than old ones (Bulman *et al.,* 1993).

Differences in barley yield and quality components could be associated with different capacities of genotypes to adapt to different environments e.g. moisture stress and soil fertility (Glen *et al.,* 2006; Aynewa *et al.,* 2013). More fertile tillers per plant and number of kernels per spike are major contributors to yield in barley varieties, since they show higher contribution (36.38%) to variability than all other agronomic yield components (Jalal and Ahmad, 2012).

These studies show that the agronomic traits of plant establishment, productive tillers, and grains per spike can be used as criteria for selecting barley varieties suitable for different environments. However, productive tillers per plant, number of kernels per spike and 1000 kernel weight would be more useful criteria for selecting evolving high yield barley genotypes due to their high heritability values and direct effect on grain yield (Sukram *et al.*, 2010; Kavitha *et al.,* 2009).

It is documented that barley grain protein content is genetically controlled but easily affected by the environmental conditions (Jung-Cang, 2005). Other studies have confirmed this, but found that genetic control was much greater than environmental control (Junmei *et al.,* 2003; Shengguan *et al.,* 2013). It is estimated that the influence of genotype on grain protein content is about 70% (Bleidere, 2008). However, there was no significant difference in grain protein content between two and six – rowed barley varieties, (Weltch, 2006). The grain protein content decreases in newer varieties of malting barley due to increase in structural carbohydrates and not the decrease of crude protein per see (Bulman *et al.,* 1993). Stability in grain protein content across locations is varied with genotype, but variability is low (Bentayehu, 2013; Krizanova *et al.,* 2010 & Jun-Cang *et. al.,* 2005). The grain protein content shows a close relationship with other malt quality parameters indicating the need to select varieties with stable grain protein content (Shengguan *et. al.,* 2013).

2.4 Relationship between seed rate and barley yield and quality components

Many studies have indicated 200 seeds m^{-2} as the optimum seed rate for malt barley (Mackenzie *et al.,* 2005). Increasing this rate tends to reduce grain protein content, kernel size, proportion of maltable grain and number of productive tillers per plant (Mackenzie *et. al.,* 2005; O'Donovan *et al.,* 2012). In studies with seed rates of 100-500 seeds m^{-2} on one malt barley variety, 300 seeds m^{-2} were found optimum since it maintained or improved yield, decreased grain protein content, decreased tillering and increased kernel uniformity (O'Donovan *et al.,* 2012). However this was only true when climatic and soil conditions were favourable. In environments with lower pH., much lower rates were more optimal (O'Donovan *et al.,* 2012). Similar studies report 136-176 seeds m^{-2} in Saskatchewan as optimal (Mackenzie *et al.,* 2005).

In Kenya a blanket recommendation of 200 seeds m^{-2} is used (EPZA, 2005). Empirical information indicates that some farmers tend to deliberately lower seed rates to attain larger size, whereas others increase seed rates to attain lower grain protein content (Mumbi, 2011, personal communication). This large variation in seed rates across regions, suggests the need for determination of seed rates specific to conditions and regions if the proportion of malt grade barley will be increased.

Specifically, many studies report difficulty in relating seed rates to plant density, an important malt barley yield component. However these studies have reported a variation in plant stand establishment at different sites and in different years (Mackenzie *et al.,* 2005; O'Donovan *et al.,* 2012). The factors that are thought to create this variation are, site altitude, soil pH., and site latitude (O'Donovan *et al.,* 2011) but in all cases, plant stand establishment increases with seed rates as expected. However, at lower seed rates a higher proportion (68%) of barley seeds established as opposed to only (58%) at higher seed rates (O'Donovan *et al.*, 2011). Studies also show that 70% of barley seeds produced a plant in western Canada (O'Donovan *et al.,* 2012); almost similar to 68% in southern Alberta (Mackenzie *et al.,* 2005). Agronomic practices that will improve plant stand establishment will improve malt barley yield and quality, since it has direct influence on other yield and quality components.

The number of tillers per plant, for example is influenced by the plant stand establishment, the genetics of the specific cultivar and the environment (Tamm 2003). At varying seed rates, thin stands and favourable conditions result in more tillers. Generally, decrease in tillering with increasing seed rates has been documented (O'Donovan *et al.,* 2012, Mackenzie *et al.,* 2005; Tamm 2003). The decrease is greater below the optimum seed rates. The reduced number of tillers at higher seed rates is thought to be advantageous in attaining uniform (plump) grain; an important malting quality. However, the tillering capacity remains stable across weather, showing more influence of genetics than the environment (Tamm 2003). These findings suggest that seed rates based on the number of tillers is more assuring since variation is more genetic than environmental.

The number of grains per spike decreases with seed rates in some environments (Mackenzie *et al.,* 2005). However, the seed rate by cultivar interaction was found to be more important in determining the number of grains per spike. While some cultivars had more grains per spike at higher seed rates, other cultivars showed a reduction (Kazimierz 2010).

Barley yield increases with seed rates to an optimum and then levels off before declining suggesting a risk of loss of yield with increasing seed rates above the optimum (O'Donovan *et al.,* 2012, Mackenzie *et al.,* 2005). This decline is linked to competition for light than for water (O'Donovan *et al.,* 2012). Studies in maize under irrigation showed reduced biomass with increasing seed rates confirming that the reduction in yield was due to competition for light than for water. However, Tamm (2003), found differences in malt barley grain yields with increasing seed rates. This increase is associated with increase in the number of ears per plant in all cultivars. These contradicting findings between similar studies suggest a weak relationship between seed rates and grain yield in malt barley.

The desired kernel size for malting barley in is a minimum of 90% of the grain attaining 2.3 mm (McClelland *et al.,* 2009; Akar *et al.,* 2004). Kernel size varies significantly with seed rates. Increasing seed rates reduces percentage plump grain (retained above a 2.3 mm screen). However reduction in kernel size is smaller in cultivars with inherently large grains. Kernels at seed rates lower than the optimum are larger in size but they are less uniform (O'Donovan *et al.,* 2012. The uniformity increases towards the optimum seed rate with little or no changes at seed rates higher than the optimum (O'Donovan *et al.*, 2012; Mackenzie et al., 2005). Kernel size uniformity is an important requirement for uniform germination during the steeping process and hence higher conversion rate from grain to malt.

The proportion of maltable grain variously referred to as plump grain or kernel weight, is the permissible amount of grain size and uniformity per unit weight of harvested malt barley. It is determined by sieving a unit weight of harvest less any dockage and weighing the grain retained on a 2.3 by 19.5mm sieve (Mackenzie *et al,* 2005, O'Donovan *et al.*, 2012). This proportion shows a negative linear relationship with seed rate, with larger decreases at lower than the optimal seed rate. At seed rates higher than the optimum, there is no advantage in the decrease in the proportion of maltable grain (O'Donovan *et al.*, 2012). However, in most studies, this proportion is often more than the lower limit. In western Canada, the lower limit is $800mgg^{-1}$, in Britain it is $940mgg^{-1}$ whereas in southern Alberta it is $900mgg^{-1}$ similar to the Kenyan malt barley industry (Brophy, 2010; Mackenzie *et al.*, 2005; EPZA, 2005).

Grain protein content in malt barley is important because it is a major component of beta – amylase activity. Beta – amylase activity is the efficiency of the grain enzymes to convert starch into simple sugars (Jankovic *et al.*, 2011; China papers, 2010). Lower grain protein content is preferred in malt barley because it results in better endosperm modification and more uniform kernels (O'Donovan *et al.*, 2011). The desired protein content in malting barley should be greater than 9.0 but less than 11.5% in two-row barley, which is the most common barley cultivar for malting (Chapman and Carter, 1978; Akar *et al.*, 2004). However, the optimum grain protein content for European beer is 10.07 % (Jankovic *et al.*, 2011). In western Canada malt barley should have grain protein content of 12.5%, but 10.5 – 13 % is acceptable for six-row barley (Brophy, 2010).

In Kenya, all malt barley is two-rowed and the acceptable range for grain protein content is 10.625 – 13.75 % or 1.7 to 2.2 % total nitrogen using the infrared reflectance spectrometer method of determination (Sterling Investment Bank, 2011).

Seed rates significantly affect grain protein content in malting barley grain (Mackenzie *et al.,* 2005). Higher seed rates reduce grain protein content with an average decline of 4 mg g^{-1} from the highest seed rate to the lowest (MacKenzie *et al.,* 2005). Grain protein content is more pronounced at seed rates lower than the optimum above which the decline is negligible. There is a reverse relationship between lower grain protein content with other malt qualities of kernel size and kernel weight but these are mitigated by the more uniform kernels at higher seed rates (O'Donovan *et al.,* 2011). However, the decrease in grain protein content at higher seed rates is likely to have less impact on malt quality than the change in kernel size and plumpness (Mackenzie *et al.,* 2005). Other studies have reported lower standard deviation for kernel weight at higher seed rates suggesting greater uniformity (O'Donovan *et al.,* 2011).

Lower seed rates produce larger grains but these are of low uniformity due to greater tillering. Higher seed rates lower grain protein content to more preferred levels and can therefore increase the proportion of malt grade barley produced by farmers, in spite of the reduction in kernel size and plumpness (O'Donovan *et al.,* 2011).

2.5 Effect of nitrogen fertilizer rate on barley yield and quality components

Nitrogen fertilizer strategies for malting barley should ensure relatively small amounts of available N at sowing for crop establishment and initial tiller development. Additional N should then be applied at the end of tillering (Baethgen *et al.,* 1995).

Nitrogen fertilizer application rate has an overall effect of decreasing plant density, because it is banded together with seed at sowing time (O'Donovan *et al.,* 2011). This rare effect was associated with variable organic matter or soil moisture during or after sowing, or the ability to consistently maintain adequate separation between seed and fertilizer (O'Donovan *et al.,* 2011). However the effect of decreased plant density on yield was minimal.

Productive tillers per plant are the main determinant of yield as nitrogen application rates increase (Moreno *et al.,* 2003). Most studies have established that the number of productive tillers per plant increase with increasing N- fertilization, irrespective of cultivar (Alam *et al.,* 2007; Singh & Singh, 2005).

Spike length increases with N addition and subsequently the number of grains per spike also increases. However, both spike length and number of grains spike^{-1}, are cultivar specific (Alam *et al.,* 2007; Singh & Singh, 2005). Grain yield is lowest at no N-application and the value at this level is significantly lower when compared to the values with N-application (Jankovic *et al.,* 2011). N-addition increases yield but Jankovic *et al.,* (2011) reported no significance beyond the initial application. Similar results were found by other studies (Mackenzie *et al.,* 2004). All cultivars increase yield with addition of N but modern cultivars respond more strongly. This is associated with increased productive tillers plant^{-1} and grains spike $^{-1}$ (Gabriela *et al.,* 2003), however, for some cultivars there is a decline in grain yield above the optimum N-application (Gabriela *et al.,* 2003).

Proportion of maltable grain and kernel uniformity decreases with N-rates, but in favourable rainfall and temperature, increasing N-application increases yield and other yield components while maintaining the proportion of maltable grain (kernel weight) (Gonzalez *et al.,* 1993). Most studies have indicated that 1000-kernel weight increases with N-application (Alam *et al.,* 2007; Singh & Singh, 2005).

Grain protein content is affected by N-fertilizer application, cultivar and the interaction between cultivar and N-rate (China papers, 2010). Although, the concentration difference among cultivars is modest, that of N-rate increases over the full range of available nitrogen (MacKenzie, *et al.,* 2005). The grain protein content difference due to cultivar is clearer at higher N-rate applications. Protein content and grain yield will increase with increased nitrogen application (Jankovic *et al.,* 2011) however, protein content increases at a lower rate; for example where nitrogen application doubles the grain yield, protein content increases by 1-2 percent (McClelland *et al.,* 2009).

N-rate has a direct impact on malting barley quality since it increases grain protein content (O'Donovan *et al.,* 2011). Breeders have manipulated genes to get high N-tolerance without increasing grain protein content out of acceptable limits. In areas of long growing season (enough moisture) the need for high grain yield resulting from increased N-rate can be balanced by split application of N; limit N at sowing with additional application after tillering (Baethgen *et al.,* 1995). But other studies have found higher grain protein content with more than one split (Singh & Singh, 2005).

Increasing grain protein content with increasing N-rate limits endosperm modification and reduces malt extract levels (Edney *et al.,* 2012). Cultivar by N-rate interaction exists where some cultivars show better modification with increasing N-rate (Edney *et al.,* 2012).

It was concluded that the negative effect of N-rate on malting quality can be reduced through cultivars with improved ability to modify protein during malting (Edney *et al.,* 2012). Modern malting barley cultivars have not shown significant increase in N use efficiency most likely due to consistent selection for low – protein cultivars (Muurinen *et al.,* 2005).

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 (MacKenzie *et al.,* 2005). However, this rate may range from 0 kg ha $^{-1}$ in sites with greater than 30 ppm $NO_{3-}N$ in soil to 96 kg ha^{-1} in soils with 0-6 ppm $NO_{3-}N$ (Davis & Westfall, 2009).

All sources of N-fertilizer are equally effective for small grains per unit of N if properly applied. Therefore, choice of N-source is determined by availability rather than type. Furthermore, dual application of ammonia-N fertilizer with P – fertilizers in a band improves efficiency of P uptake by the crops (Davis and Westfall, 2009).

In Kenya, a blanket N- rate of 40.25 kg ha^{-1} is recommended for all barley growing areas with NPK 23:23:0 as the preferred source. There is need to determine available soil N and applying the difference as additional nitrogen. Although the source of N is not important, control of independent rates of N and P is lost in the choice of a compound fertilizer like NPK.

New malting barley varieties produce more enzymes, but this means they tend to have the potential for protein levels that are too high (> 12.5%), (McClelland *et al.*, 2009). This raises the need for soil testing to supply just enough nitrogen for this advantage of powerful enzymes in potential malting varieties to be useful.

In summary, studies indicate that, selecting low-protein cultivars, seed these at high seed rates and limiting N- application lowers the risk of barley rejection by maltisters (O'Donovan *et al.*, 2011).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental sites

Two sites, Mau Narok and University of Eldoret farm were used to set up the experiments.

3.3.1 The University of Eldoret farm

University of Eldoret farm is situated 10 km North of Eldoret Town. The farm is within the Uasin Gishu plateau which is in the lower highlands (LH_3) agro-ecological zone. The site is located at Latitude 0^0 30’ N and Longitude 35^0 15’ E; at an elevation of 2180 m above sea level which is a medium altitude for barley growing. The site is characterized by a mean temperature of 23^0 C and a relative humidity range of 45 to 55% (Jaetzold and Schmidt, 1982). An average annual rainfall of 900 – 1100 mm per annum has been recorded for this site. These rains are bimodal with the long rains starting in the month of March and the second rains normally, starting in the months of May and. However the barley growing season starts in the month of May.

The soils are shallow, well drained non-humic cambisols and are characterized by low fertility and underlying murram (Jaetzold and Schmidt, 1982).

3.1.2 Mau Narok

The Mau Narok site is located 70 km south of Nakuru town at latitude 0^0 20’S and longitude 35^0 35’E. Its elevation is 2829 m above sea level which is a high altitude for barley growing (Jaetzold and Schmidt, 1982). The area is in the agro eco- zone upper highland (UH_3) and lies along the Mau escarpment with very cool (11 to 13.5^0 C) temperatures throughout the year (Jaetzold and Schmidt, 1982; Newton *et al.,* 2011).

The average annual precipitation of this site is 1200-1400 mm p.a. with the onset of the first rains in the month of March. Barley is normally planted in this region in the month of August to be ready for harvest in the drier months of January and February. The soils are well drained, deep and have high fertility. They are however very sensitive to erosion and show deficiencies of copper (Jaetzold and Schmidt, 1982).

