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Optimization of Nitrogen and Phosphorus Fertilizer for Growth and Yield of Food Barley on Nitisols in the Central High Lands of Ethiopia

Girma Chala and Temesgen Desalegn

Holeta Agricultural Research Centre, Ethiopian Institute of Agricultural Research,
EIAR P.O. Box: 2003, Addis Ababa, Ethiopia

Abstract: The objective of this study was to increase the overall performance of cropping systems by providing economically optimum nutrients to food barley production while minimizing nutrient losses from the field. A field experiment was conducted for two consecutive cropping seasons (2017-2018) on farmers' fields in Welmera district of Oromiya Regional State in Ethiopia. The treatments included five Nitrogen rates and four phosphorus rates. Nitrogen was applied in the form of urea (46% N) at a rate of 0, 23, 46, 69, 92k g N /ha and phosphorus in the form of triple superphosphate (45% P_2O_5) at 0, 10, 20, 30 kg P /ha. The treatments were laid out in a randomized complete blocks design with three replications. The results show that the highest grain yield (4858 kg/ha) was obtained at the rate of 92 kg N/ha. Similarly, with phosphorus the highest yield (4925.8 kg/ha) was recorded at the rate of 30 kg P /ha, while the maximum value cost ratio of 9.1 and 10.9 were obtained when 69kg N/ha and 10kg P/ha were applied, respectively. Balanced nutrition and fertilization is essential for soil fertility and a prerequisite for achieving adequate yields of food barley and quality of production.

Key words: Barley · Nitrogen use efficiency · Optimization · Phosphorus use efficiency

INTRODUCTION

Soil fertility is considered to be the major constraint in the highlands of Ethiopia due to continuous cultivation of these soils without adequate replenishment for long years. This made highland soils deficient in nutrients particularly nitrogen (N) and phosphorous (P). Several studies have indicated widespread nutrient mining as compared to amendments both in quality and quantity resulting in a negative nutrient balance in Africa, [1, 2]. Hence, leading to severe nutrient deficiencies across ecological zones and consequently reducing agricultural productivity. In Ethiopia, the annual net loss of nutrients is estimated to be 40 kgN ha^{-1}, 6.6 kgP ha^{-1} and 33.2 kgK ha^{-1} [3]. Nutrient depletion in Ethiopia has several causes. Application of organic fertilizer like crop residues and manure is limited because of competing uses for animal feed and house hold energy. Also problems in the fertilizer sector have restricted the wider use of inorganic fertilizers.

More soil nutrients are exported compared to natural and anthropogenic inputs [4]. Stoorvogel *et al*. [5] predicted for Ethiopia that the national nutrient balances would be on average 47 kgN ha^{-1}, 15 kgP ha^{-1} and 38 kgK ha^{-1} for the year 2000. This predication was twice as high as the average value for Sub Saharan Africa and indicates the severity of nutrient depletion in Ethiopia.

Without proper management of soil fertility continuous crop production can reduce nutrient reserves in the soil. Techniques to conserve and add nutrients to the soil through the application of organic or inorganic fertilizers can help to maintain and increase the nutrient reserves of the soil. But over supply of nutrients can also a problem, causing economic inefficiency, damage to the environment and in certain situations, harm to the plants themselves and to the animals. Whereas soil mining is primarily a problem in developing countries, over application of nutrients occurs chiefly in the developed world, some farmers to use it in amounts far in excess of plant needs and the capacity of soils to hold nutrients.

Corresponding Author: Girma Chala, Holeta Agricultural Research Centre, Ethiopian Institute of Agricultural Research, EIAR P.O. Box: 2003, Addis Ababa, Ethiopia.

Balanced in the absolute and relative application of nutrients is a part of integrated nutrient management.

