Effect of Lime and Different Phosphorus Fertilizer Sources on Barley (Hordeum vulgare L.) Yield and Chemical Properties of Acidic soils of Banja and Gozamen Districts, Western Amhara

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Abstract

In acid soils phosphorus reacts with Fe and Al oxides/hydroxides to form insoluble phosphates, hence reducing P availability to plants. Therefore, plant growth is highly impaired in acidic soils due to deficiency of phosphorus in addition to Al toxicity. To this end, a field experiment was carried out to determine the effect of different phosphorous fertilizer levels and lime on the grain yield of barley and chemical properties of acidic soils at Gozamen and Banja districts, western Amhara region, Ethiopia. The experiment had two sets; lime and un-limed which were conducted separately. The treatments include a combination of different phosphorous fertilizer type with eight levels (0, GPAPR 146, 219+ 100 UREA, MOHP 175, 116+100 UREA, NAFAKA 287, 191 + 100 UREA, and NPSZnB 136+100 UREA kg ha-1) and ¼ of exchangeable acidity lime. The experiment was laid in a randomized complete block design with three replications of each. At Gozamen the highest grain yield (2470 kg ha-1) was obtained with the application of lime together with 136 NPSZnB + 100 UREA kg /ha followed by the application of 146 GPAPR + 100 UREA kg ha-1 which recorded a grain yield of 2195 kg ha-1 without lime. At Gozamen the highest net benefits 49914.2 ETBha-1 with marginal rate of return 590.8% and 39746.3 ETB ha-1 with marginal rate of return 292.2% were obtained from the application of 1/4th lime plus 136 NPSZnB + 100 UREA kg /ha and sole use of 146 GPAPR + 100 UREA kg ha-1respectivly. In the case of Banja district, the application of 146 kg ha-1 GPAPR and 1/4th lime obtained the net benefit of 29893.8ETB ha-1 with marginal rate return of 1483.1% and sole application of 191 kg ha-1 NAKFA+100 kg ha-1 UREA generated 8765.45 ETBha-1 net benefits with marginal rate return of 584.6%. Generally, lime increased soil pH and reduced exchangeable acidity, and increase the availability of phosphorus.

Keywords: *Acid soil, Grain yield, Lime, Phosphorus, Soil pH.*

Introduction

Barley *(Hordeum vulgare L.)* is a major cereal crop in Ethiopia and accounts for 8% of the total cereal production (Wosene et al., 2015). Barley has a long history of cultivation in Ethiopia as one of the major cereal crops and it is reported to have coincided with the beginning of plow culture (Mulatu et al., 2011). In the highlands of the country, barley is grown in Oromia, Amhara, Tigray, and part of the Southern Nations, Nationalities, and

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cereal crop after wheat, maize, and rice (Martin et al,. 2006). Despite its importance and long history of cultivation in Ethiopia, the productivity of barley is lower than other major cereals. The national average yield of barley is about 2.16 t/ha, compared to 2.74 t/ha for wheatand3.94 t/ha for maize (CSA, 2018). One of the major constraints limiting the productivity of barley is poor soil fertility (Berhane et al., 1996; Tarekegne et al., 1997).

Soil acidity and its problem are common in all regions where precipitation is high enough to leach appreciable amounts of exchangeable bases from the soil surface. Although acidification is a natural process in many soil environments, agricultural practices, environmental pollution, mining and other human activities have aggravated the process (Oguntoyinbo *et al*., 1996; Curtin and Syers, 2001). Its severity is extremely variable due to the effects of parent materials, landform, vegetation, and climate pattern (Rowell, 1994). Its effects on crop growth are those related to the deficiency of major nutrients and the toxicity of aluminum (Al), manganese (Mn), and hydrogen (H) ions in the soil to plant physiological processes (Mesfin, 2009). In order to secure sustainable crop production and reasonable yield, acidic soils have to be corrected by the addition of agricultural lime to a pH range that is suitable for better yield of crop production (Mesfin, 2009). The beneficial effects of liming soil are neutralization of exchangeable Al, increase Ca, Mg, P, and Mo availability, stimulate microbiological activity in soil; improve the physical structure of soil by clumping together or flocculation, clay into more stable aggregates. Liming raises the soil pH by adding calcium & magnesium to soil and causes the aluminum and manganese to go out from the soil solution back in to precipitate then, solid (nontoxic) chemical forms (Johnston et al., 1986). The lime requirement will vary depending upon the types of soil, the desired change in pH, buffering capacity of the specific soil, type of liming material, and the fineness of texture of the lime material (Birhanu, 2010).

