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Evaluation of Nitrogen Fertilizer and Lime on Grain Yield, Protein Content and Kernel Weight of Barley (*Hordeum vulgare* L.) in Kenya

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Authors' contributions

This work was carried out in collaboration between all authors. Author NSW provided the study concept and design, performed the statistical analysis and wrote the first draft of the manuscript. Author JOO was the principal investigator of the larger project. All the four authors read and approved the final manuscript.

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ABSTRACT

Barley requires adequate nitrogen (N) for high grain yields and quality malting, but the balance between adequate and excessive N is important therefore field experiments were set up between July 2011 and July 2012 to evaluate the effects of nitrogen fertilizer rates and liming on the grain yield and malting qualities of barley (grain protein content and kernel weight). The experiments were conducted at medium altitude at University of Eldoret (2185 m asl) and at high altitude in Mau-Narok (2740 m asl) in Kenya. Nitrogen as C.A.N fertilizer was applied at 5 levels 0, 30, 40, 50 and 60 kg N/ha, at planting. Phosphorus (TSP) at 20 Kg P/ha, and potassium (muriate of potash) at 35 kg/ha as K_20, were applied as blanket in plots with nitrogen treatments. There were two controls; absolute control (no fertilizer) and the other one having phosphorus applied. Lime was applied at

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0 & 1.5 t/ha. Split plot arrangement in RCBD design was adopted. Both sites were acidic (soils) and deficient in phosphorus with Mau-Narok having more soil N. The effect of nitrogen on grain yield was highly significant (P=.001). Increasing N rates beyond 40 kg N/ha increased the grain protein content beyond the malting range. Effect of lime on grain yield was significant ($P \leq .01$) for both sites. Lime treatments had higher grain protein contents. Lime-nitrogen interaction on kernel weight was highly significant ($P \leq .001$) but not for grain yield. Application of lime in combination with N rates at 30 and 40 N kg/ha produced best results for grain yield (>7 t/ha), kernel weight and grain crude protein (10-13.5%). Nitrogen rates at 30 N and 40 N kg/ha produced highest grain yield, highest kernel weight and recommended maltable grain protein content and therefore is recommended as optimum agronomic rates for both sites. In addition, liming is recommended for Eldoret site while phosphorus use for Mau-Narok.

Keywords: Nitrogen rates; lime; yield; grain protein content; kernel weight.

1. INTRODUCTION

Barley (*Hordeum vulgare* L.) is the world's fourth important cereal crop after wheat, maize and rice. It is grown over wider environment range than any other cereal crop and probably grows in many areas unsuitable for other crops [1].

Barley requires adequate nitrogen (N) for good yields, but since grain protein in excess of industry limits, often results in rejection of a crop and since excess nitrogen leads to smaller kernel size, the line between adequate N and excessive N is fine [2]. In addition, excessive N may result in lodging, which lowers yields and increases the incidence and severity of head blight and other diseases in some [2]. For a recommended malting barley variety to be acceptable for a malting grade, the grain should contain 9 to 11.5 per cent protein [3] as per the requirements of International Malting Association (IMA). Protein levels in barley are determined by the amount of available soil nitrogen plus growing season moisture and temperature conditions. High rates of nitrogen and/or limited soil moisture may result in protein content above the acceptable levels [3]. Malting barley yields have remained low in Kenya at a national average of 2.2 tones against a potential of 5 to 7 tons per hectare and only 76% of harvested barley attained the acceptable grain nitrogen content in the year 2010 [4]. Malting barley responds well to nitrogen fertilizeron soils with low N exhibiting increases in yield and protein content [5]. However, too much nitrogen can increase protein beyond levels not acceptable to the malting industry standards. Excessive grain protein lengthens steeping times, makes germination erratic coupled with undesirable qualities in malt [5].

Besides, over application of N, excessively high grain protein levels can also arise from low rainfall and high temperatures after an thesis [5]. Therefore, malting barley grower must address field management and environmental uncertainties to produce profitable crops. Prediction of optimum rates of N-fertilizer application for malt barley can be made based on the amount of pre-plant soil NO_3-N to estimate available N in the soil [6]. The desired grain protein content in malting barley should be greater than 9.0 but less than 11.5% (1.4 – 1.7% N) in two-row barley, which are the most common barley cultivated for malting in Kenya. Grain protein content is controlled by multiple genes and the environmental factors especially precipitation during growing season [7].