Balanced fertilization does not mean a certain definite proportion of N, P and K or other nutrients to be added in the form of fertilizer, but it has to take in to account the availability of nutrients already present in the soil and crop requirement. Nutrient application achieving balance between the nutrient requirements of plants and the nutrient reserves in the soil is essential for maintaining high yields and soil fertility, preventing environmental contamination, degradation and sustaining agricultural production over the long term. In many cases, imbalance can be corrected through the application of appropriate inorganic and organic fertilizers. Barley is an old heritage with a large number of landraces and traditional practices in Ethiopia. For millennia it has been supplying the basic necessities of life for many farmers in the highlands and it has a long history of cultivation in the country [6]. Currently, barley is the most important cereal crop with total area coverage of 993,918.89 hectares and total annual production of about 1.9 million tons in main season [7].

In barley production area, the condition of the soil and its potential to provide the plant with the required nutrients are key aspects in the growth of health plant [8]. The fertility of the soil is affected by the inherent property of the soil and human interventions. In barley, applying excessive fertilizer beyond its requirement could cause lodging [9], which in turn could be accompanied with several problems. In the first place, a huge yield loss could occur due to lodging. Lodging could complicate harvesting and other operations in barely production. Moreover, it could bring discoloration of the grain, which makes it unacceptable to market.

The application of optimum amount of fertilizers is crucial to alleviate the abovementioned problems. According to CSA [10], about 128,820 ha of land cropped to barley with fertilizer application, which is about 27.5% of all crops. Even though fertilizer recommendations practices are available, they are either outdated or not location and crop-specific. Hence, determination of optimum rates of NPK for specific food barley growing locations is essential. The present study was carried out with the objective of determining the yield response of food barley to N, P and K fertilizers.

MATERIALS AND METHODS

Location of the Study Areas and Site Characteristics: The trial site was located on two sites (Welmera and Sadamo) belonging to Holeta Agricultural Research Center. Welmera areas are located in West Shewa highlands of Ethiopia, between 09°03'N latitude and 38°30'E longitude at an altitude of about 2400m above sea level. The rainfall is bimodal with long-term average annual rainfall of 1100mm, about 85% of which from June to September and the rest from January to May and average minimum and maximum air temperatures of 6.1 and 21.9°C, respectively. The environment is seasonally humid and the major soil type of the trial sites is Eutric Nitisols (FAO classification).

Experimental Design and Treatments: The experiment was conducted in 2014 and 2015 cropping seasons and the effects of five levels of N fertilizer (0,23,46,69 and 92kgN ha^{-1}) and four levels of P fertilizer (0,10,20 and 30kgPha^{-1}) in the form of triple super-phosphate -and three levels of K fertilizer (0,10 and 20kgKha^{-1}) were studied on growth, yield and yield components of barely. The experiment was conducted in a randomized complete factorial design with three replications. The cultivar used was HB1307 (Galane). The P and K fertilizers were applied at planting. Nitrogen was applied at the rate of 50% at planting but 50% at top dressing in the form of urea. Planting was done in the mid of June at the seed rate of 125kg ha^{-1} on plot size 3m x 4m. All other cultural practices were followed as per the recommendation.

Table 1: Combinations of treatments applied where

No.	Treatments	Description	No.	Treatments	Description
1	Control	Without fertilizer	9	NPK	69 kg N 10 P 20 K
2	NPK	23kg N 0P 0K	10	NPK	92 kg N 10 P 20 K
3	NPK	46kg N 0P 0K	11	NPK	69 kg N 10 P 0 K
4	NPK	69kg N 0P 0K	12	NPK	69 kg N 20 P 0K
5	NPK	92kg N 0P 0K	13	NPK	69 kg N 30 P 0 K
6	NPK	0 kg N 10 P 20 K	14	NPK	69 kg N 10 P 10 K
7	NPK	23 kg N 10 P 20 K	15	NPK	69 kg N 10 P 30 K
8	NPK	46 kg N 10 P 20 K	16	NPKSZnBMn	69 kg N 20 P 10K+ (0.5 S + 2.5 Zn + 0.5 Mn + 1B)

Data Collection: Soil physical and chemical properties were determined for samples taken during planting. These included soil texture, soil pH, organic carbon (OC), total N, available P, exchangeable cations (EC) and cation exchange capacity (CEC) of the experimental fields (Table 2). Composite surface soil samples were collected from experimental fields (0-20 cm depth) before treatment application. Similarly, soil samples were collected after harvest from each plot and then composited by replication to obtain one representative sample per treatment. Samples collected during both times were then analysed for the determinations of soil pH, organic carbon (OC), total N, available P (Table 2). Soil pH was determined with a pH electrode at soil /water ratio of 1:1 (w/v) [11].Organic carbon was determined by the method of Nelson and Sommer [12] and total nitrogen using [13]. Available P following the procedures of Bray and Kurtz [14] and Exchangeable cations and CEC were also analysed after extraction with 1 N ammonium acetate at pH 7.