Phosphorus reacts with Fe and Al oxides/hydroxides under acidic conditions to form insoluble phosphates, hence reducing P availability to plants (Kamprath, 1984). Phosphorus deficiency often, therefore, occurs simultaneously with Al^{3+} toxicity in these soils. Efforts to ameliorate the deleterious effects of soil acidity must therefore be accompanied by measures to increase available P in soils. The addition of lime to acid soils has long been widely adopted as, the amelioration strategy for many years to improve crop production which is rarely used in Ethiopia. Application of lime at an appropriate rate brings several chemical and biological changes in the soil which is beneficial or helpful in improving crop yields on acid soils. Adequate liming eliminates soil acidity and toxicity of Al, Mn, and H: improves soil structure (aeration): improves the availability of Ca, P, Mo, and Mg, pH and N_2 Fixation; and reduces the availability of Mn, Zn, Cu, and Fe leaching loss of cations (Fageria and Baligar, 2008). The appropriate combination of lime and P fertilizer is, therefore, an important strategy for improving crop growth in acid soils. There is, however, a scarcity of information on the interactive effects of lime and P fertilizer application on crop performance in western Amhara Ethiopia. Phosphate rock is recommended for application to acid soils where phosphorus is an important limiting nutrient on plant growth. The objective of this study was, therefore, to investigate the interactive effects of lime and P fertilizer on barley grain yield on the selected soil chemical properties under acid soil conditions in Western-Amhara, Ethiopia.

Materials and Methods

Description of Study Area

The study was conducted for three consecutive years during 2015to 2017 main cropping seasons at Banja district, Awi zone, and Gozamen district East Gojjam zone in western

2338m asl in the western Amhara, Ethiopia. The site with lower pH (<5.2) and with no liming history was selected for this study. Some of the selected chemical characteristics of the experimental sites are summarized in Table 1.

Table 1. Soil chemical properties of the experimental site

Location	pH(1:2.5 soil water)	[P olson](ppm)	OC%	OM%	Exchangable acidity meq/100gm	Exchangable Al meq/100gm
Gozamen	5.1	9.2	1.6	2.82	1.5	0.9
Banja	5.2	11.7	1	1.72	1.9	1

Note: P=phosphorus, OC=Organic carbon, OM=Organic matter

Experimental setup

The experiment was laid out separately in two sets (Lime & un-limed) in a randomized complete block design with three replications of each. Four types of P fertilizer with eight levels (0, GPAPR 146 , GPAPR 219, MOHP 116, MOHP 175 NAFAKA 191 NAFAKA 287.5 NPSZnB 132.5 and 100 Urea kg/ha). For limed treatments, 1/4th of the recommended lime was uniformly applied in rows by hand every year during planting and thoroughly incorporated in the soil. Lime requirement of the soil was calculated based on its exchangeable acidity (Al^{3+} plus H^{1+}) adapted from (Kamprath, 1984). The experimental plots were kept permanent to observe the residual effects of phosphorous and lime application over years. The entire dose of phosphorous was applied at planting, while the recommended N rate of 46 kg/ha was applied in split, half at sowing, and the remaining half side dressed at tillering stage of barley. Gross plot sizes were3 m × 4m and net plot sizes 3 m × 3.6m for both districts. Food barley variety BH-1307 was used as a test crop in both districts.

Soil sampling

Before planting and application of lime, composite soil samples were taken from the experimental site using a soil auger from 0-20 cm soil depth. At harvesting, soil samples from each treatment were taken and independently analyzed. Soil samples were air-dried under shade, grounded by mortar & pestle, and sieved to pass through 2 mm mesh for further chemical analysis.