3.2 Materials

Materials used in this experiment were potential barley varieties and fertilizer sources of nitrogen and phosphorus.

3.2.1 Barley varieties

Three, two-row, varieties designated V1, V2, and V3 were evaluated in this experiment.

i) V_1-HKBL-1512-5. This potential variety is characterized by large kernels when compared to the standard commercial variety, Nguzo. It has a potential yield of 8 t ha^{-1} under research.

ii) V_2- Nguzo – a commercial variety in cultivation with a yield potential of 6 tonnes ha^{-1}. This was used as a standard check.

iii) V_3 - HKBL 1385- 13 is a potential variety of intermediate kernel size in comparison with Nguzo and HKBL-1512-5. It has a potential yield of 8 t ha^{-1} under research.

Both HKBL-1215-5 and HKBL-1385 – 13 are potential varieties for release to farmers due to their high malting quality, yield, diseases resistance and nitrogen use efficiency. Their potential was evaluated with respect to nitrogen fertilizer rate and plant population density in comparison to Nguzo to determine appropriate N-rate and seed density at the two experimental sites. Planting seed for the three varieties was sourced from East African Malting Limited (EAML).

3.2.2 Fertilizers

NPK 23:23:0 was used as the basic source of both nitrogen and phosphorus. Calcium ammonium nitrate (CAN) – 26:0:0 was used to supply additional nitrogen whereas triple super phosphate (TSP) – 0:45:0 was used for additional phosphorus. In Kenya, a blanket N- rate of 40.25 kg ha^{-1} is recommended for all barley growing areas with NPK 23:23:0 as the preferred source.

3.3 Methodology

3.3.1 Soil testing

Prior to establishing the experiments, soil testing was done to establish its status with respect to nitrogen, phosphorus and pH. Random cores to a depth of 30 cm were obtained from each of the two experimental sites. Cores from each site were combined to provide composite samples. All samples were air dried and ground to pass through a 2 mm sieve. All the soil samples were analyzed for soil NO_3-N using the Laboratory methods of soil and plant analysis in the working manual (Okalebo *et al.,* 2002).

Soil Nitrogen concentration above 0.25 % is rated as high (Okalebo *et al.,* 2002). The soil test results (Appendix I) therefore indicate that nitrogen concentration at the Mau Narok site was high at 1.01 % and 1.16 % in the 0 -15 cm and 15 -30 cm core depths respectively. However, the soils at the University of Eldoret farm showed moderate levels of total Nitrogen at 0.13 % in both top and sub soil (Okalebo *et al.,* 2002)..

Organic carbon concentration, at 1.93 % in top soil and 1.92 % in sub soil at the University of Eldoret farm; and 2.14 % and 2.42 % in top and sub soil respectively at Mau Narok, was moderate at both sites since it was below 3.0 % that would be rated as high (Okalebo *et al.,* 2002).

Phosphorus concentration in the Mau Narok site was high in both the top soil (18.75 ppm) and sub soil (15.46 ppm) since crop response to phosphate fertilizers has been observed in soils where P test levels are below 10 ppm, when routine Olsen extracts are used (Okalebo *et al.,* 2002). However, at the University of Eldoret farm the phosphorus concentration was low at both depths; top soil (8.62 ppm) and sub soil (7.99 ppm).

Soil pH test results (Appendix I) show strong acidity at Mau Narok in both top soil (5.4) and sub soil (5.3), whereas the soils at the University of Eldoret farm show very strong acidity in both top soil (4.75) and, sub soil (4.7) (Panda, 2005).

This soil test results were used to calculate the additional phosphorus and nitrogen to be supplied by mineral fertilizers

3.3.2 Rainfall monitoring at the experimental Sites

Rainfall at the two sites was monitored from sowing to harvesting (Appendix II). This was used to give an indication of the amount of rainfall and its distribution during the growth phase of the barley crop. Other than nitrogen, moisture is the next most important limiting growth factor for malting barley (Mackenzie *et al.,* 2005).

The rainfall figures at the two sites (Appendix II) show that while the amount at the University of Eldoret farm site (719.4 mm) exceeded the 635 mm required for barley growth (EPZA, 2005) by 13.3 %, the amount at the Mau Narok site (444 mm), fell below the required amount by 30.1 %.

The annual minimum temperatures at Mau Narok (11.7^{o}C) and the University of Eldoret farm (10.3^{o} C) were lower than the lower optimum temperature (15^{o}C) required for barley. However the annual maximum temperatures at Mau Narok (25.6^{o}C) and the University of Eldoret farm (23.3^{o}C) were within the optimum temperature (30 ^{o}C) for barley (Chapman and Carter, 1978). The annual maximum temperature at the University of Eldoret farm (23.3^{o}C) was comparable to long term maximum temperature (23^{o} C) whereas the temperature at the Mau Narok site (25.6 ^{o} C) was way above the long term average of 15 ^{o} C (Jaetzold and Schmidt, 1982). Therefore, the temperatures at University of Eldoret farm were cooler than those at the Mau Narok site during the period of the experiment, but both were suitable for barley growing.

3.3.3 Plant population

Three seed rates of 150, 200 and 250 viable seeds m^{-2} were used, based on measured 1000- kernel weights, pure germinating seed percentage and an assumption of 5% seedling mortality (Mackenzie *et al.*, 2005). On the basis of these parameters the seed rates were calculated using the formula;

$$Seed\ rate = \frac{Thousand\ grain\ weight(g) * Target\ plant\ density(plant\ m-2)}{Expected\ establishment(\%) * Germination(\%)}$$

Equation 1

It is known that seed test weight is variety specific in malting barley (McClelland *et al.*, 2009) and this factor was incorporated in the calculation of the seed rates. 1000-kernel weight was determined for each variety by counting and weighing 100 kernels of pure seed in eight replicates (ISTA Rules, 1996).The means were multiplied by 10 to get the 1000- kernel weight for the three test varieties thus; HKBL 1512-5 (57.9 g), HKBL 1385-13 (52.9 g) and Nguzo (40.4 g) (Appendix 3). A coefficient of variation that is less than 4% is within the tolerance limits for 1000-kernel weight determination (ISTA, 1996). However these test weights were not fixed for respective varieties and varied with seed lot.

The pure germinating seed percentage (PGS) was determined in accordance with ISTA (1996) guidelines. On the basis of the this test, all the three test varieties, HKBL 1512-5 (95%), HKBL 1385-13 (87%) and Nguzo (87 %) (Appendix IV), were within the acceptable PGS for barley seed (85 %), (ISTA, 1996).

3.3.4 Site preparation and sowing

The sites were cultivated twice with a cultivator and harrowed just before seed to attain a seedbed of fine tilth suitable for the small-grain barley kernels. Eight rows with inter row spacing of 20 cm were planted in each experimental unit measuring 3 x 1.6 m. The Mau Narok site was seeded in the month of August (18 – 08 - 2011) which is the main season for commercial barley growing in the Mau Escarpment. The University of Eldoret farm site was planted in the month of May (28 – 05 - 2012) to coincide with the main season for planting barley in the Moiben barley growing zone. Sowing was done by manually drilling the seed in opened furrows. The four N fertilizer rates, (0, 30, 40 and 50 kg ha^{-1}), were manually banded together with the seed as done by farmers. The crop was conventionally managed to exclude weeds, pests and diseases.

3.4 Experimental Design

Table 3.1: Treatment table

Treatment	**Level 1**	**Level 2**	**Level 3**	**Level 4**
N rates (kg ha $^{-1}$)	0 (N0)	30 (N1)	40 (N2)	50 (N3)
Varieties	HKBL 1512-5 (V1)	NGUZO (V2)	HKB1385-13 (V3)	-
Seed rates (seeds m^{-2})	150 (D1)	200 (D2)	250 (D3)	-

The treatment levels (Table 3.1) were combined in a 4 * 3 * 3 split – split factorial arrangement in a completely randomized block design (RCBD). Varieties were in the main plots, seed rates in split-plots and nitrogen rates in the split split-plots (Table 3.2 and Appendix V). The varieties were pre-determined and therefore the effect of seed rate and nitrogen fertilizer on their yield and malting qualities was more critical, hence the placement of seed rates in the sub plot. However, between seed rates and nitrogen, the effect of nitrogen was considered more critical due to its likely high effect on grain protein content. There was, therefore, need for higher precision in measuring the effect of nitrogen, hence its placement in the sub sub-plot (Gomez and Gomez, 1976).

Table 3.2: Split split-plot factorial arrangement of treatments showing one main plot

VARIETY	SEED RATE 1	N3	N1	N0	N2
	SEED RATE 2	N0	N2	N1	N3
	SEED RATE 3	N2	N3	N1	N0

3.5 Data collection

The following parameters were recorded for analysis;

3.5.1 Plant stand (Plants m^{-2})

Plant Stand was determined by counting established seedlings in two 1 m length rows per experimental unit, 30 days after sowing and just before onset of tillering (Mackenzie *et al.,* 2005). This count was used to compute the number of plants established per square metre.

3.5.2 Number of productive tillers per plant

The number of productive tillers per plant was determined by counting tillers with spikes on a sample of 12 plants/hills randomly selected along the diagonal of each experimental unit. The mean was computed to give number of productive tillers per plant (Gomez and Gomez, 1976).

3.5.3 Spike length (cm) and number of grains spike^{-1}

The 12 plants used to determine number of productive tillers, were used to measure the length of the spike from the base of the lowest to the tip of the highest kernel, but excluding the awn. The number of filled grains was then counted and recorded.

3.5.4 Grain yield (Tones ha^{-1})

Whole plots were harvested when the crop appeared to be completely dry. The harvesting was done by cutting the stems above the ground using sickles and drying them further in the sun for ease of threshing. The dried grains were threshed by hand, winnowed and the moisture content measured (FAO, 2003). The final grain yield was determined by correcting the moisture content to 13% (FAO, 2003).

3.5.5 1,000 Kernel weight (g)

Ten random samples of 100 kernels each were weighed to determine the 1000-kernel weight of the Maltable barley. The ISTA (1996) protocol was followed in this procedure

3.5.6 Maltable grain (Grain sizing) g kg $^{-1}$

Maltable grain or grain sizing was determined by dividing the weight of grains retained on a 2.2 by 20 mm screen by one kilogram sample of grain for each treatment. The sizing was done using a mechanical shaker which was run for five minutes for every sample kilogram (Mackenzie *et al.*, 2005).

3.5.7 Grain Protein content (%)

The grain nitrogen concentration in maltable barley was determined by the infrared method. In this study, grain protein content is reported as grain – N content using a conversion factor of 6.25% crude protein to 1% N.

3.6 Data analysis

The data collected was subjected to analysis of variance (ANOVA) using SAS procedure whereas mean separations were done using Least Significant Differences (LSD (α=*0.05)).*

3.7 Statistical model

A generalized linear model shown below was assumed for this study when analyzing data from individual sites. The three factor model for each individual site was;

$Y_{ijkl} = \mu + P_i + V_j + \alpha_{ij} + D_k + VD_{jk} + \beta_{ijk} + N_l + NV_{jl} + ND_{jk} + NVD_{ikl} + \lambda_{ijkl}$

Where – Y_{ijkl} – total variation in yield

μ - overall mean yield

P_i – is main plot effect

V_j – is variety effect

α_{ij} – main plot error

D_k – plant density effect

VD_{jk} – Variety * Density interaction

β_{ijk} – split plot error

N_l – Nitrogen effect

NV_{jl} – Nitrogen * Variety interaction

ND_{jk} – Nitrogen * Density interaction

NVD_{ikl} – Nitrogen * Density * Interaction

λ_{ijkl} – split split- plot error

3.8 ANOVA Skeleton

Table 3.3: ANOVA Table of Treatment and Degrees of freedom

Sources of Variation	Degrees of Freedom (df)
Blocks (r) r-l	3-1 = 2
Variety (v) v-l	3-1 = 2
Error (a) (r-l) (v-l)	2*2 = 4
Seed rate (d) d-l	3-1 = 2
Seed rate * Variety (d-l) (v-l)	2*2 = 4
Error (b) v(r-l) (d-l)	3*2*2 = 12
Nitrogen (n) (n-l)	4-1 = 3
Nitrogen * Variety (n-1) (v-1)	3*2 = 6
Nitrogen * seed rate (n-1) (d-1)	3*2 = 6
Nitrogen * Variety* seed rate (n-1)(v-1)(d-1)	3*2*2 = 12
Error (c) vd (r-1) (n-1)	3*3*6 = 54
Total rvdn -1	(3*3*3*4) -1 = 107

CHAPTER FOUR

RESULTS

4.1 Comparison of yield and malt quality components among barley varieties

4.1.1 Yield components

There were significant varietal differences ($P < 0.05$) for plant stand establishment at the Mau Narok site. HKBL 1512-5 (180), the variety with highest plant stand establishment at Mau Narok had a higher plant stand establishment than the control, Nguzo (147) and test HKBL1385-13 (140) respectively. However, HKBL1385-13 (140) had comparable plant stand establishment with the control, Nguzo (147) (Table 4.1, Appendices VIA and VIIA).

At the University of Eldoret farm, HKBL 1512-5 (173) had significantly lower plant stand establishment than the control, Nguzo (203) and HKBL1385-13 (192), but HKBL1385-13 (192) had comparable plant stand establishment with the control, Nguzo (203) (Table 4.1 and Appendices VIB and VIIIA).

There were no varietal differences observed for productive tillers per plant at the Mau Narok site (table 4.1 and Appendices VIA and VIIB). However, at the UoE farm varieties differed ($P<0.05$) on productive tillers per plant. HKBL 1385-13 (5.8) produced more tillers per plant than the control, Nguzo (2.9) and HKBL 1512-5 (2.7). HKBL 1385-13(2.7) produced comparable number of productive tillers per plant to the Nguzo (2.9), at this site (Table 4.1, Appendices VIB and VIIIB).

Spike lengths differed significantly ($P < 0.05$) across variety at both sites. Both HKBL 1512-5 (6.8cm) and HKBL 1385- 13 (8.6 cm) produced shorter spikes than Nguzo (8.8 cm) at the Mau Narok site (Table 4.1 and Appendices VIA and VIIC). At the UoE site, HKBL 1512-5 (6.3 cm) produced shorter spikes than Nguzo (8.6 cm).

However, at this site, HKBL 1385-13 (8.7 cm) produced comparable spike lengths to Nguzo (8.7 cm) (Table 4.1 and Appendices VIB and VIIIC).

Table 4.1: Comparison of yield components for different barley varieties

Variety	Plant stand (plant m^{-2})	Tillers $plant^{-1}$	S/length (cm)	Grains $spike^{-1}$	1000 kernel wt. (g)	Grain yield t ha^{-1}
			Mau Narok			
HKBL 1512-5	180 a	4.9 a	6.8 c	25.7 b	52.5 a	4.0 c
NGUZO	147 b	6.6 b	8.8 a	29.3 a	47.6 c	4.4 b
HKBL 1385-13	140 b	6.2 b	8.6 b	29.1 a	49.0 b	4.9 a
MEAN	156	5.9	8.1	28.1	49.7	4.4
LSD(0.05)	9	0.6	0.19	0.48	0.86	0.28
CV (%)	11.7	21.7	4.9	3.6	3.6	13.2
			University of Eldoret farm			
HKBL 1512-5	173 b	2.7 b	6.3 b	24.8 b	49.9 a	3.8 b
NGUZO	203 a	2.9 b	8.6 a	28.9 a	41.8 b	3.7 b
HKBL1385-13	192 a	5.8 a	8.7 a	28.8 a	49.8 a	5.1 a
MEAN	189	3.8	7.9	27.5	47.2	4.2
LSD(0.05)	11	0.5	0.15	0.15	0.59	0.22
CV (%)	12	27.6	4.1	3.8	2.6	11.1

Values in columns followed by same letters are not significantly different from each other

Varietal differences *(P < 0.05)* were observed in the number of grains per spike at each of the sites. HKBL 1512-5 (25.7) produced fewer grains per spike than Nguzo (29.3) whereas, HKBL1385 -13 (29.1) was comparable to the control variety Nguzo (29.3) at the Mau Narok site (Table 4.1 and Appendices VIA and VIID).