Agronomic data such as grain yield, above-ground total biomass, harvest index, thousand kernel weight, plant height and spike length (average of five plants). Mature plant height was measured from the ground level to the tip of the spike excluding the awns at physical maturity. Spike length (SL in cm) was measured from the base to the top of the spike excluding awns. Thousand kernel weight (TKW in g) was measured on a sample of 250 seeds. To measure total biomass and grain yields, the entire plot was harvested at maturity in November. After threshing, the seeds were cleaned and weighed and the moisture content was measured. Total biomass (dry matter basis) and grain yields (adjusted to moisture content of 12.5%) recorded on plot basis were converted to kg ha^{-1} for statistical analysis. The SAS statistical computer package (SAS, 2002) was used to test for presence of outliers and normality of residuals.

Statistical Analysis: The first part of the analysis focussed on variation in grain yield due to fertilizer by site-year and combined across site-years. The effect of N and P fertilizer and their interactions the primary focuses of the analysis. When significant effects of N rate by P rate occurred, asymptotic regression was fitted to the yield data. The asymptotic function is given as yield (Mg ha^{-1}) $y = a - bc^N$, where *is* yield at the plateau (i.e. expected maximum), *b* is the amplitude (the gain in yield due to nutrient application), *c*is a curvature coefficient and *x* is the nutrient rate applied. The regression analyses for N rate effects included treatments with and without P and K applied, but a separate yield response analysis.

Rain use efficiency (RUE) defined as the ratio of grain yield to seasonal total rainfall was calculated and used as proxy for water use efficiency (WUE). In rain-fed agriculture, WUE is linked to the effectiveness of the use of precipitation because there is no other source of water [15]. In areas where productivity is limited by rainfall, RUE is also shown to account for rainfall variability and to some extent local soil characteristics [16]. RUE has also been proposed as a robust indicator of productivity and land degradation in moisture-limited areas [17]. Therefore, RUE was used in this study as a metric for evaluating WUE.

The second step of analyses focussed on assessment of nutrient use efficiency by food barley, mainly the agronomic efficiency of N (AEN) and phosphorus (AEP). AEN is as an integrated index of fertilizer N-recovery efficiency and physiological N-use efficiency [18]. Therefore, it closely reflects impact of the applied N fertilizer. AEN was calculated as ratio of the increased crop output to the amount of N applied. AEP was calculated in the same manner as AEN.

The third part focused on determining the financial benefits of NPK fertilizer use. Value cost ratio (VCR) was used. Before computing these values, the average yield was adjusted downwards by 15% to reflect the difference between the experimental yield and the expected yield of farmers from the same treatment. This is because, experimental yields, even from on-farm experiments under representative conditions, are often higher than the yields that farmers could expect using the same treatments and the cost of fertilizer was also taken from the study areas.

For calculation of VCR, three years average market grain price of barley (ETB 6 kg^{-1}), farm-gate price of N and P fertilizers (ETB 12kg^{-1} and 15kg^{-1}) respectively and labour cost for fertilizer application(at ETB 40 per person-day) were used. Labour for barley field management was 40 person- days per hectare. VCR was chosen as the index because it is commonly used when assessing the profitability of fertilizer use, especially in the absence of data on full production costs. Hence, VCR was calculated as a ratio of value of increased crop output to the cost of fertilizer applied. VCR measures the average gain in the value of crop output per kg of fertilizer applied. Technically, VCR = 1 means that the value of the yield increase over the control equals the cost of the fertilizer and hence the farmer's labour input is not rewarded. If there were no transaction costs in the acquisition of fertilizer, the incentive would be to apply fertilizer to the point where the VCR is 1. However, there is substantial uncertainty about the outcome of applying fertilizer and transaction costs are inevitable. A VCR $\geq$ 2 represents 100% return on the money invested in fertilizer and is sufficient to warrant investment in fertilizer [19]. Therefore, in this analysis VCR$\geq$2 was considered as a reasonable threshold for risk coverage against investment in fertilizer at the scale of smallholder farms. All analyses were done using the Statistix 9 (Analytical Software, Tallahassee, FL).

