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Wheat crop response to liming materials and N and P fertilizers in acidic soils of Tsegede highlands, northern Ethiopia

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Abstract: A greenhouse experiment was carried out on acidic soils collected from the Tsegede highlands of northern Ethiopia, where wheat production is severely constrained by soil acidity, to evaluate wheat crop response to the applications of liming materials (Wukro lime and Sheba lime) and N and P fertilizers. Three lime sources (without lime, Wukro lime and Sheba lime) and four N and P fertilizers (without N and P, recommended N, recommended P and recommended N + recommended P) were arranged in a factorial experiment using randomized complete block design with four replications. The results indicated that yield and yield attributes of wheat showed significant ($P \leq 0.01$) response to the main effects of lime and fertilizer applications. Similarly, fertilizer by lime interaction effect was significantly ($P \leq 0.05$) different in grain yield, total biomass and N and P uptakes. The soils which received only recommended N + recommended P fertilizers (NP), Wukro lime and Sheba lime showed significant grain yield increment by about 78, 76 and 96% over the control, respectively. However, the applications of NP + Wukro lime and NP + Sheba lime augmented grain yield by 239 and 233%, respectively, over the control plot. Likewise, N uptakes were enhanced by about 66, 80 and 81% and P uptakes by 93, 91 and 93% in the soils which received only NP, Wukro lime and Sheba lime over the control while the application of NP + Wukro lime and NP + Sheba lime increased N uptakes by 241 and 237% and P uptakes by 451 and 471% over the control, in that order. The highest agronomic efficiency and apparent recovery efficiency were also recorded in the soils treated with Wukro and Sheba limes along with only recommended P and NP fertilizers, respectively. Hence, a combined application of adjusted lime rate and NP fertilizers are recommended to achieve sustainable wheat crop production on acidic soils of the Tsegede highlands.

Keywords: Agronomic Efficiency, Apparent Recovery Efficiency, Neutralizing Value, N and P Uptakes, Sheba Lime, Wukro Lime

1. Introduction

Ethiopia is one of the largest wheat producing countries in the sub-Saharan Africa [1]. Out of the total grain crops covered area [11.82 million hectares (ha)] in the country, 81.97% (9.69 million ha) was under cereals and wheat (*Triticum aestivum* L.) occupied 16.03% (1.55 million ha) of the cereal crops area [2]. In general, low soil fertility, low levels of input use (particularly fertilizers, pesticides and improved seeds), moisture stress, soil chemical degradation such as soil acidity and salinity/sodicity [3] are some of the major crop production constraints in Ethiopia. Although a report on the extent of wheat yield decline due soil acidity is not available, soil acidity is one of the serious problems constraining wheat crop production in small-scale farmers of the central, western and southern highlands of Ethiopia where precipitation is high enough to leach down soluble salts. Generally, more than 30% of the highly weathered soils of Ethiopia have been reported to be acidic [4, 5].

Liming is an effective and widespread practice for improving crop production on acid soils [6]. Usually, liming acidic soils improve soil physical, chemical, and biological activities [6, 7]. Although, liming material contains Ca and Mg compounds that are capable of neutralizing soil acidity [8], it is often difficult to distinguish the quality of one liming material from the other by visual inspection. Thus, parameters such as calcium carbonate equivalence (CCE), moisture factor, fineness factor and relative neutralizing value are principal quality standards used to differentiate liming materials from one another [9]. The relative neutralizing value, effective neutralizing value and agricultural index are also synonymous terms used to describe the quality index of a liming material based on purity and fineness of the materials [9-11]. However, even if liming materials have not the same chemical composition, they all follow the same process to neutralize soil acidity [12].

In general, limestone, dolomite, marl and marble are some of the major liming materials currently being produced in different parts of Ethiopia for use within the country [13]. Of these, Wukro lime (limestone) and Sheba lime (marble) are some of the liming materials produced in Tigray Region, mainly for building material purposes and now days, these are also being utilized for reclamation of soil acidity in the Tsegede District of Tigray Regional State, northern Ethiopia [14]. Starting from the recent past, there was a massive campaign to demonstrate the beneficial effects of liming in reclaiming soil acidity for several crops across different locations under farmers' fields in Ethiopia. Besides, a national acidity management project, including lime production and distribution, is underway through Ministry of Agriculture and Rural Development and Ethiopian Institute of Agricultural Research [15]. Accordingly, farmers are being encouraged to increase productivity of acid soils by liming.