Soil analysis

The soil pH was determined using glass electrode pH meter in 1:2.5 soils to water ratio volume and exchangeable acidity (Al^{+3} and H^{+}) were extracted with KCl solutions using the (Keeney et al 1982). Available phosphorous was determined by (Olsen & Sommer, 1982). Soil organic carbon (SOC) was determined following the wet digestion method used by Walkley and Black (Van Reeuwijk, 1992)

Agronomic Data Collection and Interpretation

Dry biomass and grain yield data were collected and analyzed using the analytical procedure of SAS 9.2 version (SAS, 2008). In a condition where ANOVA is significant, the treatment means were compared using the Least Significance Difference test (LSD).

Economic Analysis of Treatment

Partial budget analysis of treatments was done according to CIMMYT (1988). The mean grain yield data of barley which was produced by each treatment over three experimental years (2015 and 2017) were used to do the partial budget analysis. The mean grain yield data were adjusted down by 10% to minimize the yield gap that may occur due to plot management differences by researchers and farmers (CIMMYT, 1988). The average prices of relevant data which were needed to do the partial budget analysis were collected from different sources. Thus, the field price of 1 kg of barley in 2018 at the local market was 15 Ethiopian Birr (ETB) and was taken as a field price of barley. The current price of Urea 12.76 ETBkg^{-1}, NPSZnB 13.82 ETBkg^{-1} and lime was 1.6 ETB kg^{-1}. The price of different phosphorous fertilizers sources (NAFAKA, MOHP, and GPAPR) were calculated by the current price of NPSZnB fertilizer.

Results and Discussions

Grain yield

The analysis of variance indicated that lime and P fertilizer application significantly ($P<0.05$) affected the grain yield of barley in two years at Gozamen District (Table 2). However, the effect of lime and P fertilizer application on grain yield of barley was found significant only during the initial and the last years at Gozamen (Table 2). But in the case of Banja district, no significant effect of lime and phosphorous fertilizer all year. The combined analysis of variance over years of both districts showed a significant ($P<0.05$) effect of P and lime application. In general, progressive increases in grain yields were recorded from the first year to second year lime and P fertilizer application. Grain yield response was found more pronounced with the second than the first due to the residual effect of lime and P application. This implies that the application of phosphate rock (PR) would benefit farmers at least from the second planting season. The extractable soil P at the second cropping season that PR continued to decompose and release P (residual effect) into the soil (Husnain., 2013).

Table 2. The main effect of lime and different source of phosphorous fertilizer on Barley yield at Gozamen District

Treatment	2015				2016				2017			
	Straw Yield kgha-1		Grain yield Kgha-1		Straw Yield Kgha-1		Grain yield Kgha-1		Straw Yield Kgha-1		Grain yield Kgha-1	
	Unlime	Lime	Unlime	lime	Unlime	lime	Unlime	lime	Unlime	lime	Unlime	lime
Control	1803	1963	579	695	3701	5059	1564	1586	1967	2722	1009	1391
2/3 GPAPR	2673	2952	1349	1523	4735	5842	2227	2835	5007	5907	2710	2881
Full GPAPR	2838	2973	1405	1483	4927	5830	2243	2597	4781	4981	2708	2781
2/3 MOHP	2445	2363	1131	1145	4726	4897	2147	2271	3804	5130	2053	2861
Full MOHP	2501	2357	1122	1114	4590	5048	2162	2395	4204	4874	2996	3247
2/3 NAFAKA	2404	2580	1183	1284	4303	5674	2006	2709	4878	5085	2674	3418
Full NAFAKA	2268	2734	1033	1341	4752	5301	2142	2462	4833	3456	2697	2088
Rec. NPSZnB	2960	4227	1342	1950	5680	6026	2585	2782	3407	4911	1693	2797
CV %	16.3	23.8	22.2	22.5	13	14.3	14.6	18.3	29	22.6	32	23.9
LSD 5%	675.8	1098.7	423.8	NS	NS	NS	NS	NS	NS	1835.7	NS	1112.8