At the UoE site, HKBL 1512-5 (24.8) produced fewer grains per spike than both Nguzo (28.9) and HKBL 1385-13 (28.8). However, HKBL 1385-13 (28.8) had similar number of grains per spike with Nguzo (28.9) (Table 4.1 and Appendices VIB and VIIID).

1000 kernel weight differed significantly ($P<0.05$) among varieties at both sites. At the Mau Narok site, both HKBL 1512-5 (52.5g.) and HKBL 1385-13 (49.0 g.) had heavier kernels than both Nguzo (47.6g), however HKBL 1512-5 (52.5g.) produced significantly heavier kernels than HKBL 1385-13 (49.0g) (Table 4.1 and Appendices VIA and VIIF).

At the UoE, site, HKBL 1512-5(49.9g) produced heavier kernels than Nguzo (41.8g), but was similar to HKBL 1385-13 (49.8g). Likewise HKBL 1385-13 (49.7g) had heavier kernels than Nguzo (41.8g) (Table 4.1 and Appendices VB and VIIIF)

Grain yield differed significantly ($P < 0.05$) among the varieties at both sites. HKBL 1512-5 (4.0 t ha^{-1}) had lower grain yield when compared to Nguzo (4.4 t ha^{-1}). However, HKBL 1385-13 (4.9 t ha^{-1}) produced higher grain yield than both Nguzo (4.4) and HKBL1512 -5 (4.0) at the Mau Narok site (Table 4.1 and Appendices VIA and VIIE).

At the UoE site, HKBL 1512-5 (3.8 t ha^{-1}), produced similar grain yield with Nguzo (3.7 t ha^{-1}). HKBL 1385-13 (5.1 t ha^{-1}), produced higher grain yield than both, Nguzo (3.7 t ha^{-1}) and HKBL 1512-5 (3.8 t ha^{-1}) (Table 4.1 and Appendices VIB and VIIIE).

4.1.2 Quality components

Varietal differences were significant ($P < 0.05$) for maltable grain at both sites. At the Mau Narok site, HKBL 1512-5 (980.2 g kg^{-1}) produced a higher maltable grain than, both Nguzo (962.2 g kg^{-1}) and HKBL 1385-13 (964.8 g kg^{-1}). However, HKBL 1385-13 (964.8 g kg^{-1}) produced similar maltable grain to Nguzo (962.2 g kg^{-1}) (Table 4.2 and Appendices VIA and VIIG). At the UoE, site, both HKBL 1512-5 (981.7 g kg^{-1}) and HKBL 1385-13 (987.6 g kg^{-1}) produced higher maltable grain than Nguzo (875.5 g kg^{-1}). However, the two varieties HKBL 1512-5 (981.7 g kg^{-1}) and HKBL 1385-13 (987.6 g kg^{-1}) produced similar amounts of maltable grain (Table 4.2 and Appendices VB and VIIIG).

Grain nitrogen content was significantly ($p<0.05$) different in varieties at both sites. At the Mau Narok site, both HKBL 1512-5 (2.33 %) and HKBL 1385-13 (2.21 %) accumulated more nitrogen in the grain than Nguzo (2.080 %). However, amongst the two HKBL 1512-5 (2.33 %) accumulated higher grain nitrogen content than HKBL 1385-13 (2.21 %), (Table 4.1.8). But these two, HKBL 1512-5 (2.33 %) and HKBL 1385-13 (2.21 %) accumulated more nitrogen in the grain than the acceptable upper limit of 2.2% for malt barley in Kenya (Table 4.2 and Appendices VIA, VIIH and X). At the UoE site, HKBL 1512-5(1.97%) had similar grain nitrogen content with Nguzo (1.91%), but significantly higher content than HKBL 1385-13 (1.87 %). At this site, all varieties accumulated grain nitrogen content within the acceptable malting range of 1.7 – 2.2 % (Table 4.2 and Appendices VIB, VIIIH and X).

Table 4.2: Comparison of malting quality components among different barley varieties

Variety	Maltable grain g kg^{-1}	Grain nitrogen content (%)
	Mau Narok	
HKBL 1512-5	980.2 a	2.33 a
NGUZO	962.9 b	2.08 c
HKBL 1385-13	964.8 b	2.21 b
MEAN	**969.3**	**2.21**
LSD(0.05)	3.69	0.043
CV (%)	0.8	3.1
	University of Eldoret farm	
HKBL 1512-5	981.7 a	1.97 a
NGUZO	875.5 b	1.91 ab
HKBL 1385-13	987.6 a	1.87 b
MEAN	**948.3**	**1.92**
LSD (0.05)	8.9	0.07
CV (%)	2.0	3.9

Values in columns followed by same letters are not significantly different from each other

4.2 Comparison of yield and quality components of malting barley at different seed rates

4.2.1 Yield components

Plant stand establishment was significantly (*P<0.05*) different for different seed rates at either of the sites. At the Mau Narok site, 150 viable seeds m^{-2} produced lower plant stand establishment (125 plants m^{-2}) than seed rates, 200 and 250 viable seeds m^{-2} which produced a plant stand establishment of 152 and 190 plants m^{-2} respectively (Table 4.3 and Appendices VIA and VIIA).

At the UoE, the three seed rates (150,200 and 250 seed m^{-2}), produced increasing different plant stand establishments of 147,196 and 224 plants m^{-2} respectively (Table 4.3 and Appendices VIB and VIIIB).

Productive tillers per plant also differed significantly (*P< 0. 05*) for different seed rates at both sites. Increasing seed rate from 150 to 250 viable seeds m^{-2} reduced the number of productive tillers per plant at the same rate at both sites; 7 to 5 at Mau Narok and 5 to 3 at the UoE (Table 4.3 and Appendices VIA, VIB, VIIB and VIIIB).

Spike lengths for all varieties were significantly different (*P< 0. 05*) at different seed rates at the Mau Narok site. 150 viable seeds m^{-2} produced longer spikes (8.2 cm) than 200 viable seed m^{-2} (8.0 cm). However, 250 viable seeds m^{-2} produced spikes of similar length (8.0 cm) with 200 seeds m^{-2} (8.0 cm) (Table 4.3 and Appendices VIA and VIIC). At the UoE site spike lengths were not different (Table 4.3 and Appendices VIB and VIIIC).

Increasing seed rate generally, reduced the spike length at both sites (Table 4.3). Number of grains per spike was significantly (*P<0.05*) different for all seed rates at both sites At the Mau Narok site, 150 viable seeds m^{-2} produced a similar number of grains per spike (28.4) to that produced by 200 viable seeds m^{-2} (28.0), but these lower than those at 250 viable seeds m^{-2} (27.7) (Table 4.3 and Appendices VIA and VIID). At the UoE, 150 viable seeds per square meter produced a lower number of grains per spike (28.5) than 200 seeds m^{-2} (27.5). Likewise, 250 viable seeds m^{-2} produced a much lower number of grains $spike^{-1}$ than 200 viable seeds m^{-2} (26.5) (Table 4.3 and Appendices VIB and VIIID).

Increasing seed rate had a general effect, of reducing the number of grains per spike at all the three seed rates and at both sites (Table 4.3).

Table 4.3: Expression of yield components of malting barley at different seed rates

Seed rate (Seeds m^{-2})	Plant stand (plant m^{-2})	Tillers $plant^{-1}$	S/length (cm)	Grains $spike^{-1}$	1000 Kernel Wt. (g)	Grain Yield (t ha^{-1})
		Mau Narok				
150	125 c	7.0 a	8.2 a	28.4 a	50.90 a	3.9 c
200	152 b	6.0 b	8.0 b	28.0 ab	49.70 b	4.4 b
250	190 a	5.0 c	8.0 b	27.8 b	48.40 c	4.9 a
Mean	**156**	**6.0**	**8.1**	**28.1**	**49.70**	**4.4**
LSD	8.6	0.61	0.19	0.48	0.86	0.28
CV (%)	11.7	21.7	4.9	3.6	3.6	13.2
		University of Eldoret farm				
150	147 c	5.0 a	7.9 a	28.5 a	47.30 a	3.9 b
200	196 b	4.0 b	8.0 a	27.5 b	47.40 a	4.3 a
250	224 a	3.0 c	7.9 a	26.5 c	46.90 a	4.4 a
Mean	**189**	**4.0**	**7.9**	**27.5**	**47.20**	**4.2**
LSD	10.7	0.50	0.15	0.50	0.59	0.22
CV (%)	12	27.6	4.1	3.8	2.6	11.1

Values within columns followed by the same letter are not significantly different

Grain yield differed significantly for all seed rates at either of the sites. At the Mau Narok site, 150 viable seeds m^{-2} produced a lower grain yield (3.9 t ha^{-1}) than 200 viable seeds m^{-2}, which produced a grain yield of 4.4 t ha^{-1}. However, the higher seed rate of 250 viable seeds m^{-2} produced a higher grain yield (4.9 t ha^{-1}) than both 150 and 200 viable seeds m^{-2} respectively. At this site, increasing seed rate had the effect of increasing grain yield (Table 4.3 and Appendices VIA and VIIE).

At the UoE site, 150 viable seeds m^{-2} produced a lower grain yield (3.9 t ha^{-1}) than both 200 and 250 viable seed $^{-2}$, which produced grain yields of 4.3 and 4.4 t ha^{-1} respectively. However, 200 and 250 viable seed m^{-2} produced similar grain yields. Increase seed rate did not produce significant increase in grain yield beyond 200 viable seeds m^{-2} (Table 4.3 and Appendices VIB and VIIIE).

1000 kernel weights were significantly (*$P<0.05$*) different for all seed rates at the Mau Narok site. 150 viable seeds m^{-2} produced heavier kernels (50.9g) than 200 viable seeds m^{-2} (49.70g). 250 viable seeds m^{-2}, on the other hand, produced lighter kernels (48.40g) than both 150 and 200 viable seeds m^{-2}; 49.70g and 50.9g respectively. Increasing seed rate, at this site reduced 1000 kernel weights (Table 4.3 and Appendices VIA and VIIF). At the UoE site, increasing seed rate had no effect on 1000 kernel weight (Table 4.3 and Appendices VIB and VIIIF).

4.2.2 Quality components

Maltable grain (g kg^{-1}) differed significantly *($P<0.05$)* with increasing seed rates at either of the sites. At the Mau Narok site, 150 viable seeds m^{-2} produced a similar maltable grain (973.1 g kg^{-1}) with 200 viable seeds m^{-2} (969.9 g kg^{-1}). However 250 viable seeds m^{-2} produced lower maltable grain (964.8g kg^{-1}) than 200 viable seeds m^{-}

^{2} (969.9g kg^{-1}) (Table 4.4 and Appendices VIA and VIIG). At the UoE site, 150 viable seeds m^{-2} produced similar proportion of maltable grain (958.4 g kg^{-1}) with 200 viable seeds m^{-2} (949.9 g kg^{-1}) However, the higher seed rate of 250 viable seeds m^{-2} produced a lower proportion of maltable grain (936.5g kg^{-1}), than both, 150 and 200 viable seeds m^{-2} respectively (Table 4.4 and Appendices VIB and VIIIG). The increase in seed rate led to a general reduction in maltable grain at both sites rates (Table 4.4).

Table 4.4: Expression of barley malting quality components at different seed rates

Seed rate (Seeds m^{-2})	**Maltable grain g kg^{-1}**	**Grain nitrogen content (%)**
	Mau Narok	
150	973.1 a	2.22 a
200	969.9 a	2.22 a
250	964.8 b	2.18 a
Mean	**969.3**	**2.2**
LSD	3.7	0.042
CV (%)	0.8	3.1
	University of Eldoret farm	
150	958.4 a	1.92 a
200	949.9 a	1.93 a
250	936.5 b	1.90 a
Mean	**948.3**	**1.92**
LSD	8.9	0.056
CV (%)	2.0	3.9

Values within columns followed by the same letter are not significantly different

Grain nitrogen content was not significantly different for all seed rates at both sites. However, at the Mau Narok site, the grain nitrogen content was greater than the upper limit for 150 and 200 seeds m^{-2} respectively, whereas, at the UoE site, the content was within the acceptable range of 1.7-2.2%N (Table 4.4 and Appendices VIA, VIB, VIIH and VIIIH).

4.3 Effect of nitrogen fertilizer on yield and quality components of barley

4.3.1 Yield components

Plant stand establishment differed significantly *(P<0.05)* with increasing nitrogen fertilizer application rate at the Mau Narok site. 30 kg ha^{-1} (166) of nitrogen fertilizer had a higher plant stand establishment than 40 kg ha-^{1} (155). Similarly, 50 kg ha^{-1} (150), produced reduced plant stand establishment, than both 30 kg ha^{-1} (166) and 40 kg ha^{-1} (155) (Table 4.6 and Appendices VIA and VIIA). At the UoE site, no differences were observed in plant stand establishment among different nitrogen fertilizer application rates (Table 4.6 and Appendices VIB and VIIIA).

The number of productive tillers per plant differed significantly *(P<0.05)* with the interaction between nitrogen fertilizer and seed rates at the Mau Narok site. Increasing both rates simultaneously reduced the number of productive tillers per plant (Tables 4.5 and 4.6, and Appendices VIA and VIIB). At the U.o.E site, both 30 kg –N ha^{-1} (4) and 50 kg-N ha^{-1} (4) produced similar numbers of productive tillers per plant with the control rate of 40 kg-N ha-1 (4). However, with 0 kg-N ha-1, fewer tillers per plant were produced when compared to addition of nitrogen fertilizer (Table 4.6 and Appendices VIB and VIIIB).

Table 4.5: Number of productive tillers per plant at the Mau Narok site and the interaction between nitrogen fertilizer and seed rates

Nitrogen (kg ha^{-1})	**N0 (0)**	**N1 (30)**	**N2 (40)**	**N3(50)**
S/Rate (Seeds m^{-2})				
150	6.0	7.0	7.0	9.0
200	6.0	6.0	6.0	6.0
250	4.0	4.0	4.0	5.0

There were no significant differences in spike lengths (cm) with increasing nitrogen fertilizer application rates at the Mau Narok site (Table 4.6). However, at the UoE site, spike lengths differed significantly *($P<0.05$)* with increasing rates of nitrogen fertilizer application. 30 kg-N ha^{-1} (7.9 cm) produced longer spikes than 0 kg-N ha^{-1} (7.2 cm), but the spike lengths, at this lower rate, were shorter than that at 40 kg-N ha^{-1} (8.1 cm). 50 kg-N ha^{-1} (8.2 cm) produced comparable spike lengths with the control rate of 40kg-N ha^{-1} (8.1 cm). There was a general increase in spike lengths with increasing nitrogen fertilizer application at the UoE site. No interactions were observed (Table 4.6 and Appendices VIB and VIIIC).