RESULTS AND DISCUSION

Soil Chemical and Physical Characteristics: The initial soil physical and chemical characteristics of the till layer (0-20cm depth) are presented in Table 2. The collected samples were analysed for the determinations of exchangeable cations, cation exchange capacity (CEC), pH, organic carbon (OC), total N and available P. The soil pH at both sites was below the critical level of 5.6 which is known to limit nutrient availability for crops. Organic carbon and total nitrogen at both sites were below the critical levels of 2% and 2 g kg^{-1}, respectively. The soil available P status below 13 mgkg^{-1} grain yield of food barley could show a significant response to applications of P fertilizer. In order to get high yield of food barley optimum level of P fertilizer application is necessary. Following the pre-planting of soil analysis results of the two trial sites had lower soil P values than the critical P concentration and this had a direct relationship with the crop growth and yields.

Grain Yield: Barley yield significantly varied with N rate (Table 3). This finding is in agreement with Minale Liben *et al.* [20] who reported that the growth parameters as well as grain yield increased as nitrogen rate is increased in barley production. Yields of barley increased by 142% over the control (without N fertilization) with N applied at the rate of 92kg ha^{-1}. The same trend was observed for phosphorus fertilizer application. Analysis of variance results revealed that phosphorous had highly significant effect on yield of food barley and grain yield consistently increased as the rate of phosphorous increased (Table 5). The highest grain yield of barley (4925.8 kg ha^{-1}) obtained at 30kg P/ha rate of application. There was no significant interaction between nitrogen and phosphorus fertilizers levels of the agronomic traits evaluated.

Rain Use Efficiency: Average rain-use efficiency (RUE) varies between 0- 92 kg ha^{-1} of nitrogen rates. As observed from this study as rain use efficiency increase the grain yield of barley also decreased (Table 3). The highest grain yield (4858kg/ha) was obtained at the lower rain use efficiency (0.242 kg ha^{-1} mm) achieved at N rate of 92kg N ha^{-1}.

As farmers attempt to evaluate the economic benefits of shift in practice, partial budget analysis was done to identify the rewarding treatments. Yield from on-farm experimental plots was adjusted downward by 15% i.e., 10% for management difference and 5% for plot size difference, to reflect the difference between the experimental yield and the yield that farmers could expect from the same treatment [21].

The economic analysis revealed that the highest VCR of (9.1) was obtained from the application 69kg N ha^{-1} fertilizers, whereas the control treatment (no application of input) non- applicably.

Agronomic Use Efficiency of Nitrogen (AEN): Increased use of fertilizer N in agricultural production has raised concerns, because the nitrogen surplus is at risk of leaving the plant-soil system causing environmental contamination and increased costs associated with the

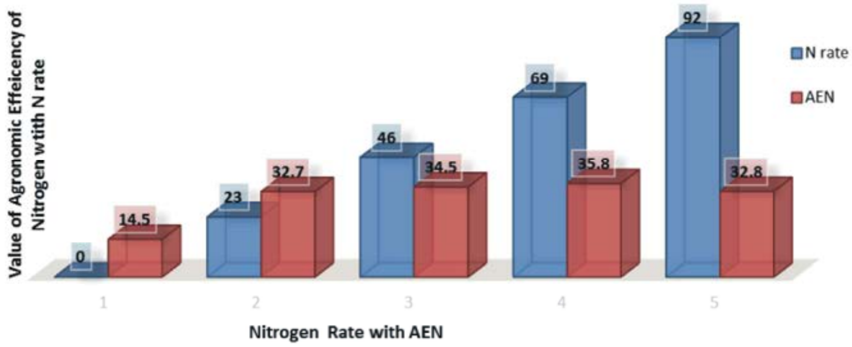
Table 2: Initial soil physical and chemical characteristics (0-20cm depth) of the experimental sites at Welmera and Sadamo