The combined analysis over years at both locations revealed that all P sources and/or rates significantly increased grain yield of barley compared to the untreated control under limed and un-limed conditions (Table 3 and 4). At Gozamen the highest grain yields (2470 kg ha^{-1}) of barley were recorded from the application of ¼ the recommended lime together with 136 kg/ha NPSZnB fertilizer, followed by 191 kg ha^{-1}NAFAKA which recorded a grain yield of 2469 kg ha^{-1}. But it was statistically at par with all the rest treatments except the control (Table 3). Similarly, the highest grain yield (1675 kg ha^{-1}) at Banja district was recorded from the application of 136 kg/ha NPSZnB under limed condition followed by the application of 146 kg ha GPAPR phosphorous in combination with 1/4th the recommended lime which recorded the grain yield of 1669 kg ha^{-1} (Table 4). Mean barley grain yield increment of Goazamen district in the combined analysis at 136 NPSZnB kg/ha P fertilizer plus ¼ of recommended lime was 12.4Q/ha yield difference over the limed control treatment (Table 4).

ication of lime increased barley grain yield over the un-limed condition.

Table 3. The main effect of lime and different source of phosphorous fertilizer on Barley yield at Gozamen District combined over year

Treatment	Pooled over year			
	Straw Yield kgha-1		Grain yield kgha-1	
	Un-limed	lime	Un-limed	Lime
Control	2490	3248	1051	1224
2/3 GPAPR	4138	4900	2119	2380
Full GPAPR	4182	4595	1954	2287
2/3 MOHP	3658	4130	1777	2092
Full MOHP	3765	4093	2093	2252
2/3 NAFAKA	3862	4446	2095	2469
Full NAFAKA	3951	3830	1957	1964
Rec. NPSZnB	4016	5055	1873	2470
CV %	15	13.4	18.6	14.9
LSD 5%	990.1	1004.3	608.2	559.3

According to Achalu, (2012), the increase in crop yield through the application of lime may be attributed to the neutralization of Al^{3+} supply of Ca^{2+} and increasing availability of some plant nutrients like P. Furthermore, increase in grain yield with the application of lime could be due to the favorable effect on the chemical, physical, and microbial properties of the soil. Numerous authors (Scott et al., 1999; Farhoodi and Coventry, 2008) reported that the application of lime brings about several chemical and biological changes in the soil, which is beneficial to improve crop yields in acid soils. In the present study, the higher grain yield realized from the calcitic lime application during the initial years indicates fast dissolution reaction and high acid neutralization capacity of calcite lime. Similar behavior and performance were reported by other researchers about the fast dissolution and high reactivity of calcite (Hartwig and Loeppert, 1992), as well as its high effect (Bailey et al., 1989), and high solubility in acid (Merry et al., 1995).

Table 4. The Main effect of lime and different source of phosphorous fertilizer on Barley yield at Banja District

Treatment	2016				2017				combined			
	Straw Yield Kgha-1		Grain yield Kgha-1		Straw Yield kgha-1		Grain yield Kgha-1		Straw Yield kgha-1		Grain yield Kgha-1	
	Un-limed	lime	Un-limed	lime	Un-limed	lime	Un-limed	lime	Un-limed	Lime	Un-limed	Lime
Control	2037	2762	553.9	1363	1000	2111	327	804	1519	2436	440.5	1083
2/3 GPAPR	2593	3300	638.8	1412	2296	3741	1377	1881	2537	3520	854.4	1669
Full GPAPR	2284	2991	727.4	1574	2667	4148	1356	1952	2475	3570	830.3	1637
2/3 MOHP	2593	3300	734.4	1426	2007	2778	799	1337	2300	3039	766.6	1455
Full MOHP	2346	2960	601.7	1289	2139	3296	1075	1563	2242	3128	838.5	1426
2/3 NAFAKA	2438	3331	693.4	1550	2243	3370	967	1709	2340	3351	1041.7	1629
Full NAFAKA	2593	3084	632.7	1417	2870	3148	1246	1565	2731	3116	939.4	1491
Rec. NPSZnB	2438	3238	606.6	1426	3185	4102	1442	1923	2812	3670	1024.4	1675
CV %	18.1	14.8	24.5	10.1	23	19.8	14.9	15.5	25.5	21.3	33.1	13.6
LSD 5%	NS	NS	NS	NS	882.8	NS	266.1	NS	695.5	791.6	320.4	236.6