Table 4.6 Comparison of yield components of malting barley at different nitrogen fertilizer rates

Nitrogen Fertilizer (kg ha^{-1})	**Plant stand (plant m^{-2})**	**Tillers plant^{-1}**	**S/length (cm)**	**Grains spike^{-1}**	**1000 Kernel Wt. (g)**	**Grain Yield (t ha^{-1})**
	Mau Narok					
0	151 b	5.0 c	8.0 a	28.0 a	49.3 a	3.9 c
30	166 a	6.0 b	8.1 a	28.0 a	49.2 a	4.4 b
40	155 b	6.0 b	8.1 a	28.0 a	50.1 a	4.6 ab
50	150 b	7.0 a	8.0 a	28.0 a	50.2 a	4.8 a
Mean	156	6.0	8.1	28.0	49.7	4.4
LSD	10	0.7	0.21	0.55	1.0	0.32
CV (%)	11.7	21.7	4.9	3.6	3.6	13.2
	University of Eldoret farm					
0	187 a	3.0 b	7.2 c	25.0b	44.3 c	3.4 c
30	186 a	4.0 a	7.9 b	28.0a	47.4 b	4.3 b
40	187 a	4.0 a	8.1 a	28.0 a	48.2 a	4.5 ab
50	198 a	4.0 a	8.2 a	28.0 a	48.8 a	4.6 a
Mean	**189**	**3.8**	7.9	27.0	47.2	4.2
LSD	12	0.6	0.18	0.57	0.7	0.25
CV (%)	12.0	27.6	4.1	3.8	2.6	11.1

Values within columns followed by the same letter are not significantly different

The number of grains spike $^{-1}$ did not show differences with increasing nitrogen fertilizer application rate at the Mau Narok site (Table 4.6 and Appendices VIB and VIIID). At the UoE site, the number of grains spike^{-1} differed significantly (*P<0.05*) with the interaction between nitrogen fertilizer and variety. All varieties produced low numbers of grains at 0 kg ha^{-1} N than when the nitrogen fertilizer was applied. Applying the initial N-fertilizer, increased the number of grains spike^{-1}, but applying it beyond the initial application had no effect on the number of grains spike^{-1}. HKBL 1512-5 showed no response to N-addition beyond the initial application, whereas HKBL 1385-13 showed a decline in the number of grains spike $^{-1}$ with increasing N-addition beyond the control N-rate. HKBL 1512-5 produced significantly fewer grains spike^{-1} with increasing nitrogen rates, than both Nguzo and HKBL 1385-13 (Tables 4.6 and 4.7, and Appendices VIB and VIIID).

Table 4.7: Comparison of the number of grains spike^{-1} among varieties and different N-rates at the UoE site 2012

Nitrogen (kg ha^{-1})	**N0 (0)**	**N1 (30)**	**N2 (40)**	**N3(50)**
Variety				
HKBL 1512-5	22.0	26.0	26.0	26.0
NGUZO	27.0	29.0	29.0	30.0
HKBL 1385-13	27.0	29.0	30.0	29.0

Grain yield differed significant (*P<0.05*) with increasing nitrogen fertilizer application rate at both sites. The increase in grain yield was greater between 0 kg ha^{-1} and 30 kg-N ha^{-1} at either of the sites. However 30 kg-N ha^{-1}(4.4 & 4.3 t ha^{-1}) produced similar grain yields with 40 kg-N ha^{-1} (4.6 and 4.5 t ha^{-1}) at Mau Narok and UoE sites respectively. Similarly, 50 kg-N ha^{-1} (4.8 & 4.6 t ha^{-1}) produced comparable grain yields with 40 kg-N ha^{-1} (4.6 & 4.5 tonnes ha^{-1}), but higher than the yield at 30 kg-N ha^{-1}(4.4 & 4.3 t ha^{-1}) at either of the sites (Table 4.6 and Appendices VIA, VIB, VIIE and VIIIE).

An interaction between seed and nitrogen fertilizer application rates was observed on grain yield at the Mau Narok site. Increasing seed and nitrogen fertilizer rates simultaneously increased grain yield from 3.8 t ha^{-1} to 5.4 t ha^{-1} (Table 4.8 and Appendices VIA and VIIF).

Table 4.8: Interaction between seed rate and nitrogen fertilizer rate on grain yield (t h^{-1}) at the Mau Narok site

Nitrogen (kg ha^{-1})	**N0 (0)**	**N1 (30)**	**N2 (40)**	**N3(50)**
S/Rate (Seeds m^{-2})				
150	3.8	3.6	3.9	4.2
200	4.2	4.5	4.3	4.6
250	3.7	5.2	5.4	5.4

There were no significant differences in 1000 kernel weight with increasing nitrogen fertilizer rates at the Mau Narok site (Table 4.6 and Appendices VIA and VIIF).

However, at the U.o.E site, significant ($P<0.05$) differences were observed. 30 kg-N kg ha^{-1} (47.4 g) produced heavier kernels when compared to 0 kg ha^{-1} (44.3 g). However, 30 kg ha^{-1} (47.4 g) produced lighter kernels than 40 kg-N ha^{-1} (48.2g). 50 kg –N ha^{-1}(48.8g) produced similar kernel weights with 40 kg –N kg ha^{-1} (48.2g) (Table 4.3.6). No interactions were observed for this parameter (Table 4.8 and Appendices VIB and VIIIF).

4.3.2 Quality components

Maltable grain was not significantly different for different nitrogen fertilizer rates at the Mau Narok site (Table 4.9 and Appendices VIA and VIIG). At the UoE site, maltable grain differed significantly (*P<0.05*) with increasing nitrogen fertilizer rate. 30 kg ha^{-1} (948.8 g kg^{-1}) produced higher maltable grains than 0 kg ha^{-1} (927.5g kg^{-1}).

There was no increase in maltable grain beyond application of 30 kg ha^{-1} N at either of the sites (Table 4.9 and Appendices VIB and VIIIG). There was interaction between variety and nitrogen fertilizer application rate (Table 4.10 and Appendices VIB and VIIIG).

Table 4.9: Expression of barley malting quality components at different nitrogen fertilizer rates

Seed rate (Seeds m^{-2})	Maltable grain g kg^{-1}	Grain nitrogen content (%)
	Mau Narok	
0	970.1 a	2.13 b
30	968.6 a	2.22 a
40	969.6 a	2.22 a
50	968.8 a	2.26 a
Mean	969.3	2.21
LSD	4.3	0.038
CV (%)	1.0	3.1
	University of Eldoret farm	
0	927.5 b	1.79 d
30	948.8 a	1.90 c
40	958.5 a	1.96 b
50	958.4 a	2.02 a
Mean	948.3	1.92
LSD	10.3	0.041
CV (%)	2.0	3.9

Values within columns followed by the same letter are not significantly different

Significant differences (*P<0.05*) in grain nitrogen content were observed at both sites. At the Mau Narok site, addition of 30 kg-N ha^{-1} (2.22%) resulted in more grain nitrogen content than the acceptable level of 2.2%. Similarly, further increases in N-fertilizer addition had similar results on the grain N-content. At the UoE site, increasing nitrogen fertilizer increased grain N-content for all nitrogen fertilizer rates, but at all levels of N-fertilizer rates, the resultant grain N-content was within the acceptable malting range of 1.7 – 2.2%. There was interaction between variety and nitrogen fertilizer rate for this quality component at UoE (Tables 4.9 and 4.11; and Appendices VB and VIIIH).

Table 4.10: Maltable grains (g kg $^{-1}$) and the interaction between nitrogen fertilizer rate and variety at UoE

Nitrogen (kg ha^{-1})	N0 (0)	N1 (30)	N2 (40)	N3(50)
Variety				
HKBL1512-5	973.4	983.3	986.2	983.9
NGUZO	830.2	872.0	896.9	902.9
HKBL1385-13	978.8	991.1	992.4	988.4

The interaction between variety and nitrogen fertilizer application rate on grain N-content was significant (*P<0.05*) at the UoE site. HKBL 1512-5 (1.97%) accumulated more grain nitrogen with increasing nitrogen fertilizer than Nguzo (1.91%). However, HKBL 1385-13 (1.87%) had similar grain nitrogen content with Nguzo (1.91%). Increasing nitrogen fertilizer rates in the soil increased grain nitrogen content in all varieties (Table 4.11).

Table 4.11: Grain nitrogen content (% N) and the interaction between variety and nitrogen fertilizer rate at UoE site

Nitrogen (kg ha^{-1})	N0 (0)	N1 (30)	N2 (40)	N3(50)
Variety				
HKBL1512-5	1.88	1.92	2.01	2.07
NGUZO	1.82	1.90	1.92	1.98
HKBL1385-13	1.69	1.86	1.94	2.00

CHAPTER FIVE

DISCUSSION

5.1 Experimental sites

Crop yield components make varied contributions to final plant yield and quality. In small cereal crops, these components include plant establishment, number of tillers per plant or unit area, biomass, harvest index, leaf area index, spike numbers per unit area, spike length, number of kernels per spike and kernel weight. This study found that varietal differences exist in their ability to establish at different locations.

This can be explained by genetic differences, soil fertility, and aerial environmental factors. While the mean temperatures at both sites in this study were conducive for barley growth and development rainfall, was inadequate at the Mau Narok site (444mm), when compared to the University of Eldoret site (719.4 mm) (Appendix II). Barley requires 635 mm of rainfall in its growth phase (EPZA, 2005). Zadok's scale for small cereal crop growth and development recognizes moisture stress, and varietal differences as contributors to plant establishment in cereal crops (Zadok, 1974).

Soil fertility was varied at the two sites. The high altitude Mau Narok (2829masl) site had higher total soil nitrogen and organic matter. This means that continuous mineralization could add more nitrogen to the soil during the period of crop growth (Okalebo, *et. al.,* 2002). In contrast, the soil at the University of Eldoret site had lower nitrogen levels, although they were above the critical level of 0.25% (Okalebo, *et al.,* 2002). With the lower %OC at this site the possibility of additional soil-nitrogen from mineralization was lower meaning, less soil-N addition in the growth period of the barley.

Soil pH test results (Appendix I) show strong acidity at Mau Narok in both top soil (5.4) and sub soil (5.3), whereas the soils at the University of Eldoret farm show very strong acidity in both top soil (4.75) and sub soil (4.7) (Panda, 2005). Barley requires soils tending towards alkalinity (pH 7.0 – 8.0) (Chapman and Carter, 1978).

While the soil acidity at the University of Eldoret should be studied further to determine the necessary amendments to suit barley growth, acid tolerant barley varieties could be selected for the Mau Narok site. Soil acidity beyond pH of 5.0 may not need addition of lime as an amendment.

5.2 Effect of variety on barley yield and quality

Barley varieties are known to have different yield potentials (Fettel *et al.*, 1999; Mackenzie *et al.*, 2005; EPZA, 2005, Glen *et al.*, 2006). Barley yield differences among varieties were modest in this study. The total grain yields for individual varieties were above the national average of 2.2 t ha^{-1} but below the grain yield potential of 7 t ha^{-1}. The yield components of spike length, number of grains spike $^{-1}$ and 1000 kernel weight showed strong differences among cultivars at both sites (Appendices VIA and VIB). This finding indicates that these components are controlled more by genetics than by environment. Similar findings have been associated with high heritability of these agronomic traits in evolving high yield barley genotypes (Sukram *et al.*, 2010; Kavitha *et al.*, 2009 and Alam *et al.*, 2006).

Cultivar did not affect the number of productive tillers per plant at the Mau Narok site, while it did at the UoE, site. This finding agrees with other studies that found no genotypic differences in the number of productive tillers per plant (O’Donovan *et al.*, 2011). Whereas HKBL 1512-5 had lower grain yield than the control and the HKBL

1385-13 at either of the sites, it had consistently superior 1000 kernel weight throughout the study. This result suggests that 1000 kernel weight is affected more by genotype than with environment. These results agree with the findings of (Sukram *et al.,* 2010; Kavitha *et al.,* 2009 and Alam *et al.,* 2006) who reported that selection of varieties should be based on 1000-kernel weight rather than on other morphological components of grain yield. However, HKBL 1512-5 had poor tillering ability than HKBL 1385-13, which showed profuse tillering especially at the more acidic medium altitude site of university of Eldoret farm. This finding agrees with other studies which found that environment had an effect on tillering ability in barley although the effect of genotype was greater (Tamm 2003).

HKBL1512-5 had also the disadvantage of very short spike lengths when compared to both Nguzo and HKBL 1385-13. This attribute could have limited the grain yield as it limited the number of grains per spike despite the superior kernel weight. The heavier grains in this variety could not adequately compensate for the short spike length, the low number of grains per spike and the poor tillering, especially at the medium altitude (2180 masl) site of university of Eldoret. This study shows that the choice of a suitable variety for any of these two sites could not be determined from grain yields alone, but from other agronomic traits of plant characteristics. These results agree with the findings of (Mackenzie *et al.,* 2005) who found only modest differences in grain yield among varieties.

Two barley malting qualities of maltable grain (g kg^{-1}) and grain nitrogen content (%) were determined in this study. On average, the two test varieties produced higher maltable grain when compared to the control variety. While the two test varieties performed comparably at both sites, the control variety performed better at the more fertile high altitude site than at the medium altitude site. The test varieties were, therefore not site specific with respect to maltable grain in this study. These results agree with (Mackenzie *et. al.,* 2005; McClelland *et al.,* 2009; Akar *et al.,* 2004) who found significant differences in maltable grain among varieties. The results also agree with findings of (Glen *et al.,* 2006) who found that genetic effect on grain size was greater than environmental effect, even when the environment suffered from terminal moisture stress. Although significant differences were observed among varieties, all varieties produced acceptable maltable grain of more than 90%. On this basis, the two test varieties were comparable and therefore, choice of variety for the sites on this basis could be combined with a consideration of other yield and malting qualities at either of the sites.

Grain nitrogen content is one of the most important malting qualities of barley. Low grain content lowers enzymatic activity during steeping whereas high grain N-content leads to fizzing in the final product, beer. Varietal differences in grain N-content were stronger at the Mau Narok site than at the UoE, site. This finding agrees with (Bentayehu *et al.,* 2003; Krizanova *et al.,* 2010 and Jun-Cang *et al.,* 2005) who found that stability of grain nitrogen content was varied across site. Whereas the test varieties had acceptable grain N-content at the less fertile, medium altitude UoE site, HKBL 1512-5 tended to accumulate nitrogen in the grain beyond acceptable malting levels at the more fertile, high altitude site of Mau Narok. Similar results have been reported by (Bleidere, 2008) who indicated that genotypic influence on grain nitrogen content was higher than that of environment and the interaction between genotype and environment combined. On this basis alone, both HKBL 1512-5 (2.331 % N) and HKBL 1385-13 (2.21 % N) were found to be unsuitable for the fertile Mau Narok. Mackenzie *et al.,* (2005) reported modest grain protein differences among varieties, across 71% of the experimental locations. He further reported acceptable grain protein content at 50-60 % of the sites tested. Molina-cane, *et al.,* (2001) reported a consistent 2% difference in grain protein content between varieties across sites.

5.3 Effect of seed rate on barley yield and quality

Seed rate had a strong effect on grain yield and its components at the Mau Narok site. It also had a strong effect on the malting quality of proportion of maltable grain but had no effect on grain nitrogen content (Appendix VIA). As expected, seed rate had the effect of increasing plant establishment and subsequently the number of productive tillers per plant. At 150 seeds m^{-2}, 83% of the seeds produced a plant, whereas at 250 seeds m^{-2}, only 76% of the seeds produced a plant; indicating that at the lower seed rate more plants establish than at the higher seed rate. This can be explained by the increasing intra-row competition at higher seed rates with subsequent increases in seedling mortality.

This finding agrees with (O'Donovan *et al.*, 2011) who found that at lower seed rates, a higher proportion (68%) of barley seeds established as opposed to only (58%) at higher seed rates. This reduction in the number of seeds that establish as seed rate increases is associated with soil pH., site altitude and site latitude, with fewer seeds establishing in more acidic soils (O'Donovan *et al.,* 2011). Reduction in productive tillers per plant with increasing seed rate as found in this study can be associated with competition for light since tillering was still high at the Mau Narok site despite the inadequate rainfall (Appendix II).