Currently, farmers are faced with higher N fertilizer prices. Fertilizer N prices are impacted by natural gas prices since natural gas and petroleum fuel represents a major portion of production costs of fertilizer N [5] which increases the overall cost of barley production reducing the profit margin. Due to increase in demand for beer from barley, malting companies need the right quality of barley grain in terms of correct grain protein content that will produce the best beer quality for consumers.

From this one question arises; what are the correct N fertilizer applications rates which farmers would use to get satisfactory yields and good quality grain for malting? To answer these questions, it warranted a study to try and get the solution.

The main objective of the study was to evaluate how varying nitrogen fertilizer rates and liming affect grain yield, grain protein content and kernel weight. In addition, lime effects on phosphorus availability in soils were studied.

2. METHODOLOGY

The experiments were done at the University of Eldoret (0.52ºN, 35.27ºE) as Eldoret sitewith altitude of 2185m asl and Mau Narok (0^o 20'S, 35º 35'E) as Mau sitewith altitude of 2740 m asl. Barley variety hybrid HKBL-5 was used in this study. The University of Eldoret site is classified as lower highlands agro-ecological zone with annual rainfall 900-1100 [8]. It has acidic soils classified as rhodic ferralsols (USDA) with $_P$H 4.8. Mau Narok site is classified as upper highlands zone with annual rainfall 1200 – 1400 mm p.a. [8]. The site has humic, deep, well drained soils known as andosols (FAO/ UNESCO) having $_P$H 5.4.

Split plot arrangement in completely randomized block design was adopted. Lime was taken as the main treatment and applied at the rates of 0 & 1.5 t/ha in the main plot. Each plot unit measured 1.5 by 3 m with row to row spacing of 20 cm.

Nitrogen treatment was split into 5 levels i.e. 0, 30, 40, 50 and 60 kg N/ha in each of the two blocks created from lime application (no lime block and the one with lime). Phosphorus (TSP) at 45 kg/ha as P_20_5 or 20 Kg P, and potassium (muriate of potash) at 35 kg/ha as K_20, were applied as blanket in plots with nitrogen treatments. There were two controls; absolute control (no fertilizer) and the other one having phosphorus applied. Treatments in each block were randomly allocated. Each study site had 3 replicates.

For laboratory analyses, soil samples for initial characterisation were randomly taken to a depth of 20 cm from the field.The analyses included; Total N, available P, organic carbon and soil pH before planting. In addition, Soil total N, soil pH and soil available P determined after harvest maturity of the crop.

Plants population was established from the recommended seeding rate of 200 plants/m^2. This was based on measured 1000-kernel weights of pure seed germination percentage and an assumption of 5% seedling mortality [6].

One hundred (100) healthy plants were randomly sampled for analysis of total N, total P and protein content in grain just after harvesting of the crop. Total N was by colorimetric method, soil organic carbon using Walkley-Black method, soil pH using water, grain total P and soil available P (Olsen method) as per[9] and crude protein content [10]. Grain weight (1000 kernel weight) was done as per the procedures of [11].

Data analysis was done using Genstat Edition 12, 2012 statistical package using General Linear Model which involved analysis of variance to ascertain the effect of N rates, lime and soil type on yield, grain protein content and kernel weight. Multiple comparisons on N rates were done while separation on means of different N rates was by Duncan Multiple Range Test (DMRT) at 5% level of significance respectively.

3. RESULTS AND DISCUSSION

3.1 Soil Fertility Status

Initial soil characterization of study sites indicated that both sites had acidic soils, with low levels of available phosphorus. The University of Eldoret site was deficient in both nitrogen and phosphorus coupled with high acidity i.e. low pH. The results are given below (Table 1).

In addition to the results In Table 1, both study sites had similar texture class of sandy loams with 61% and 71% sand, 14% and 8% clay and 25% and 21% silt respectively.