Soil Chemical Properties

As shown in Tables 5 and 6 generally liming slightly increased soil pH and available P and reduce exchangeable acidity. Essentially amelioration of soil acidity comprises detoxification of Al and Mn activity with the aid of lime amendment. Detoxification of Al can be achieved by increasing soil pH which in turn certainly results in a decrease in Al solubility thereby minimizes its toxic effect on plants (Gover et al.,2017). The increase in the grain yield of barley due to lime application in combination with different P sources and/or rates could be related to the improvement in the soil pH and availability of P which is in line with the finding of (Olabanji, 2015). Application of lime and phosphate rock its residual effect highly decreased exchangeable acidity and Al^{+3} from the initial (Table 5 and 6). Meng et al. (2004) reported similar findings with the application of lime; acidity, particularly exchangeable $Al^{3}+$, was reduced from 5.46 to 1.52 cmol/kg.

Table 5. Lime and phosphorus residual effect on some soil chemical property of Gozamen District

Treatment	Unlime						lime					
	pH	P/PPM	OC %	OM %	Exch Acidity meq/100gm	Exch Al meq/100 gm	pH	P/PPM	OC %	OM%	Exch Acidity meq/100gm	Exch Al meq/100 gm
Control	5.3	10.9	1.60	2.82	1.20	0.09	5.4	12.9	1.60	2.76	0.73	0.00
2/3 GPAPR	5.2	14.1	1.40	2.57	0.80	0.00	5.6	15.4	1.81	3.12	0.85	0.00
Full GPAPR	5.0	12.1	1.50	2.63	1.14	0.10	5.4	11.8	1.51	2.61	0.71	0.04
2/3 MOHP	5.3	12.0	1.40	2.57	0.66	0.00	5.4	14.7	1.48	2.58	0.94	0.06
Full MOHP	5.3	12.7	1.30	2.23	0.89	0.00	5.3	14.2	1.95	3.36	0.88	0.02
2/3 NAFAKA	5.2	11.1	1.50	2.58	1.08	0.00	6.1	17.2	1.54	2.66	0.59	0.00
Full NAFAKA	5.2	12.1	1.50	2.66	0.86	0.00	5.6	14.4	1.76	3.03	0.60	0.00
Rec. NPSZnB	5.2	12.6	1.60	2.69	0.87	0.00	5.5	16.6	1.28	2.20	1.05	0

Note: P=Phosphorus, OC=Organic Carbon, OM=Organic Matter

Table 6. Lime and phosphorus residual effect on some soil chemical property of Banja District

Treatment	Unlime						lime					
	pH	P/PPM	OC%	OM%	Exch Acidity Meq/100 gm	Exch Al Meq/ 100 gm	pH	P/PPM	OC %	OM %	Exch Acidity Meq/100 gm	Exch Al meq/100gm
Control	5.2	11.7	1.003	1.73	0.971	0.216	5.2	12.9	0.78	1.35	1.36	0.798
2/3 GPAPR	5.5	14.0	0.672	1.16	0.824	0.256	5.7	15.4	0.55	0.94	1.05	0.282
Full GPAPR	5.3	11.6	1.017	1.75	0.941	0.194	5.5	14.4	0.76	1.31	1.17	0.958
2/3 MOHP	5.6	11.8	0.427	0.74	0.531	0.169	5.6	11.9	0.95	1.64	1.51	0.568
Full MOHP	5.4	12.6	0.863	1.49	0.869	0.245	5.5	12.5	0.82	1.42	1.70	0.856
2/3 NAFAKA	5.4	13.8	0.798	1.38	0.704	0.000	5.4	12.1	0.75	1.29	1.21	0.531
Full NAFAKA	5.6	15.2	0.518	0.89	0.416	0.000	5.5	12.2	0.94	1.63	1.35	0.666
Rec. NPSZnB	5.3	10.0	1.009	1.74	1.432	0.661	5.4	11.7	0.98	1.68	1.04	0.337