This finding agrees with (O'Donovan *et al.,* 2011) who reports that even under irrigation maize showed reduced biomass with increasing plant density. Since productive tillers have been shown to be influenced more by genotype than by environment (Tamm 2003) it is a better criterion for choice of optimum seed rate in malt barley.

The number of grains spike^{-1} reduced with seed rate but no interactions were observed. However, the reduction beyond the control seed rate was not significant at the Mau Narok site (Table 4.3). Similar results were found by (Mackenzie *et al.,* 2005) who also reported an interaction between variety and seed rate in determining the number of grains spike^{-1}. On this basis, choice of optimum seed rate should consider other agronomic traits rather than number of grains spike^{-1} alone.

Grain yield increased at all seed rates at the Mau Narok site indicating that higher seed rates could achieve higher yields. This increase is associated with increase in the number ears per unit area (Tamm 2003). These higher seed rates could be advantageous at this site because, they can help in lowering grain N-content associated with this site (Table 4.4). Other studies have found similar results but with a declining grain yield beyond the optimum seed rate (Mackenzie *et al.,* 2005; Donovan *et al.,* 2011). The grain yield at this site can be an indicator of the higher optimum seed rate since it increased at all seed rates in the study.

Maltable grain reduced with increasing seed rate. However at all the tested seed rates the maltable grain was greater than the lower limit of 900 g kg^{-1}. This reduction can be associated with increased number of grains per unit area beyond the ability of the plant to support them in development. Therefore choice of optimum seed rate on the basis of maltable grains should be combined with other agronomic traits. Similar studies in Western Canada, Britain and Southern Alberta show that maltable grain has often been more than the lower limit (Brophy, 2010; Mackenzie *et al.,* 2005).

Seed rate had no significant effect on grain N- content at the Mau Narok site (Table 4.4). However at the lower test seed rate there was a tendency for the grain N- content to be greater than the upper limit of 2.2% (Table 4.4). It was only at the highest test seed rate that the grain N- content was below the limit. This could be due to the higher fertility at this site or the continuous mineralization of the high %OC (Appendix I) in the soil which continued to supply nitrogen during the growth period. This finding is in agreement with (O'Donovan *et al.,* 2011) who found more pronounced grain protein content at lower seed rates than above the optimum.

On the basis of this finding choice of optimum seed rate should be combined with other agronomic traits, and especially kernel size and uniformity (plumpness) which is greater at higher seed rates and have a higher impact on malting quality than grain protein content per see (Mackenzie *et al.,* 2005).

In summary, this study found that the optimum seed rate at the Mau Narok site should be more than 250 seeds m^{-2}. This will mitigate the high grain N- content, and attain high yield. The limiting agronomic trait for this site would appear to be kernel size or maltable grain. This then becomes the most important criterion upon which the optimum seed rate can be determined for the Mau Narok site.

Similar findings were observed, at the UoE site except that seed rate had no effect on spike length, 1000 kernel weight and grain N- content (Tables 4.3 and 4.4). Grain yield increase was not significant beyond the control seed rate of 200 seeds m^{-2}(Table 4.3). The number of grains $spike^{-1}$ were increasing significantly even at the higher seed rate, but productive tillers $plant^{-1}$ were reducing at higher seed rates although plant stand was increasing. This is due to the intra-row competition as indicated earlier.

Plant stand, productive tillers plant^{-1}, and number of grains spike^{-1} were the major contributors to grain yield (O'Donovan *et al.,* 2012). Increasing seed rate reduced all these except plant stand establishment which increased at a reducing rate as competition for resources may have resulted in more seedling mortality (O'Donovan *et al.,* 2011). This leaves grain yield as the major determinant of the optimum seed rate at the UoE site. This would appear to be 200 seeds m^{-2}, since the malt quality traits of maltable grain and the grain N- content are within the acceptable ranges at all test seed rates (Table 4.4).

5.4 Effect of nitrogen Fertilizer rate on barley yield and quality

At the Mau Narok site, Nitrogen fertilizer had relatively weak effect on yield and malt qualities. The N-fertilizer rate affected the yield qualities of plant establishment, productive tillers per plant, and the quality component of grain N- content. The N-rate had no effect on the other agronomic traits of spike length, number of grains spike^{-1}, 1000-kernel weight, maltable grain and the overall yield.

The effect on plant stand at this site could indicate that either, soil moisture was inadequate or the ability to maintain adequate separation between seed and fertilizer was low. Similar studies have reported that N-rate effect on plant stand is rare but it can occur (O'Donovan *et al.,* 2011); however the effect of the mixed response in plant stand at this site had almost no effect on grain yield (Table 4.6).

At the UoE site, N-rate had no effect on plant stand establishment, most likely due to adequate soil moisture at sowing and throughout the growing phase (Appendix II). These findings indicate that the optimum N-rate at either site cannot be determined on the basis of plant stand establishment alone.

The yield component of productive tillers per plant was strongly affected by N-rate at either of the sites. However at the Mau Narok site, the interaction between N-rate and seed rate was more important in determining productive tillers per plant than N-rate alone (Table 4.8). There was a direct relationship between seed rate and N-rate as increasing both reduced the number of productive tillers. This result may indicate that at higher seed and N-rates the many tillers that are produced do not survive to bear an ear due to competition for light as shown by similar studies (Mackenzie *et al.,* 2005; O'Donovan *et al.,* 2011). At the UoE site there was no increase in tillering beyond the initial N-application of 30 kg N ha^{-1} (Table 4.6).

This result may indicate that with the application of all the N-fertilizer at sowing combined with the high precipitation at this site (Appendix II), most of the applied nitrogen may have been leached before the onset of tillering. It is also possible that with the low %OC (Appendix I), soil-N from mineralization was inadequate to support more tillers. On this basis of productive tillers per plant it is appears difficult to determine the optimum N-rate at either site.

The yield components of spike length and number of grains per spike were not affected by N-rate at the Mau Narok site (Tables 4.6). However, at the UoE site, spike length increased with N-rate with the increase being significant below the control N-rate. At this site, the interaction of cultivar and N-rate was more important in determining the number of grains per spike (Table 4.7). This finding is in agreement with (Alam *et al.,* 2007; Singh & Singh 2005) who found that both spike length and number of grains per spike were cultivar specific. This being the case these two yield components cannot be adequate in determining the optimum N-rate at either site, except in combination with other yield and quality components.

Grain yield increased with N-rate at both sites. The yield was lowest at no 0 kg ha^{-1} and the value at this level was significantly lower when compared to the values with N-application. Similar results were obtained by (Jankovic *et al.,* 2011). There was increase with increasing N-rate but the response was not strong (Table 4.6). Jankovic *et al.,* (2011) reported no significant increase in grain yields of barley beyond the initial N-application, whereas others have reported a decline beyond the optimum N-rate in some varieties. Other studies have reported that modern varieties respond more strongly due to increased numbers of productive tillers, but with the risk of attaining grain N-concentration above the upper limit (Gabriela *et al.,* 2003).

At the Mau Narok site, the interaction between N-rate and seed rate was an important determinant of the grain yield. Increasing both increased grain yield at this site (Table 4.8). However, all test varieties have been shown to concentrate more nitrogen in the grain above the upper limit at this site (Table 4.9). This fact will mitigate against increasing N-rate further for higher yields, but rather to hold it as seed rate is increased so that lower grain N- content is achieved.

The maltable grain was not affected by N-rate at the Mau Narok site. Increasing N-rate reduced the proportion of maltable grains. However, at all test rates including none application of N-fertilizer, maltable grain was above the lower limit of 90%

(Table 4.9). Similar studies have found that, in favourable conditions, yield and other agronomic traits increase with N-rate but maintain maltable grain (Gonzalez et al., 1993). At the UoE site, N-rate by variety interaction was a stronger determinant of maltable grains (Table 4.10). The potential varieties for release, HKBL1512-5 and HKBL 1385-13 showed lower response to increasing N-rate at about 1% compared to the control variety Nguzo at 8.8%.

Whereas, test varieties attained levels above the lower limit at all rates of N-application and none application, the control variety, Nguzo was below the lower limit at all rates except at the highest test rate of 50 kg ha^{-1} N (Table 4.9).

Grain N- content has a major impact on malt barley since it determines the quality of beer and the proportion of harvested barley that attains malt grade. Increasing N-rate has a tendency to increase grain N- content. This increase may go beyond the upper limit. In this study, increasing N-rate at the Mau Narok site, increased the grain N-content above the upper limit of 2.2% except for none application (Table 4.9). This may be due to the strong response of the modern varieties and /or the continuous availability of soil nitrogen because of high %OC that continued to be mineralized throughout the growth phase or further still due to accumulation of more structural carbohydrates at the expense of proteins because of the inadequate precipitation. Similar studies have shown that grain N- content increases over the full range of available nitrogen (Mackenzie *et al.,* 2005). For this site, the optimum N-rate cannot be determined exclusively on the basis of grain N- content.

At the UoE site, grain N-content was above the lower limit (1.7%) and below the upper limit (2.2%). However, there was variety by N-rate interaction which was a more important determinant (Table 4.11). HKBL 1512-5 had a stronger response to N-rate than Nguzo, whereas, HKBL 1385-13 had the lowest response. This is likely due to the profuse tillering of HKBL 1385-13 at this site when compared to both HKBL 1512-5 and Nguzo (Table 4.1). This may have increased competition and denied the grains adequate nitrogen for protein synthesis. In these conditions, HKBL 1385-13 would be a choice of last resort for the UoE site, due to the relatively poor enzymatic activity that may result from this low grain N- content. These results agree with findings in (China papers 2010) which indicate an interaction between variety and N-rate in determining grain N- content. Other studies by (O'Donovan *et al.,* 2011, Edney *et al.,* 2012; Muurinen *et al.*, 2005), agree with the finding that grain N-content increases with N-rate but also depends on the variety and the conditions in which the crop is grown.

From these findings, it is difficult to determine the optimum N-rates for malt barley on the basis of changing the N-rates alone. While 0 kg ha^{-1} would be recommended for Mau Narok site to attain acceptable grain N- content, more than 50 kg-N ha^{-1} would be required at the UoE site without surpassing the upper limit. Similar difficulty has been reported in other studies which have given a very wide range of between 0 and 96 kg-N ha^{-1} (Davis &Westfall 2009). This confirms the need for thorough soil testing prior to sowing so that only enough N-fertilizer for the specific region and conditions is added to the available soil nitrogen, and especially with the modern varieties which are powerful enzyme producers (McLelland *et al.*, 2009).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Variety, seed rate and N-application were equally important agronomic variables in determining barley yield and malting qualities in this study. The following conclusions can be made from the findings;

1. HKBL 1385-13 out yielded both Nguzo and HKBL 1512-5 at both sites

2. HKBL 1512-5 had consistently superior 1000-kernel weight and maltable grain, but with poor agronomic traits for yield components of productive tillers plant^{-1}, spike length, number of grains spike^{-1} and overall grain yield at all sites

3. Proportion of maltable grain for all test varieties was above the lower limit for all seed and N-rates at all sites

4. At the UoE site all test varieties accumulated grain N- content within the acceptable range for malting, whereas, at the Mau Narok site, all test varieties accumulated grain N- content above the upper limit

5. At lower seed rates, more plants established than at higher seed rates

6. Seed rates higher than the highest test rate could produce significant grain yield increases at the Mau Narok site, whereas the control seed rate was sufficient at the UoE site, where grain yield was the limiting parameter for higher seed rates.

7. There was more pronounced grain-N concentration at lower seed rates

8. Grain yield did not show strong response to Nitrogen fertilizer addition, except between application and non-application at both sites. At the Mau Narok site an interaction between N-rate and seed rate increased yield but this was mitigated against by grain-N accumulation above the upper limit

6.2 Recommendations/Way forward

1. HKBL 1385-13 is suitable for both sites based on its high grain yield resulting from high tillering at the study sites

2 HKBL 1512-5 is more suitable for crop improvement of other malt barley varieties since it has superior traits of 1000-kernel weight and maltable grain but poor traits for grain yield components

3 Seed rates of more than 250 seeds m^{-2} is recommended for the Mau Narok site to specifically lower the grain-N content although there is also a possibility of higher grain yields

4 Seed rates of not more than 200 seeds m^{-2} are recommended for the UoE site

5 N-rate of 0 kg ha^{-1} is recommended for the Mau Narok site but this can be changed at higher seed rates, but for U.o.E a rate of 40 kg-N ha^{-1} is recommended.

6.3 Further research

Further research is recommended to determine;

1 The degree of acid tolerance for the test variety HKBL 1385-13

2 The level and type of soil amendments required for the U.o.E site to make it produce higher grain yields of malt grade barley

3 Optimum seed rate at the Mau Narok site to get grain N- content within malt-grade limits

4 Whether split application of N-fertilizer is beneficial for malt grade barley production

REFERENCES

Adrian, C.N., A.J. Flavell, T.S. George, P. Leat, B. Mullholland, L. Ramsay, C. Revoredo - Giha, J. Russell, B.J. Stephenson, J.S. Swanston, W.T.B. Thomas, R. Waugh, P.J. White, I.J. Bingham, (2011). Crops that feed the world 4. Barley: a resilient crop? Strengths and weaknesses in the context of food security.Food sec. (2011) 3: 141-178.

Ahmed A., B. Humeid, K.Street, N. Rukhkyan, J. Konopka, S. Asaad, A. Omran, F. Alố), J. ValkounA.lDiederichsen (2011). *Genetic resources.* ICARDA, Syria.

Akar, T., M. Avci, F. Ducunceli (2004). *Barley : Post-harvest operations.* The central research institute for field crops, Ulns, Ankara, Turkey.

Alam, A. K., M. M., Begum, M., Chaudhury, M. J. A., Naher, N., Gomes, R. (2007). D^2 Analysis in Early Maturity Hull-Less Barley (*Hordeum vulgare* L.). *International Journal of Sustainable Crop Production,* 2 (1): 15-17.

Alam, M.Z., S.A. Haider and N.K. Paul (2006). Yield and Yield Components of Barley (Hordeum vulgare L.) cultivars in Relation to Nitrogen Fertilizer. *Journal of Applied Sciences Research,* 3(10): 1022-1026

Australian Govt. (2008). The biology of *Hordeum vulgare* L. (Barley). Office of the Gene Technology Regulator. Available at http://www.ogtr.gov.au.

Aynewa Y., T. Dessalegn and W. Bayu (2013). Participatory Evaluation of Malt Barley and other Agronomic Traits at Northern Ethiopia. *Wudpecker Journal of Agricultural Research* VOL. 2(8):218 -222

Baethgen W. E., Christianson C. B., Lamothe AG (1995). Nitrogen fertilizer effects on growth, grain yield and yield components of malting barley. *Field Crop Research* 43: 87-99

Baik B. K. and S.E. Ullrich (2008). Barley for food: characteristics, improvement and renewed interest. *Journal of Cereal Science* 48: (2) 233-24.

Bentayehu M. (2013). Study on malting barley genotypes under diverse agro ecologies of north western Ethiopia. *African Journal of Plant Science* 7(11) 548-557.

Bleidere M., (2008). Genetic and environmental effect on the grain quality of spring barley. *Latvian Journal of Agronomy* 11:33-39

Brophy M., (2010). *Quality factors in malting barley.* Brewing and malting barley research institute (BMBRI), Winnipeg, Manitoba, Canada. Available online at: http://www.bmbrics/PDF/QualityFactorsinmaltingbarley.

Bulman P., D. E. Mather and D. L. Smith (1993). Genetic improvement of spring barley cultivars in Eastern Canada. *Euphytica* 71:35-48

Ceccarelli, S. & S. Grando, (2006). *Hordeum vulgare* L. In: Brink, M. & Belay, G. (Editors). PROTA 1: Cereals and pulses/Cereals et legumes secs. [CD-Rom].PROTA, Wageningen, Netherlands.