Application of lime increased the available phosphorus in the soils (Figs. 1 and 2). Soil available P after harvest was much higher than initial levels before planting in the limed treatments. Increase in soil available P was also supported by the increase in soil pH after lime application. The increase in soil pH resulting from

Table 1. Initial top-soil (0-20 cm depth) characterization of the sites before planting

Parameter Eldoret	Mau	Narok	Method
$_P$H H_20	4.75	5.40	Glass electrode
P (ppm)	8.62	12.75	Olsen method
Total %N	0.03	0.16	Kjeldahl method
% OC	1.93	2.14	Walkly-Black method
Bulk density	1.5 g/cm	1.65 g/cm	Core sampler
Field capacity	43%v/v	40.7%v/v	Anderson and Ingram

the application of lime provides a more favorable environment for soil microbiological activity which increases the rate of release of plant nutrients, particularly nitrogen. Reduced acidity due liming increased the availability of other plant nutrients mostly phosphorus.

3.2 Effect of Liming on Soil Available Phosphorus (Olsen)

It has been observed [12] that limestone treatments increased C.E.C, P_2O_5 and Ca content of the soil, but the lime application had no significant effects on available K_2O and bulk density of the topsoil. On acid soils (pH less 6.0) as those reported in this study, the fixed phosphorus is retained in less available forms than on slightly acid to neutral soils (pH 6.1 to 7.5) [12]. Therefore the major benefits of liming acid soils are the increased utilization of residual fertilizer phosphorus by crops.

3.3 Effect of Varying Nitrogen Rates and Use of Lime on Grain Yield of Barley

Increase in nitrogen rates was not proportional to yield increase. At low rates of nitrogen, grain yield increased but there was no yield response at higher rates (Table 2). Basing on the initial soil analysis, it was clear that the Mau-Narok soil had adequate N for barley growth. Therefore at higher N rates, nitrogen applied was not assimilated to grain but to other parts like shoot biomass etc. The results from this study were in agreement with those of [3] who indicated that in favorable conditions, increasing applications of fertilizer nitrogen increase dry matter production and grain yield.

A correlation between N fertilizer rates and yield, though imperfect, was found in this study (r=0.4). This has also been reported in barley by [3] except at a high nitrogen levels. In addition, [13] found a highly significant interaction effect of lime and superphosphate on enzyme activity but no direct effects of lime on yield were established. According to [6] grain yield was strongly affected by rate of N fertilizer application. According to [13], fertilizer N, soil N and variety significantly affected yield, and the responses of the varieties varied significantly with fertilizer N rate. From the results presented, lime treatments produced more grain yield compared to un-limed treatments for the two different site soils. This shows that lime alone has the capacity to increase yield by facilitation of nutrient availability to the crop by changing the soil pH. Lime raised soil pH that increased availability of soil P by unlocking the soil fixed P into available P for crop use. Lime increases availability of other nutrient elements mostly basic cations essential to crop use especially calcium which forms plant structure. Lime with N rates at 40 kg N/ha produced the highest yields ($P \leq .01$).

3.4 Effect of varying Nitrogen Rates and Use of Lime on Grain Protein Content of Barley

Lime treatments had higher grain protein contents than non-limed ones (Table 3). Increasing nitrogen rates increased the protein content beyond malting range as indicated below (10-13.5%). Grain protein content at harvest ranged from 8.3% to 12.3%. Absolute controls (no N applied) for Mau had very low protein values not suitable for malting. This was because the Eldoret soils had a critical N deficient that led to rapid absorption and utilization of the applied nitrogen. All treatments except control and 60 N/kg had acceptable or required grain protein as 9-11.5% protein [3] and protein content of 11 to 12.5%. This was also consistent with the East Africa Malting Limited (EABL) protein ranges of 10-13.5% [4]. It is well known that lime affects P availability in the soil which then affects protein synthesis in the plant. Lime also increases availability of cations like Ca, Mg which acts as catalysts in protein synthesis. Protein content obtained just after physiological maturity stage was lower than those determined after harvest. This could be explained by the fact that at grain filling stage the plants were still actively absorbing nitrogen from the soil. In addition, the nitrate reductase (NR) activity responsible for nitrogen translocation in the plant was still active [3].