Note: P=Phosphorus, OC=Organic Carbon, OM=Organic Matter

Economic analysis

Partial budget analysis of lime with different phosphorus fertilizers was presented in Table 7 to Table 10. The net benefit of 49914.2 ETB ha^{-1} and marginal rate return of 590.8 % was obtained from the application of 136 kg NPSzB ha^{-1} and lime for barley production at Gozamen district. The next higher net benefits 39746.3ETB ha^{-1} and the marginal rate return of 292.2% was gained from sole use of 146 kg GPAPR phosphorus fertilizer. At Banja district, the net benefit 29893.8ETB ha^{-1} and marginal rat return of 1483.1% was obtained from the application of 146 kg GPAPR ha^{-1} and lime. The next higher MRR (584.6%) with a net benefit of17618 ETB ha^{-1} was obtained from the sole use of 191NAFAKA kg ha^{-1} phosphorus fertilizers.

Table 7. Partial budget analysis of lime and different phosphorus sources on barley at Gozamen

Treatment With lime	TVC (ETB^{-1})	GY ($kgha^{-1}$)	AdGY ($kgha^{1}$)	ST Y ($kgha^{1}$)	Ad STY ($kgha^{1}$)	GB ($ETBha^{-1}$)	NB ($ETBha^{-1}$)	MRR (%)
Control	478.3	1224	1101.6	3248	2923.3	16524	29200.1	
2/3 GPAPR	5573.42	2380	2142	4900	4410	32130	46201.58	50.0
Full GPAPR	5783.02	2287	2058.3	4595	4135.5	30874.5	43701.23	D
2/3 MOHP	4367.82	2092	1887.8	4130	3717	28317	40675.68	D
Full MOHP	5174.52	2252	2026.8	4098	3683.7	30402	41804.13	D
2/3 NAFAKA	4526.27	2470	2223	4446	4001.4	33345	46825.03	570.3
Full NAFAKA	5501.68	1964	1767.6	3830	3447	26514	36523.82	D
Rec. NPSZnB	3984.6	2476	2228.4	5055	4549.5	33426	49914.15	590.8

Note: AGY (kg/ha)=Adjusted grain yield, GB (GY)=Gross benefit, TVC (ETB/ha)=Total variable costs, NB (Birr/ha)=Net benefit and MRR (%)=Marginal rate of return, D=Dominated treatment and ETB=Ethiopian Birr.

Table 8. Partial budget analysis of different phosphorus sources on barley at Gozamen

Treatment Without lime	TVC ($ETBha^{-1}$)	GY ($kgha^{-1}$)	AdGY ($kgha^{-1}$)	STY ($kgha^{-1}$)	AdSTY ($kgha^{-1}$)	GB ($ETBha^{-1}$)	NB ($ETBha^{-1}$)	MRR (%)
Control	0	1051	945.9	2490	2241	24273	24273	
2/3 GPAPR	5295.12	2095	1885.5	4138	3724.2	45041.4	39746.28	292.2
Full GPAPR	5304.72	2119	1907.1	4182	3763.8	45543.6	40238.88	9.3
2/3 MOHP	3889.52	1777	1599.3	3658	3292.2	38804.4	34914.88	D
Full MOHP	4696.22	2093	1883.7	3765	3388.5	43503.75	38807.53	82.9
2/3 NAFAKA	4047.97	1954	1758.6	3862	3475.8	42020.1	37972.13	D
Full NAFAKA	5023.38	1957	1761.3	3951	3555.9	42421.05	37397.67	D
Rec. NPSZnB	3506.3	1873	1685.7	4016	3614.4	41550.3	38044	18.4

Note: AGY (kg/ha)=Adjusted grain yield, GB (GY)=Gross benefit, TVC (ETB/ha)=Total variable costs, NB (Birr/ha)=Net benefit and MRR (%)=Marginal rate of return, D=Dominated treatment and ETB=Ethiopian Birr.