Chapman, S.R. and L.P. Carter (1978). *Crop Production Principles and Practices.* W.H. Freeman and Company, San Francisco 1978.

China papers (2010). China's outstanding Doctoral Dissertations; *Genotypic and Environmental variations of Hordein Fraction and Malting Quality in Barley.*

Davis J.G., and D.G. Westfall (2009). *Fertilizer spring-seeded small grains;* fact sheet no.0.534

Edney M. J, John T. O., T Kelly T., George W. C., McKenzie R., Pat J., Guy P. L., Stewart B., Cynthia A G., Harker K. N., Eric J. and William M. (2012). Effects of seed rate, nitrogen rate and cultivar on barley malt quality, *Journal of the Science of Food and Agriculture* 92 (13): 2672–2678.

EPZA (Export Processing Zone Authority) (2005). *The Kenyan beer industry.* Nairobi, Kenya.

FAO (Food and Agriculture Organization), (2003). Explore on-farm: *On-Farm Trials for Adapting and Adopting Good Agricultural Practices.* Food and Agricultural organization of the United Nations, Rome, Italy.

Fettell, N.A., D.B. Moody, N. Long and Flood, (1999). Determinants of Grain Size in malting barley. In ''9th Australian Barley Technical Symposium''. Melbourne, Victoria. (Eds. D. B. Moody, R. G. Flood).

Gabriela A. L., D.l F. Calterini and G. A. Slafer (2003). Genetic improvement of yield responsiveness to nitrogen fertilizer and its physiological determinant in barley (*abs.). Euphytica* 133:295-298

Glen P. F., A. Kelly, D. Poulson, A. Inkerman, and R. Henry (2006). Selecting for increased barley grain size *Journal of Cereal Science*, Vol. 43 (2) pp. 198-208.

Gomez, K. A., and A. A. Gomez (1976). Statistical procedures for agricultural research, with emphasis on rice. International Rice Research Institute; Los Banos, Phillippines.

Gonzalez R. P., S. C. Mason, M. L. Salas, R. J. Sabata, and A. Herce (1993). Environment, seed rate, and N rate influence on yield of winter barley. *Fertilizer Research* 34: 59-65

ISTA International Rules for Seed Testing, Rules (1996). International Seed Testing Association (ISTA). Seed Science and Technology 24 (supplement). Zurich, Switzerland.

Jaetzold, R. and H. Schmidt, (1982). *Farm management handbook of Kenya, vol. IIIB.*Nairobi, Kenya.

Jalal A. A. and Ahmad H. A. (2012). Genetic Variation, Heritability, Phenotypic and Genotypic Correlation Studies for Yield and Yield Components in Promising Barley Genotypes. *Journal of Agricultural Science* (4)193-210

Jankovic, R., D. Glamoclija, R. Maletic, S. Rakic, N.Hristov and J. Ikanovic (2011). Effects of Nitrogen Fertilizer on Yield and Grain Quality in Malting Barley. *African Journal on Biotechnology* Vol. 10 (84): 19534-19541.

Jason D., B. Schultz and A. Widaman (2011). *Malting barley in Nevada;* University of Nevada Cooperative extension; Fact sheet FS-01-47.

Jung-cang Q., Jin-xin C., Jun-mei W., Fei –bo W., Lian-pu C. and Guo-ping Z. (2005). Protein and hordein fraction content in barley seeds as affected by sowing date and their relations to malting quality. *Journal of Zhejiang University Science.* 6(11): 1069-1075

Junmei W., Guoping Z., Jinxin C., Quiqnan S. and Feibo W. (2003). Genotypic and environmental variation in barley beta-amylase activity and its relation to protein content. *Food Chemistry* 83(2): pp163-165

Kavitha G., G. S. Dhindsa, Sarvjeet S. and Johar S. (2009). Stability Analysis of Yield and its Components in Malt Barley (*Hordeum vulgare* L.) Genotypes; *Journal of Crop Improvement* 36 (1): 29 – 34.

Kazimierz N. (2010). Effect of sowing rate on yields and grain quality of new cultivars of spring barley. *Polish Journal of Agronomy* 3: 20-23.

Krizanova K.; Z. AlZbeta; H. Michaela; S. Lodovlt; G. Sona; M. Daniela; G. Jozef and H. Jana (2010). Grain yield and malting quality of new spring barley genotypes. *Agriculture/pol'nohospodarstvo,* 56(3):90-94

Mackenzie R., H., A.B. Middleton and E. Brener (2005). Fertilization, Seed Rate and Seed Rate of Malting Barley Yield and Quality in Southern Alberta. *Canadian Journal of Plant Science* 85 (3): 603-614.

Mackenzie R. H., A. B. Middleton, L. Hall, J. DeMulder and E. Bremer (2004). Fertilizer Response of Barley Grain in South and Central Alberta. *Canadian Journal of Soil Science* 84(4): 513-523.

McClelland, K.P., B. Green, D. Campell, Dr. B. Rossnagel, J.Foster, Dr. N. Kendall (2009). *Malting Barley.*

Molina-Cane, J. P. Polo, E. Romera, J. L. Arans, J. Zarco and J. S. Swaston (2001). Relationship between Barley Hordines and Malting Quality in Mutant of cv. Triumph 1; Genotype by Environment Interaction on Hordein Content (abs). *Journal of Cereal Science* 34 (30): 285-294.

Moreno A., M. M. Moreno. F. Ribas and M. J. Cabello (2003). Influence of nitrogen fertilizer on grain yield of barley (*Hordeum vulgare* L.) under irrigated conditions. *Spanish Journal of Agricultural Research* 1(1):71-100

Muurinen S., G. A. Slafer and P. Peltonen-Saino (2006). Breeding Effeect on Nitrogen Use Efficiency of Spring Cereals under Northern Conditions. *Journal of Crop Science* 46 (2): 561-568

Nanak C., S. R. Vishwakarma, O. P. Verma and M. Kumar (2008). Worth of Genetic Parameters to Sort out New Elite Barley Lines over Heterogeneous Environments. *Barley Genetics Newsletter* 38:10-13

Newman, R.K. and Newman, C.W. (2008). *Current Status of Global Barley Production and Utilization,* in Barley for Food and Health: Science, Technology, and Products, John Wiley & Sons, Inc., Hoboken, NJ, USE, Doi: 10.1002/9780470369333.ch9

Newton, A.C., A.J. Flavell, T.S. George, P. Leat, B. Mullholland, L. Ramsay, C. Revoredo Giha, J. Russell, B.J. Stefferson, J.S. Swanston, W.T.B. Thomas , R. Waugh, P.J. White, I.J. Bingham (2011). Crops that feed the world 4. Barley: a resilient crop? Strengths and weaknesses in the context of food security. *Food Security* 3:141-178.

O'Donovan, J .T., Turkington T. K., Edney M .J, Clayton G. W., Mackenzie R. H., Justkiw P. E., Lafond G. P., Grant C. A., Brandt S., Harker K. N., Johnson E. N. and May W. E. (2011). Seed Rate, Nitrogen Rate And Cultivar Effects On Malting Barley Production. *Agronomy Journal* 103 (3); 709-716 (doi: 10.2134/agronj2010.0490).

O'Donovan, J .T., Turkington T. K., Edney M .J, Justkiw P. E., Mackenzie R. H., Harker K. N., Clayton G. W., Lafond G. P., Grant C. A., Brandt S., Johnson E. N., May W. E., and Smith, E. (2012). Effect of seed date and seed rate on malting barley production in western Canada. *Canadian Journal of Plant Science 92:321-330.*

Okalebo, J.R., K.W. Gathua and P.L. Woomer (2002). *Laboratory methods of soil and plant analysis: A Working Manual, 2nd edition.*TSBF-CIAT and SACRED AFRICA, Nairobi Kenya.

Panda, S. C. (2005). *Agronomy AGRIBIOS, INDIA*

Rao W. M., Abdul Q., Shoib L., Amir H., Malik M. Y., Bashir A., Jahangir S., Mumtaz H., Ahmad N. A., Sajjad H. Q. and Etrat N. (2012). Variability, Heritability and Genetic Advance for Some Yield and Yield Related Traits in

Barley (*Hordeum vulgare* L.) Genotypes in Arid Conditions; *Journal of Food, Agriculture and Environment* Vol. 10 (3&4):626 – 629.

Shengguan C., Gang Y., Xianhong C., Yechang H., Xiaogang J., Guoping Z. and Xiaoli J. (2013). Grain protein content variation and its association analysis in barley. *BMC Plant Biology* 13:35.

Singh Ramesh K. & Singh R.K. (2005). Effect of time and levels of nitrogen application on malt barley (*Hordeum vulgafre*). *Indian Journal of Agronomy. 50(2): 137-139.*

Soudabeh A., Davoud H., Naser M., and Marefat G. (2013). Evaluation of Genetic Diversity Genotypes of Barley Using Agronomic and Morphological Traits. *International Journal of Agronomy and Plant Production* Vol. 4 (2): 350-354

Sterling Investment Bank, (2010). *Company report – EABL.*Nairobi, Kenya.

Sukram P., Singh T. and Ramesh B., (2010). Estimation of Genetic Parameters in Barley (*Hordeum vulgare* L.); *Journal of Crop Improvement* (Abs.) 37 (1): 52 – 56

Tambussi E. A., S. Nogues, P. Ferrio, J. Voltas and J.L. Araus (2005). Does Yield Potential Improve Barley Performance in Mediterranean Conditions? A Case Study; *Field Crops Research,* 91: 149 – 160

Tamm, U., (2003). The variation of agronomic characteristics of European malting barley varieties. *Agronomy Research* 1:99-103.

Weltch w. R. (2006). Genotypic variation in oil and protein in barley grain. *Journal of the Science of Food and Agriculture* 29 (11) PP 953-958

Western Australian Department of Agriculture and Food (2007). *Barley Mutation.* Available at http://www.agric.wa.gov.au. Access on 16/06/2012.

Zadoks J. C., T. T. Chang and C. F. Konzak (1974). A decimal code for the growth stages of cereals. *Weed Research.,* 14:415-421.

APPENDICES

Appendix I: Extractable soil nutrients at Mau Narok and UoE experimental sites

Site	Site history	Core depth	pH(H_2O)	P(ppm)	Total N(%)	% OC
Chepkoilel	stubble	0 – 15 cm	4.75	8.62	0.13	1.93
Mau Narok	stubble	0 – 15 cm	5.40	18.75	1.16	2.14
Chepkoilel	stubble	15 – 30cm	4.70	7.99	0.13	1.92
Mau Narok	stubble	15 – 30cm	5.30	15.46	1.01	2.42

Appendix II: Rainfall amount during the growth phase at Mau Narok and UoE

Mau Narok (August, 2011 – January, 2012)		UoE (May – September, 2012)	
Month	Amount (mm)	Month	Amount (mm)
August 2011	97	May	231.2
September	73	June	140.6
October	83	July	137.8
November	100	August	110.3
December	61	September	99.5
January, 2012	30	October	0
Total	**444**		**719.4**

Appendix III: 1000 – Kernel weight in grams for the test varieties

Sample(100 grains)	HKBL 1512-5 (g)	HKBL 1385-13 (g)	NGUZO (g)
1	5.814	5.424	4.072
2	5.943	5.468	4.068
3	5.945	5.215	3.838
4	5.786	5.192	4.06
5	5.897	5.245	4.146
6	5.682	5.136	4.047
7	5.686	5.369	4.136
8	5.569	5.296	3.916
Total	46.322	42.345	32.283
Mean	**5.79025**	**5.293125**	**4.035375**
Variance	0.01869	0.01383	0.11245
S. Dev.	0.1367	0.1176	0.106.44
CV (%)	2.4	2.2	2.65
1000-Kernel wt.	**57.9 gms**	**52.9 gms**	**40.4 gms**

Appendix IV: Pure germinating seed (PGS) for test varieties

Appendix IVA: Pure germinating seed (PGS) for HKBL 1512-5 variety

Seedling category	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Total	**Mean**	%
Normal	24	24	24	23	95	**23.75**	95
Abnormal	0	0	0	2	2	**0.5**	2
Hard	0	0	0	0	0	**0.0**	0
Soft	1	1	1	0	3	**0.75**	3
Total	**25**	**25**	**25**	**25**	**25**	**25**	**100**

Appendix IVB: Pure germinating seed (PGS) for HKBL 1385-13 variety

Seedling category	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Total	**Mean**	%
Normal	23	19	21	24	87	**21.5**	87
Abnormal	1	1	0	1	3	**0.75**	3
Hard	0	0	0	0	0	**0.0**	0
Soft	1	5	4	0	10	**2.25**	10
Total	**25**	**25**	**25**	**25**	**25**	**25**	**100**

Appendix IVC: Pure germinating seed (PGS) for Nguzo variety

Seedling category	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Total	**Mean**	%
Normal	21	23	22	21	87	**21.5**	87
Abnormal	1	0	0	2	3	**0.75**	3
Hard	0	0	0	0	0	**0.0**	0
Soft	3	2	3	2	10	**2.25**	10
Total	**25**	**25**	**25**	**25**	**25**	**25**	**100**

Appendix V: Experimental Plot Layout

BLOCK I				BLOCK II				BLOCK II		
V2D3	V2D2	V2D1		V2D2	V2D1	V2D1		V3D2	V3D1	V3D3
1 N3	24N0	25 N2		48 N2	49 N1	72 N0		73 N2	96 N3	97 N1
2 N1	23N0	25 N3	1M	47N0	50N3	72 N1	1M	74N0	95N2	98 N3
3N0	22N1	27 N1		46 N3	51 N0	70 N2		75 N1	94 N0	99 N2
4 N2	21N3	28 N0		45 N1	52 N2	69N3		76 N3	93 N1	100N0
					1M					
V1D1	V1D3	VID2		V3D2	V3D3	V3D3		V1D1	V1D3	V1D2
5N 2	20 N1	29N0		44N3	52N0	68 N1		77N0	92 N3	101N2
6 N1	19 N2	30 N3		43 N0	53 N0	68 N1		77 N0	92 N3	101N2
7 N3	18 N0	31 N2		42 N1	55N3	66 N0		79 N3	90 N2	103N0
8 N0	17N3	32N1		41 N2	56N1	65 N3		80N2	89 N1	104N3
					1M					
V3D1	V3D3	V3D2		V1D2	VID1	V1D3		V2D1	V2D3	V2D2
9 N2	16N3	33 N0		40 N0	57 N3	64 N1		81N2	88N3	105N0
10 N3	15 N1	34N2		39 N2	58 N0	63 N2		82 N3	87 N1	106N2
11 N1	14 N0	35 N3		38 N1	59 N1	62 N3		83 N0	86 N2	107N1
12 N0	13 N2	36 N1		37 N3	60 N2	61 N0		84 N1	85 N1	108N3

Key: V1 – Variety 1 (HKBL 1512-5), V2 – Variety 2 (Nguzo), V3 – Variety 3 (HKBL 1383-13);

D1, D2 and D3 – Seed rates (150, 200, 250 plants per square meter, respectively);

N0, N1, N2 and N3 – Nitrogen rates at 0, 30, 40.25 and 50kg ha^{-1} respectively).