Grain protein levels in barley are a function of amount of available soil nitrogen plus soil moisture and temperature conditions during a season. High rates of nitrogen and/or limited soil moisture result in protein content above acceptable malting levels [3].

An increase in nitrogen above 1.6% makes the grain unsuitable for malting. Grains with 2.0 to 2.6%N may be preferred for highly enzymatic malts [3]. According to [6] grain protein concentration is affected by cultivar, N fertilizer application and the interaction of cultivar and N rate.

Research [3] reports that on soils with low N supplies, malting barley responds well to N fertilizer, exhibiting increases in yield and protein content. However, too much nitrogen can increase protein beyond levels not acceptable to the malting industry standards. Excessive grain protein lengthens malting steeping periods, makes germination not uniform, and creates undesirable qualities in malt [5].

3.5 Effect of Varying Nitrogen Rates and use of Lime on Kernel Weight of Barley

Grain weight increased with nitrogen rates up to a certain point and then reduced (Table 4). Liming also had a positive effect as it increased the kernel weight whereby lime treatments

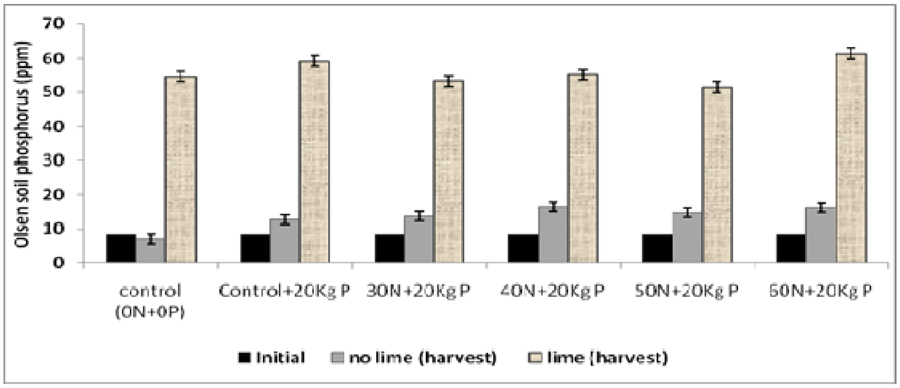

Fig. 1. Effect of liming on Olsen soil phosphorus (Eldoret)

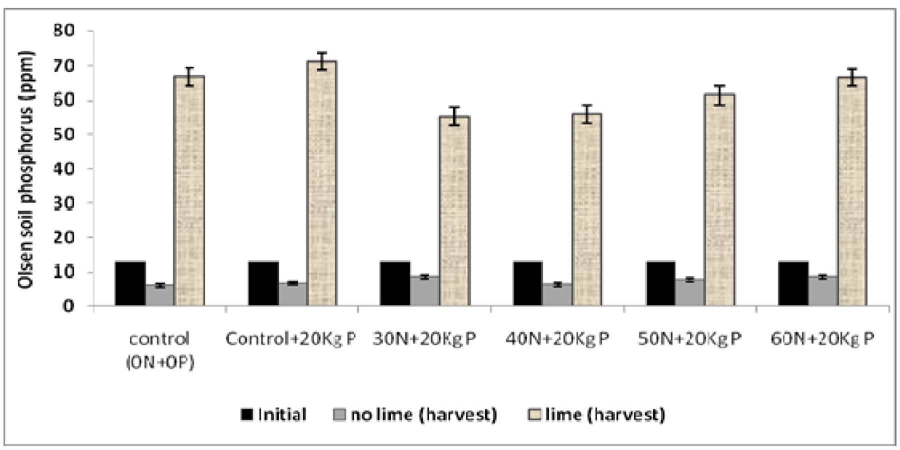

Fig. 2. Effect of liming on Olsen soil phosphorus (Mau Narok)

Table 2. Effect of nitrogen rates and lime on barley yield (t/ha) for field results after harvest