		Texture		Chemical properties				
Location	Clay (%)	Silt (%)	Sand (%)	pH (1:1H_2O)	OC (%)	TN (g kg^{-1})	P (ppm)	CEC (meq 100g^{-1})
Welmera	72.5	11.25	16.25	4.84	1.94	0.19	8.26	24.98
Sedamo	66.75	12.5	20.75	5.12	1.84	0.20	9.82	25.12

Table 3: Effect value cost ratio nitrogen rate on yield and agronomic nitrogen use efficiency of food barley

N rate	Yield (kg/ha)	RUE (mm/kgha^{-1})	Value cost ratio
0	2007.8^{d}	0.556	NA
23	2760.8^{c}	0.404	8.3
46	3596.4^{b}	0.309	8.7
69	4478.2^{a}	0.247	9.1
92	4858.0^{a}	0.242	8.3
F value	30.13	48.9	0.96
P value	54.43	0.0000	0.4288
CV (%)	11.11	13.1	10.69

RUE- Rain Use efficiency, *the same letter in Columns is not significant difference according to Tukeys.HSD



AEN- Agronomic efficiency of Nitrogen

Fig. 1: Asymptotic nonlinear regression coefficients for grain yield and economically optimal N rates for food barely

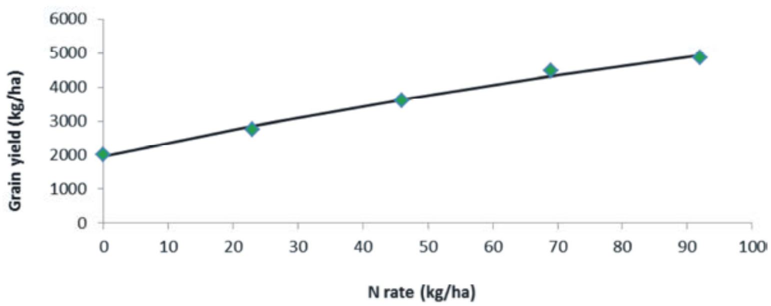


Fig. 2: Barley yield response to applied N when P rate was fixed at 0 kg/ha

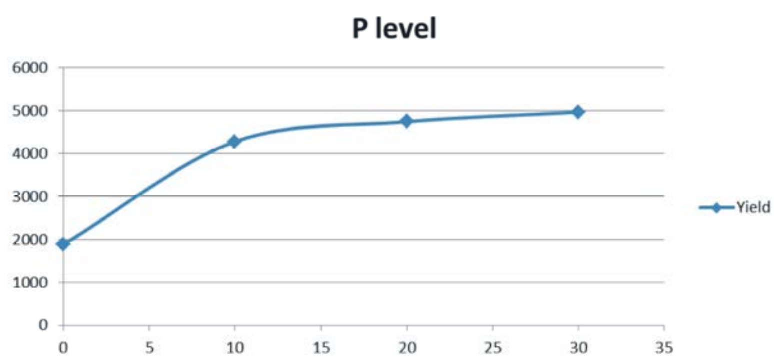


Fig. 3: Barley yield response to applied P when N rate was fixed at 69 kg/ha

manufacture and distribution of N fertilizer. Nitrogen use efficiency indexed by AEN is a parameter representing the ability of the plant to increase yield in response to N applied. Crop physiological nitrogen requirements are controlled by the efficiency with which N in the plant is converted to biomass and grain yield. The agronomic use efficiency of N significantly differed ($P< 0.005$) with treatment. The mean values of nitrogen use efficiency ranged from 14.5-35.8 (Fig. 1).

The observed asymptotic nonlinear regression coefficients analysis indicated that grain yield of food barley was positively and significantly correlated as nitrogen rate increased (Figure 1). Higher nitrogen uptake with increasing biomass is t hought to be r elated to the increased sink in plant tissues for nitrogen and may contribute to increased grain yields at maturity [22, 23].