Table 9. Partial budget analysis of lime and different phosphorus sources on barley at Banja

Treatment With lime	TVC ($ETBha^{-1}$)	GY ($kgha^{-1}$)	AdGY ($kgha^{-1}$)	STY ($kgha^{-1}$)	AdSTY ($kgha^{-1}$)	GB ($ETBha^{-1}$)	NB ($ETBha^{-1}$)	MRR (%)
Control	3263.6	1083	974.7	2436	2192.4	25582.5	22318.9	
2/3 GPAPR	8558.72	1675	1507.5	3520	3168	38452.5	29893.78	1483.1
Full GPAPR	8568.32	1637	1473.3	3570	3213	38164.5	29596.18	D
2/3 MOHP	7153.12	1455	1309.5	3039	2735.1	33318	26164.88	D
Full MOHP	7959.82	1426	1283.4	3128	2815.2	33327	25367.18	D
2/3 NAFAKA	7311.57	1629	1466.1	3351	3015.9	37071	29759.43	514.6
Full NAFAKA	8286.98	1491	1341.9	3116	2804.4	34150.5	25863.52	399.4
Rec. NPSZnB	6769.9	1689	1520.1	3670	3303	39316.5	32546.6	291.7

Note: AGY (kg/ha)=Adjusted grain yield, GB (GY)=Gross benefit, TVC (ETB/ha)=Total variable costs, NB (Birr/ha)=Net benefit and MRR (%)=Marginal rate of return, D=Dominated treatment and ETB=Ethiopian Birr.

Table 10. Partial budget analysis of different phosphorus sources on barley at Banja

Treatment Without lime	TVC ($ETBha^{-1}$)	GY ($kgha^{-1}$)	AdY ($kgha^{-1}$)	STY ($kgha^{-1}$)	AdSTY ($kgha^{-1}$)	GB ($ETBha^{-1}$)	NB ($ETBha^{-1}$)	MRR (%)
Control	0	440.5	396.4	1519	1503.1	12709.95	12709.95	
2/3 GPAPR	5295.12	854.4	768.9	2537	2521.1	22878.45	17583.33	D
Full GPAPR	5304.72	1041.7	937.5	2475	2459.1	25128.45	19823.73	391.0
2/3 MOHP	3889.52	766.6	689.9	2300	2284.1	20626.95	16737.43	D
Full MOHP	4696.22	838.5	754.6	2242	2226.1	21336.45	16640.23	D
2/3 NAFAKA	4047.97	830.3	747.2	2340	2324.1	21666.45	17618.48	584.6
Full NAFAKA	5023.38	939.4	845.4	2731	2715.1	24898.95	19875.57	51.0
Rec. NPSZnB	3506.3	1024.4	922.2	2812	2796.1	26415.45	22909.15	124.9

Note: AGY (kg/ha)=Adjusted grain yield, GB (GY)=Gross benefit, TVC (ETB/ha)=Total variable costs, NB (Birr/ha)=Net benefit and MRR (%)=Marginal rate of return, D=Dominated treatment and ETB=Ethiopian Birr.

Conclusions and Recommendation

Information on crop response to lime and different P sources of fertilizer rates is crucial to come up with profitable and sustainable barley production. The application of 136 kg NPSZnB ha^{-1} together with $1/4^{th}$ of recommended lime annually was found to be economically feasible for barley production around Gozamen district. However, farmers who have no access to lime can apply 146 kg ha^{-1} GPAPR phosphorus for optimum production of barley in the area. At Banja, the combined application of 146 kg ha^{-1} GPAPR and $1/4^{th}$ of recommended lime applied annually and sole use of 191 kg ha^{-1} NAFKA was economically feasible.

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