1-108 – Plot serial numbers

Appendix VI: Combined Analysis of variance (ANOVA) tables

Appendix VIA: Combined ANOVA table for Mau Narok 2012

Source of variation	Plants m^{-2}	Tillers/ Plant	Spike length(cm)	No. of Grains spike^{-1}	Grain yield (t ha^{-1})	1000 kernel wt. (g)	Maltable grains(g/kg)	N_2 Content (%)
Variety	**	NS	***	***	*	**	***	***
Seed rate	***	***	**	**	***	**	**	NS
Variety*seed rate	NS	NS	NS	NS	NS	NS	NS	NS
Nitrogen level	**	***	NS	NS	***	NS	NS	***
Variety*nitrogen level	NS	NS	NS	NS	NS	NS	NS	NS
Seed rate*nitrogen level	NS	*	NS	NS	***	NS	NS	NS
Variety*seed rate*nitrogen level	NS	NS	NS	NS	NS	NS	NS	*

Legend: * significant at α=0.05, ** significant at α=0.01, *** significant at α=0.001, NS-not significant at α≤0.05

Appendix VIB: Combined ANOVA table for University of Eldoret Farm 2012

Source of variation	Plants m^{-2}	Tillers/ Plant	Spike length(cm)	No. of Grains spike^{-1}	Grain yield (t ha^{-1})	1000 kernel wt. (g)	Maltable grains(g/kg)	N_2 Content (%)
Variety	NS	**	***	**	*	***	**	*
Seed rate	***	***	NS	***	**	NS	*	NS
Variety*seed rate	NS	NS	NS	NS	NS	NS	NS	NS
Nitrogen level	NS	**	***	***	***	***	***	***
Variety*nitrogen level	NS	NS	NS	**	NS	NS	***	*
Seed rate*nitrogen level	NS	NS	NS	NS	NS	NS	NS	NS
Variety*seed rate*nitrogen level	NS	NS	NS	NS	NS	NS	NS	NS

Legend: * significant at α=0.05, ** significant at α=0.01, *** significant at α=0.001, NS-not significant at α≤0.05

Appendix VII: ANOVA tables for yield and quality components a the Mau Narok

Appendix VIIA: ANOVA table for plant establishment (plants m^{-2}) at Mau Narok 2012

Dependent Variable: Plant count

R-Square	CoeffVar	Root MSE	Plant count Mean
0.883227	11.73568	18.25006	155.5093

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Block	2	3730.35185	1865.17593	5.60	0.0062
Variety	2	32570.90741	16285.45370	48.90	<.0001
Block*variety	4	2769.64815	692.41204	2.08	0.0963
Seedrate	2	77142.51852	38571.25926	115.81	<.0001
Variety*seedrate	4	2582.81481	645.70370	1.94	0.1172
Block*variety*seedrate	12	2786.50000	232.20833	0.70	0.7470
Nitrogen	3	4389.58333	1463.19444	4.39	0.0077
Variety*nitrogen	6	3453.61111	575.60185	1.73	0.1321
Seedrate*nitrogen	6	3246.00000	541.00000	1.62	0.1583
Variety*seedrate*nitrogen	12	3363.55556	280.29630	0.84	0.6084
Error	54	17985.5000	333.0648		
Corrected Total	107	154020.9907			

Tests of Hypotheses Using the Anova MS for block*variety as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Variety	2	32570.90741	16285.45370	23.52	0.0061

Tests of Hypotheses Using the Anova MS for block*variety*seedrate as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Seedrate	2	77142.51852	38571.25926	166.11	<.0001
Variety*seedrate	4	2582.81481	645.70370	2.78	0.0759

Appendix VIIB: ANOVA table for productive tillers per plant at Mau Narok

Dependent Variable: Productive tillers (No.)

R-Square	CoeffVar	Root MSE	Productive tillers (No) Mean
0.812452	21.70496	1.280191	5.898148

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Block	2	21.2407407	10.6203704	6.48	0.0030
Variety	2	52.2407407	26.1203704	15.94	<.0001
Block*variety	4	37.4814815	9.3703704	5.72	0.0007
Seedrate	2	122.7962963	61.3981481	37.46	<.0001
Variety*seedrate	4	22.0925926	5.5231481	3.37	0.0156
Block*variety*seedrate	12	26.7777778	2.2314815	1.36	0.2132
Nitrogen	3	50.9166667	16.9722222	10.36	<.0001
Variety*nitrogen	6	2.0555556	0.3425926	0.21	0.9725
Seedrate*nitrogen	6	24.8333333	4.1388889	2.53	0.0315
Variety*seedrate*nitrogen	12	22.9444444	1.9120370	1.17	0.3300
Error	54	88.5000000	1.6388889		
Corrected Total	107	471.8796296			

Tests of Hypotheses Using the Anova MS for block*variety as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Variety	2	52.24074074	26.12037037	2.79	0.1745

Tests of Hypotheses Using the Anova MS for block*variety*seedrate as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Seedrate	2	122.7962963	61.3981481	27.51	<.0001
Variety*seedrate	4	22.0925926	5.5231481	2.48	0.1005

Appendix VII C: ANOVA table for spike length (cm) at Mau Narok 2012

Dependent Variable: spike length (cm)

R-Square	CoeffVar	Root MSE	spike length (cm) Mean
0.927627	4.875280	0.392641	8.053704

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Block	2	7.99796296	3.99898148	25.94	<.0001
Variety	2	92.86351852	46.43175926	301.18	<.0001
Block*variety	4	0.17037037	0.04259259	0.28	0.8920
Seedrate	2	0.98685185	0.49342593	3.20	0.0486
Variety*seedrate	4	0.51814815	0.12953704	0.84	0.5058
Block*variety*seedrate	12	0.50666667	0.04222222	0.27	0.9911
Nitrogen	3	0.29962963	0.09987654	0.65	0.5877
Variety*nitrogen	6	1.50092593	0.25015432	1.62	0.1587
Seedrate*nitrogen	6	0.79092593	0.13182099	0.86	0.5337
Variety*seedrate*nitrogen	12	1.06851852	0.08904321	0.58	0.8505
Error	54	8.3250000	0.1541667		
Corrected Total	107	115.0285185			

Tests of Hypotheses Using the Anova MS for block*variety as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Variety	2	92.86351852	46.43175926	1090.14	<.0001

Tests of Hypotheses Using the Anova MS for block*variety*seedrate as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Seedrate	2	0.98685185	0.49342593	11.69	0.0015
Variety*seedrate	4	0.51814815	0.12953704	3.07	0.0589

Appendix VII D: ANOVA table for number of grains spike^{-1} at Mau Narok 2012

Dependent Variable: No. of grains/spike

R-Square	CoeffVar	Root MSE	No. of grains/spike Mean
0.864970	3.618655	1.016105	28.07963

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Block	2	1.7512963	0.8756481	0.85	0.4338
Variety	2	303.4479630	151.7239815	146.95	<.0001
Block*variety	4	0.2309259	0.0577315	0.06	0.9940
Seedrate	2	7.4362963	3.7181481	3.60	0.0340
Variety*seedrate	4	0.7659259	0.1914815	0.19	0.9450
Block*variety*seedrate	12	5.1977778	0.4331481	0.42	0.9492
Nitrogen	3	2.5633333	0.8544444	0.83	0.4845
Variety*nitrogen	6	9.4327778	1.5721296	1.52	0.1884
Seedrate*nitrogen	6	6.0400000	1.0066667	0.98	0.4511
Variety*seedrate*nitrogen	12	20.2755556	1.6896296	1.64	0.1089
Error	54	55.7533333	1.0324691		
Corrected Total	107	412.8951852			

Tests of Hypotheses Using the Anova MS for block*variety as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Variety	2	303.4479630	151.7239815	2628.10	<.0001

Tests of Hypotheses Using the Anova MS for block*variety*seedrate as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Seedrate	2	7.43629630	3.71814815	8.58	0.0048
Variety*seedrate	4	0.76592593	0.19148148	0.44	0.7761

Appendix VIIE: ANOVA table for grain yield (Tonnes ha^{-1}) at Mau Narok 2012

Dependent Variable: Grain Yield (t/ha)

R-Square	CoeffVar	Root MSE	Grain yield (t/ha) Mean
0.814405	13.19648	0.582845	4.416667

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Block	2	5.86437222	2.93218611	8.63	0.0006
Variety	2	15.62940000	7.81470000	23.00	<.0001
Block*Variety	4	4.46211111	1.11552778	3.28	0.0176
Seedrate	2	19.80097222	9.90048611	29.14	<.0001
Variety*Seedrate	4	0.74369444	0.18592361	0.55	0.7017
Block*Variety*Seedrate	12	1.67910000	0.13992500	0.41	0.9526
Nitrogen	3	10.01215556	3.33738519	9.82	<.0001
Variety*Nitrogen	6	4.43860000	0.73976667	2.18	0.0593
Seedrate*Nitrogen	6	10.63049444	1.77174907	5.22	0.0003
Variety*Seedrate*Nitrogen	12	7.23488333	0.60290694	1.77	0.0764
Error	54	18.34421667	0.33970772		
Corrected Total	107	98.84000000			

Tests of Hypotheses Using the Anova MS for block*variety as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Variety	2	15.62940000	7.81470000	7.01	0.0493

Tests of Hypotheses Using the Anova MS for block*variety*seedrate as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Seedrate	2	19.80097222	9.90048611	70.76	<.0001
Variety*seedrate	4	0.74369444	0.18592361	1.33	0.3149

Appendix VII F: ANOVA table for 1000 kernel weight (g kg $^{-1}$) at Mau Narok 2012

Dependent Variable: 1000 Kernel weight (g)

R-Square	CoeffVar	Root MSE	1000 Kernel weight (g) Mean
0.817873	3.644997	1.811375	49.69481

Source	**DF**	**Anova SS**	**Mean Square**	**F Value**	**Pr> F**
Block	2	22.6085407	11.3042704	3.45	0.0391
Variety	2	465.0358796	232.5179398	70.87	<.0001
Block*Variety	4	25.0260093	6.2565023	1.91	0.1226
Seedrate	2	111.1500019	55.5750009	16.94	<.0001
Variety*Seedrate	4	11.8128815	2.9532204	0.90	0.4705
Block*Variety*Seedrate	12	71.5234333	5.9602861	1.82	0.0685
Nitrogen	3	20.7142000	6.9047333	2.10	0.1104
Variety*Nitrogen	6	25.1749056	4.1958176	1.28	0.2826
Seedrate*Nitrogen	6	8.3054722	1.3842454	0.42	0.8612
Variety*seedrate*nitrogen	12	34.2983556	2.8581963	0.87	0.5800
Error	54	177.1782167	3.2810781		
Corrected Total	107	972.8278963			

Tests of Hypotheses Using the Anova MS for block*variety as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Variety	2	465.0358796	232.5179398	37.16	0.0026

Tests of Hypotheses Using the Anova MS for block*variety*seedrate as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Seedrate	2	111.1500019	55.5750009	9.32	0.0036
Variety*seedrate	4	11.8128815	2.9532204	0.50	0.7396

Appendix VII G: ANOVA table for maltable grain (g kg-1) at Mau Narok 2012

Dependent Variable: Maltable grain (g/kg)

R-Square	CoeffVar	Root MSE	Maltable grain (g/kg) Mean
0.782529	0.806655	7.818700	969.2741

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Block	2	694.445185	347.222593	5.68	0.0058
Variety	2	6464.696852	3232.348426	52.87	<.0001
Block*Variety	4	168.053704	42.013426	0.69	0.6039
Seedrate	2	1251.359074	625.679537	10.23	0.0002
Variety*Seedrate	4	332.066481	83.016620	1.36	0.2607
Block*Variety*Seedrate	12	692.556111	57.713009	0.94	0.5116
Nitrogen	3	37.764444	12.588148	0.21	0.8919
Variety*Nitrogen	6	761.448333	126.908056	2.08	0.0712
Seedrate*Nitrogen	6	491.657222	81.942870	1.34	0.2556
Variety*Seedrate*Nitrogen	12	984.448333	82.037361	1.34	0.2231
Error	54	3301.13167	61.13207		
Corrected Total	107	15179.62741			

Tests of Hypotheses Using the Anova MS for block*variety as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Variety	2	6464.696852	3232.348426	76.94	0.0006

Tests of Hypotheses Using the Anova MS for block*variety*seedrate as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Seedrate	2	1251.359074	625.679537	10.84	0.0020
Variety*seedrate	4	332.066481	83.016620	1.44	0.2808

Appendix VII H: ANOVA table for grain nitrogen content (%) at Mau Narok 2012

Source of variation	D.F.	s.s.	m.s.	v.r.	F pr
Block stratum	2	0.005880	0.002940	0.67	
Variety	2	1.143013	0.571506	130.19	<.001
Residual	4	0.017559	0.004390	0.66	
Seed rate	2	0.034341	0.017170	2.58	0.117
Variety*seed rate	4	0.008581	0.002145	0.32	0.858
Residual	12	0.079911	0.006659	1.40	
Nitrogen level	3	0.236744	0.078915	16.58	<.001
Variety*nitrogen level	6	0.058965	0.009827	2.07	0.073
Seed rate*nitrogen level	6	0.020615	0.003436	0.72	0.634
Variety*seed rate*nitrogen level	12	0.136619	0.011385	2.39	0.015
Residual	54	0.256983	0.004759		
Total	107	1.999210			

Appendix VIII: ANOVA table for barley yield and quality components at UoE site

Appendix VIII A: ANOVA table for Plant establishment (plants m^{-2}) at the University of Eldoret farm 2012

Dependent Variable: Plant count (plants/m^2)

R-Square	CoeffVar	Root MSE	Plant count (plants/m^2) Mean
0.860438	11.95327	22.60606	189.1204

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Block	2	1433.5741	716.7870	1.40	0.2548
Variety	2	15611.1852	7805.5926	15.27	<.0001
Block*Variety	4	6706.0926	1676.5231	3.28	0.0177
Seedrate	2	107861.2407	53930.6204	105.53	<.0001
Variety*Seedrate	4	6405.7593	1601.4398	3.13	0.0217
Block*Variety*Seedrate	12	15253.8333	1271.1528	2.49	0.0113
Nitrogen	3	2688.4722	896.1574	1.75	0.1670
Variety*Nitrogen	6	5062.2222	843.7037	1.65	0.1511
Seedrate*Nitrogen	6	4283.7222	713.9537	1.40	0.2327
Variety*seedrate*nitrogen	12	4829.5000	402.4583	0.79	0.6607
Error	54	27595.8333	511.0340		
Corrected Total	107	197731.4352			

Tests of Hypotheses Using the Anova MS for block*variety as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Variety	2	15611.18519	7805.59259	4.66	0.0903

Tests of Hypotheses Using the Anova MS for block*variety*seedrate as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Seedrate	2	107861.2407	53930.6204	42.43	<.0001
Variety*seedrate	4	6405.7593	1601.4398	1.26	0.3385

Appendix VIII B: ANOVA table for productive tillers per plant at the University of Eldoret farm 2012

Dependent Variable: Productive tillers (No.)