	Mau site		Eldoret site	
Treatments	**no lime(t/ha)**	**Lime(t/ha)**	**no lime(t/ha)**	**Lime(t/ha)**
Control (0N+0P)	3.62a	4.95a	2.62a	3.19a
Control+20Kg P	6.04c	6.87bc	3.37ab	4.20bcd
30N	5.80b	7.02c	3.87b	4.17cd
40N	6.11c	7.05c	4.07b	4.88d
50N	6.16c	6.76b	3.44ab	4.84ab
60N	6.16c	6.90bc	3.40ab	3.94abc
Mean	5.65	6.59	3.46	4.20
CV%	1.85	2.00	14.40	11.00
SED	0.09	0.10	0.40	0.37
LSD	0.21	0.21	0.88	0.80

Mean values followed by the same letter do not differ significantly from each other at 5% level of significance according to Duncan's Multiple Range Test (DMRT)

Table 3. Effect of N rates, lime on protein content (% Crude Protein) for field results after harvest

	Mau site		Eldoret site	
Treatment	**no lime(%CP)**	**Lime(%CP)**	**no lime(%CP)**	**Lime(%CP)**
Control (0N+0P)	9.17a	10.04a	9.80a	10.44a
Control+20Kg P	8.30b	10.11a	10.43ab	9.63a
30N	10.01c	10.44a	11.33b	12.50bc
40N	9.82c	10.22a	11.63b	12.17b
50N	10.36c	10.85a	13.17c	13.37bc
60N	11.07d	12.23b	13.10c	13.73c
Mean	9.79	10.64	11.57	11.97
CV%	3.00	4.60	6.30	5.70
SED	0.23	0.39	0.59	0.55
LSD	0.51	0.86	1.30	1.21

Mean values followed by the same letter do not differ significantly from each other at 5% level of significance according to Duncan's Multiple Range Test (DMRT)

Table 4. Effect of N rates and lime on kernel weight (g) for field results after harvest

	Mau site		Eldoret site	
Treatment	**no lime(g)**	**Lime(g)**	**no lime(g)**	**Lime(g)**
Control (0N+0P)	40.47a	45.34a	40.88a	46.20b
Control+20Kg P	44.69b	45.26a	46.42c	51.43cd
30N	44.28b	46.61b	46.73c	49.21c
40N	43.00b	46.61ab	49.67d	52.36d
50N	43.77b	46.61b	42.60ab	43.07a
60N	45.35b	46.61b	44.30b	44.57ab
Mean	43.60	46.17	45.10	47.81
CV%	3.00	2.40	2.50	2.70
SED	1.07	0.92	0.90	1.06
LSD	2.33	2.01	1.97	2.32

Mean values followed by the same letter do not differ significantly from each other at 5% level of significance according to Duncan's Multiple Range Test (DMRT)

produced grains with higher weights than those without lime. These results were in agreement with those of [14] where different nitrogen rates showed a significant effect on the absolute grain weight and volume grain weight. Studies by [15] revealed high N application rate significantly increases grain yield, grain protein and grain N content, and decreases kernel weight and kernel plumpness [6] reported higher N rates generally reduced kernel size.

It has also been reported that the proportion of kernel plumpness was affected by cultivar, kernel size is less responsive to N fertility, but may be reduced with increasing N fertility [16] [13] reported that lime caused a 12% reduction in the percentage of husk.

4. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

Nitrogen increased the yields proportionately for the Eldoret site but not for the Mau site. Nitrogen rates at 30 N and 40 N kg/ha produced highest grain yield, highest kernel weight and maltable grain protein content for both site soils. Lime with nitrogen rates of 30 N and 40 N kg/ha produced highest grain yield, highest kernel weight and maltable grain protein content both site soils. Liming the soil increased soil pH and available phosphorus. Mau Narok site had a positive response to phosphorus application.

4.2 Recommendations

For Eldoret site and its environments; liming should be given priority as the key soil amendment to reduce acidity, increase P availability and to enhance efficient water use. This will lead to sustainability in barley production in the two regions (sustainable yields and soil fertility). Apply nitrogen at 40 N kg/ha rates for better yields and grain quality. For Mau Narok; apply 30 N kg/ha (nitrogen not deficient). Increase rates of phosphorus for quality grain.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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