Table 4: Coefficients of the asymptotic regression describing yield response (kg/ha) to N rate (kg/ha)

Parameter	Estimate	Lower 95% C.I.	Upper 95% C.I.
A	6410.187	2230.669	10589.71
B	4935.209	1887.465	7982.953
C	0.987223	0.965411	1.009035

A,B,C= Predefined Model

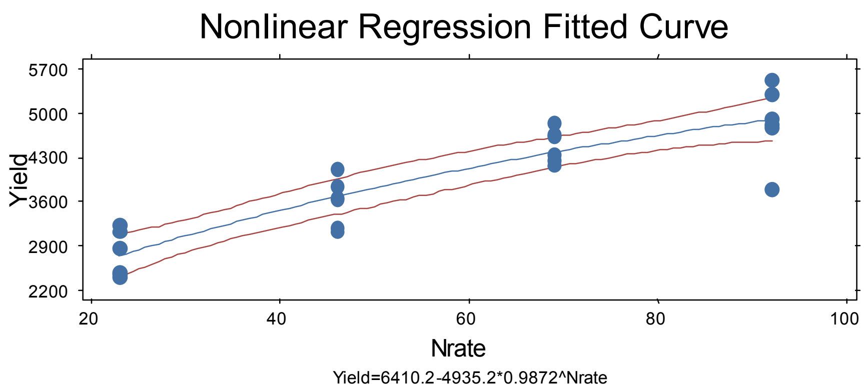


Table 5: Phosphorus application effect at rates of 0, 10, 20 and 30 kg ha^{-1} on food barley grain yields with 69kgNha^{-1} applied and the P rate × year interaction was not significant

P rate	Yield (kg/ha)	P use efficiency	RUE	Value cost ratio
0	1879.0^{b}	18.9^{b}	0.5893	NA
10	4221.4^{a}	42.7^{a}	0.2580	10.9^{a}
20	4745.1^{a}	47.4^{a}	0.2750	7.5^{b}
30	4925.8^{a}	49.7^{a}	0.2420	7.0^{b}
F value	11.11	10.95	17.18	5.37
P value	0.0002	0.0002	0.0000	0.017
CV (%)	26.2	25.77	28.77	26.48

RUE- Rain Use efficiency,*the same letter in Column is not significant difference according to Tukeys. HSD

Phosphorus Use Efficiency: Yields of barley increased in the whole range of phosphorus rates and the differences between control treatment without P fertilization and the highest P rate applied in the experiment increased by 162%. The highest P fertilizer efficiency was obtained at highest rate of phosphorus (30 kg P/ha) and lowest P use efficiency (PUE) was observed with the control treatment without P fertilization (Table 7). To evaluate the phosphorus supply in soils, different soil test have been used for a Long time; however they differ markedly in extract ants and extraction methods. Nevertheless, the result of the test is generally reported as phosphorus available to plants. When the supply of available ´phosphorus in soil is given, it is always necessary to specify the used soil test including the end-point analytical technique of phosphorus determination to avoid the misleading interpretation of results [24].

The need for economic use of phosphorus in agriculture is accentuated by the finite supply of economically P resources (phosphates) for the production of concentrated fertilizers. Sufficient reserves of P resources are estimated to last for about 70 years and maximally for 300 years [25, 26]. The economic analysis revealed that the highest VCR of (10.9) was obtained from the application10kg P/ha fertilizers, whereas the control treatment (no application of input) non- applicably.

CONCLUSION

The result demonstrate that the two years result were significantly different from each other. This is probably attributed to season differences and the carry over effect of the previous year fertilizer application as the plots were fixed during the experimental period. Interventions to increase nutrient use efficiency and reduce NP losses to the environment must be accomplished at the farm level through a combination of improved technologies and carefully crafted local policies that promote the adoption of improved N management practices while sustaining yield increases. Improved fertilizer products play an important role in the global quest for increasing nutrient use efficiency. Indeed prevalence of such nutrient below supply and depletion in different cereal grain yields implies that sustainability is threatened and nutrients are not optimally used. While these problem areas account for the largest fraction of cereals and they should be the focus of future interventions promoting optimal nutrient redistribution and inputs.

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