R-Square	CoeffVar	Root MSE	Productive tillers (No) Mean
0.864407	27.59068	1.042315	3.777778

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Block	2	6.2222222	3.1111111	2.86	0.0658
Variety	2	222.7222222	111.3611111	102.50	<.0001
Block*Variety	4	14.7222222	3.6805556	3.39	0.0152
Seedrate	2	54.0555556	27.0277778	24.88	<.0001
Variety*Seedrate	4	6.5555556	1.6388889	1.51	0.2127
Block*Variety*seedrate	12	26.3888889	2.1990741	2.02	0.0396
Nitrogen	3	13.8518519	4.6172840	4.25	0.0091
Variety*Nitrogen	6	14.0925926	2.3487654	2.16	0.0610
Seedrate*Nitrogen	6	4.3148148	0.7191358	0.66	0.6805
Variety*seedrate*nitrogen	12	11.0740741	0.9228395	0.85	0.6008
Error	54	58.6666667	1.0864198		
Corrected Total	107	432.6666667			

Tests of Hypotheses Using the Anova MS for block*variety as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Variety	2	222.7222222	111.3611111	30.26	0.0038

Tests of Hypotheses Using the Anova MS for block*variety*seedrate as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Seedrate	2	54.05555556	27.02777778	12.29	0.0012
Variety*seedrate	4	6.55555556	1.63888889	0.75	0.5795

Appendix VIII C: ANOVA table for spike length (cm) at the University of Eldoret farm 2012

Dependent Variable: spike length (cm)

R-Square	Coeff Var.	Root MSE	spike length (cm) Mean
0.964749	4.111853	0.323846	7.875926

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Block	2	0.2468519	0.1234259	1.18	0.3160
Variety	2	130.2235185	65.1117593	620.84	<.0001
Block*variety	4	1.3437037	0.3359259	3.20	0.0197
Seedrate	2	1.0496296	0.5248148	5.00	0.0101
Variety*seedrate	4	0.8059259	0.2014815	1.92	0.1201
Block*variety*seedrate	12	2.3327778	0.1943981	1.85	0.0622
Nitrogen	3	15.5033333	5.1677778	49.27	<.0001
Variety*nitrogen	6	0.8327778	0.1387963	1.32	0.2628
Seedrate*nitrogen	6	0.7000000	0.1166667	1.11	0.3674
Variety*seedrate*nitrogen	12	1.9555556	0.1629630	1.55	0.1340
Error	54	5.6633333	0.1048765		
Corrected Total	107	160.6574074			

Tests of Hypotheses Using the Anova MS for block*variety as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Variety	2	130.2235185	65.1117593	193.83	0.0001

Tests of Hypotheses Using the Anova MS for block*variety*seedrate as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Seedrate	2	1.04962963	0.52481481	2.70	0.1076
Variety*seedrate	4	0.80592593	0.20148148	1.04	0.4282

Appendix VIII D: ANOVA table for number of grains spike^{-1} at the University of Eldoret Farm 2012

Dependent Variable: No. of grains /spike

R-Square	CoeffVar	Root MSE	No. of grain /spike Mean
0.923010	3.821115	1.051160	27.50926

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Block	2	5.7962963	2.8981481	2.62	0.0818
Variety	2	403.2407407	201.6203704	182.47	<.0001
Block*variety	4	25.7037037	6.4259259	5.82	0.0006
Seedrate	2	72.0185185	36.0092593	32.59	<.0001
Variety*seedrate	4	0.8148148	0.2037037	0.18	0.9456
Block*variety*seedrate	12	8.1666667	0.6805556	0.62	0.8193
Nitrogen	3	162.1759259	54.0586420	48.92	<.0001
Variety*nitrogen	6	22.2407407	3.7067901	3.35	0.0070
Seedrate*nitrogen	6	2.1296296	0.3549383	0.32	0.9231
Variety*seedrate*nitrogen	12	13.0370370	1.0864198	0.98	0.4764
Error	54	59.6666667	1.1049383		
Corrected Total	107	774.9907407			

Tests of Hypotheses Using the Anova MS for block*variety as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Variety	2	403.2407407	201.6203704	31.38	0.0036

Tests of Hypotheses Using the Anova MS for block*variety*seedrate as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Seedrate	2	72.01851852	36.00925926	52.91	<.0001
Variety*seedrate	4	0.81481481	0.20370370	0.30	0.8728

Appendix VIII E: ANOVA table for grain yield (tonnes ha^{-1}) at the University of Eldoret Farm 2012

Dependent Variable: Grain yield (t/ha)

R-Square	CoeffVar	Root MSE	Grain yield (t/ha) Mean
0.899421	11.13195	0.467099	4.196019

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Block	2	6.38471852	3.19235926	14.63	<.0001
Variety	2	42.50147407	21.25073704	97.40	<.0001
Block*Variety	4	8.19910370	2.04977593	9.39	<.0001
Seedrate	2	6.53280741	3.26640370	14.97	<.0001
Variety*Seedrate	4	4.32416481	1.08104120	4.95	0.0018
Block*variety*seedrate	12	5.33319444	0.44443287	2.04	0.0382
Nitrogen	3	24.94309907	8.31436636	38.11	<.0001
Variety*Nitrogen	6	2.38339259	0.39723210	1.82	0.1123
Seedrate*Nitrogen	6	1.61041481	0.26840247	1.23	0.3055
Variety*seedrate*nitrogen	12	3.14543519	0.26211960	1.20	0.3062
Error	54	11.7817833	0.2181812		
Corrected Total	107	117.1395880			

Tests of Hypotheses Using the Anova MS for block*variety as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Variety	2	42.50147407	21.25073704	10.37	0.0262

Tests of Hypotheses Using the Anova MS for block*variety*seedrate as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Seedrate	2	6.53280741	3.26640370	7.35	0.0082
Variety*Seedrate	4	4.32416481	1.08104120	2.43	0.1046

Appendix VIII F: ANOVA table for 1000- kernel weight (g) at the University of Eldoret Farm 2012

Dependent Variable: 1000 kernel weight (g)

R-Square	CoeffVar	Root MSE	1000 kernel weight (g) Mean
0.959575	2.641718	1.246377	47.18056

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Block	2	45.448006	22.724003	14.63	<.0001
Variety	2	1540.798350	770.399175	495.93	<.0001
Block*Variety	4	20.077144	5.019286	3.23	0.0189
Seedrate	2	6.332939	3.166469	2.04	0.1401
Variety*Seedrate	4	8.944811	2.236203	1.44	0.2336
Block*variety*seedrate	12	17.002667	1.416889	0.91	0.5413
Nitrogen	3	315.250056	105.083352	67.64	<.0001
Variety*Nitrogen	6	12.876961	2.146160	1.38	0.2388
Seedrate*Nitrogen	6	10.151239	1.691873	1.09	0.3807
Variety*seedrate*nitrogen	12	14.343344	1.195279	0.77	0.6783
Error	54	83.886650	1.553456		
Corrected Total	107	2075.112167			

Tests of Hypotheses Using the Anova MS for block*variety as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Variety	2	1540.798350	770.399175	153.49	0.0002

Tests of Hypotheses Using the Anova MS for block*variety*seedrate as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Seedrate	2	6.33293889	3.16646944	2.23	0.1496
Variety*seedrate	4	8.94481111	2.23620278	1.58	0.2429

Appendix VIII G: ANOVA table for maltable grain (g kg $^{-1}$) at the University of Eldoret Farm 2012

Dependent Variable: Maltable grain (g/kg)

R-Square	CoeffVar	Root MSE	Maltable grain (g/kg) Mean
0.953936	1.992383	18.89345	948.2843

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Block	2	17186.5420	8593.2710	24.07	<.0001
Variety	2	286754.8877	143377.4438	401.66	<.0001
Block*Variety	4	33212.1072	8303.0268	23.26	<.0001
Seedrate	2	8777.7578	4388.8789	12.30	<.0001
Variety*Seedrate	4	6562.6715	1640.6679	4.60	0.0029
Block*variety*seedrate	12	10253.3582	854.4465	2.39	0.0146
Nitrogen	3	17304.4982	5768.1661	16.16	<.0001
Variety*Nitrogen	6	14046.3368	2341.0561	6.56	<.0001
Seedrate*Nitrogen	6	1485.9601	247.6600	0.69	0.6556
Variety*seedrate*nitrogen	12	3596.2351	299.6863	0.84	0.6104
Error	54	19275.9815	356.9626		
Corrected Total	107	418456.3360			

Tests of Hypotheses Using the Anova MS for block*variety as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Variety	2	286754.8877	143377.4438	17.27	0.0108

Tests of Hypotheses Using the Anova MS for block*variety*seedrate as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr> F
Seedrate	2	8777.757813	4388.878906	5.14	0.0245
Variety*seedrate	4	6562.671543	1640.667886	1.92	0.1717

Appendix VIII H: ANOVA table for grain nitrogen content (%) at the University of Eldoret Farm 2012

Variate: N_2 (%)

Source of variation	D.F.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.022785	0.011393	1.00	
Variety	2	0.176402	0.088201	7.72	0.042
Residual	4	0.045687	0.011422	0.95	
Seedrate	2	0.018141	0.009070	0.75	0.491
Variety* Seedrate	4	0.008915	0.002229	0.19	0.942
Residual	12	0.144278	0.012023	2.10	
Nitrogen level	3	0.742973	0.247658	43.33	<.001
Variety*.nitrogen level	6	0.083769	0.013961	2.44	0.037
Seedrate*.nitrogen level	6	0.025363	0.004227	0.74	0.620
Variety*seedrate*.nitrogen level	12	0.052870	0.004406	0.77	0.677
Residual	54	0.308650	0.005716		
Total	107	1.629832			

Appendix IX: Summary of Means

Appendix IX A: Effect of Variety on Barley Yield and Malting Quality Components

Variety	Mau Narok	UoE
	Plant stand(plants m^{2})	
HKBL 1512-5	179.8 a	173.4 c
NGUZO	146.6 b	202.5 a
HKBL 1385-13	140.1 b	191.5 b
L.S.D	8.6242	10.683
CV (%)	11.7	11.95327
	Productive tillers (No.)	
HKBL 1512-5	4.94 b	2.667b
NGUZO	6.58 a	2.861 b
HKBL 1385-13	6.17 a	5.806 a
LSD	0.605	0.4926
CV (%)	21.7	27.59068
	Spike length (cm)	
HKBL 1512-5	6.753 c	6.325 b
NGUZO	8.847 a	8.583 a
HKBL 1385-13	8.561 b	8.719 a
L.S.D	0.1855	0.153
CV (%)	4.9	4.111853
	Grains spike $^{-1}$	
HKBL 1512-5	25.72 b	24.78 b
NGUZO	29.43 a	28.94 a
HKBL 1385-13	29.10 a	28.81 a
L.S.D	0.48	0.4967
CV (%)	3.6	3.821115
	Grain yield -tonnes ha^{-1}	
HKBL 1512-5	3.987 c	3.838 b
NGUZO	4.352 b	3.673 b
HKBL 1385-13	4.912 a	5.078 a
L.S.D	0.2754	0.2207
CV (%)	13.2	11.13195
	1000 Kernel wt. (gm.)	
HKBL 1512-5	52.51 c	49.93 a
NGUZO	47.57 a	41.84 b
HKBL 1385-13	49.00 b	49.77 a
L.S.D	0.856	0.589
CV (%)	3.6	2.641718
	Maltable grain (gm. Kg^{-1})	
HKBL 1512-5	980.2 a	981.7 a
NGUZO	962.9 b	875.5 b

HKBL 1385-13	964.8 b	987.6 a
L.S.D	3.6948	8.9282
CV (%)	0.8	1.992383
	Grain N-content (%)	
HKBL 1512-5	2.331 a	1.9708 a
NGUZO	2.080 c	1.9050 ab
HKBL 1385-13	2.210 b	1.8739 b
L.S.D	0.04336	0.06994
CV (%)	**3.1**	**3.9**

Appendix IX B: Effect of Seed Rate (Seeds m^{-2}) on Barley Yield and Malting Quality Components

S/Rate (Plantsm^{-2})	Mau Narok	UoE
	Plant stand (plants m^{2})	
S/Rate 1 (150)	124.9 c	147.4 c
S/Rate 2 (200)	151.6 b	196.1 b
S/Rate 3 (250)	190.0 a	223.9 a
L.S.D	8.6242	10.683
CV (%)	11.7	11.95327
	Productive tillers (No.)	
S/Rate 1(150)	7.222 a	4.694 a
S/Rate 2(200)	5.861 b	3.667 b
S/Rate 3(250)	4.611 c	2.972 c
L.S.D	0.605	0.4926
CV (%)	21.7	27.59068
	Spike length (cm)	
S/Rate 1 (150)	8.189 a	7.922 a
S/Rate 2 (200)	7.986 b	7.967 a
S/Rate 3 (250)	7.986 b	7.739 b
L.S.D	0.1855	0.153
CV (%)	4.9	4.111853
	Grains spike $^{-1}$	
S/Rate 1 (150)	28.43 a	28.50 a
S/Rate 2 (200)	28.00 ab	27.53 b
S/Rate 3 (250)	27.81 b	26.50 c
L.S.D	0.4802	0.4967
CV (%)	3.6	3.821115
	Grain yield -tonnes ha^{-1}	
S/Rate 1 (150)	3.899 c	3.854 b
S/Rate 2 (200)	4.404 b	4.311 a
S/Rate 3 (250)	4.947 a	4.423 a
L.S.D	0.2754	0.2207
CV (%)	13.2	11.13195
	1000 Kernel wt. (gm.)	
S/Rate 1 (150)	50.92 a	47.28 a

S/Rate 2 (200)	49.72 b	47.41 a
S/Rate 3 (250)	48.44 c	46.85 a
L.S.D	0.856	0.589
CV (%)	3.6	2.641718
	Maltable grain (gm. Kg^{-1})	
S/Rate 1 (150)	973.1 a	958.4 a
S/Rate 2 (200)	969.9 a	949.9 a
S/Rate 3 (250)	964.8 b	936.5 b
L.S.D	3.6948	8.9282
CV (%)	0.8	1.992383
	Grain N-content (%)	
S/Rate 1 (150)	2.2186 a	1.9153 a
S/Rate 2 (200)	2.2208 a	1.9331 a
S/Rate 3 (250)	2.1819 a	1.9014 a
L.S.D	0.04191	0.05631
CV (%)	3.1	3.9

Appendix IX C: Effect of N-Addition (kg ha^{-1}) on Barley Yield and Malting Quality Components

N-fertilizer rate (Kgha^{-1})	Mau Narok	UoE
	Plant stand (plants m^{2})	
N 0 (0)	151.1 b	186.9 a
N1 (30)	166.1 a	185.3 a
N2 (40)	154.8 b	186.6 a
N3 (50)	150.0 b	197.7 a
L.S.D	9.96	12.4
CV (%)	11.7	11.95327
	Productive tillers (No.)	
N 0 (0)	5.222 b	3.185 b
N1 (30)	5.556 b	3.889 a
N2 (40)	5.778 b	3.889 a
N3 (50)	7.037 a	4.148 a
L.S.D	0.699	0.5687
CV (%)	21.7	27.59068
	Spike length (cm)	
N 0 (0)	7.981 a	7.237 c
N1 (30)	8.111 a	7.948 b
N2 (40)	8.096 a	8.148 a
N3 (50)	8.026 a	8.170 a
L.S.D	0.2142	0.1767
CV (%)	4.9	4.111853
	Grains spike $^{-1}$	
N 0 (0)	27.885 a	25.41 b

N1 (30)	28.252 a	27.96 a
N2 (40)	28.207 a	28.22 a
N3 (50)	27.974 a	28.44 a
L.S.D	0.5544	0.574
CV (%)	3.6	3.821115
	Grain yield -tonnes ha^{-1}	
N0 (0)	3.930 c	3.397 c
N1 (30)	4.424 b	4.250 b
N2 (40)	4.559 ab	4.514 a
N3 (50)	4.754 a	4.623 a
L.S.D	0.3180	0.2549
CV (%)	13.2	11.13195
	1000 Kernel wt. (gm.)	
N 0 (0)	49.29 a	44.34 c
N1 (30)	49.23 a	47.43 b
N2 (40)	50.07 a	48.18 a
N3 (50)	50.19 a	48.77 a
L.S.D	0.988	0.680
CV (%)	3.6	2.641718
	Maltable grain (gm. Kg^{-1})	
N 0 (0)	970.08 a	927.5 b
N1 (30)	968.60 a	948.8 a
N2 (40)	969.59 a	958.4 a
N3 (50)	968.83 a	958.5 a
L.S.D	4.266	10.310
CV (%)	**0.8**	**1.992383**

	Grain N-content (%)	
N 0 (0)	2.131 b	1.7937 d
N1 (30)	2.218 a	1.8956 c
N2 (40)	2.222 a	1.9600 b
N3 (50)	2.258 a	2.0170 a
L.S.D	0.03764	0.04125
CV (%)	**3.1**	**3.9**