However, there is still a knowledge gap with regard to the nature and degree of effectiveness of the different liming materials produced in the different parts of the country in general and in the Tigray Regional State in particular. Moreover, farmers and extension workers of the Tsegede District of Tigray Regional State are claiming that application of urea and diammonium phosphate fertilizers in the acidic soils without liming are not bringing the expected yield increment levels [16]. This problem is supported by Hart [17] who pointed out that soil acidity may be one of the factors that limit yield and growth responses of crops to applied fertilizers. On the other hand, there are reports indicating that the availability and recovery efficiencies of fertilizers can be greatly affected by liming due to its effects in nutrient dynamics [18-20]. Thus, evaluating the interaction effects of the locally available liming materials and chemical fertilizer applications are also of paramount importance. Therefore, this study was conducted to evaluate wheat crop response to the applications of two different liming materials (Wukro and Sheba limes) and N and P fertilizers in acidic soils of the Tsegede District under greenhouse conditions.

2. Materials and Methods

2.1. Soil Sampling and Analysis

The greenhouse experiment was conducted using Humic Cambisols [21] collected from the highlands of Tsegede in Tigray Regional State, northern Ethiopia. The bulk soil sample was taken from the topsoil (0-30 cm) a site located at $13^0 22' 30''$ north latitude and $37^0 21' 60''$ east longitude with an altitude of 2948 meters above sea level.

Analysis of the experimental soil (Table 1), prior to experiment, was conducted by taking a representative soil sample from the collected bulk soil, air-dried, ground and sieved to pass through a 2 mm sieve except for soil organic carbon (OC) and total N analysis which passed through 0.5 mm sieve. Particle size and bulk density were determined following Bouyoucos hydrometer [22] and core sampling [23] methods, respectively. Soil pH (1: 2.5 soils to water ratio) was measured using a glass electrode pH meter as described by Peech [24]. Soil organic carbon (OC) was determined by the chromate acid oxidation method [25] and soil OM was calculated by multiplying percent OC by a factor of 1.724. Total nitrogen was analyzed using the macro-Kjeldahl digestion followed by ammonium distillation and titration method [26]. Available Phosphorus was extracted following the Bray I method [27] and determined spectrophotometrically. Exchangeable acidity and exchangeable aluminium (Al) were analyzed as per the method described by Sumner [28] and Pansu et al [29], respectively. Exchangeable bases (Ca, Mg, K and Na) and CEC were determined following the method described by Chapman [30].

***Table 1**. Some physical and chemical property of the experimental soil*

Parameter	Value
Sand (%)	59.12
Silt (%)	28.00
Clay (%)	12.88
Bulk density (g cm^{-3})	1.13
pH (H_2O)	4.47
Organic matter (%)	10.59
Total N (%)	0.28
Available P (mg kg^{-1})	3.55
Exchangeable acidity ($cmol_C$ kg^{-1})	3.68
Exchangeable Al ($cmol_C$ kg^{-1})	3.36
Cation exchange capacity ($cmol_C$ kg^{-1})	24.87

2.2. Lime Sampling and Characterization

Two types of liming materials known locally as Sheba lime and Wukro lime were sampled. The Sheba lime is a calcite limestone ($CaCO_3$) which is the byproduct of Sheba Marble Factory whereas the Wukro lime is a burnt lime (CaO) produced locally by roasting crushed limestone. For each lime, 10 sub-samples were taken from different locations of the pile in order to provide a representative sample of each distinct pile. A sampling tube was inserted to its full length of about 2 meters to obtain each sub-sample. The 10 sub-samples were bulked in a bucket and were thoroughly mixed. Finally, about 500 grams of lime was taken using quartering method from the bucket and placed in separate paper bags which were properly labeled and analyzed for different chemical properties (Table 2).

The liming materials were analyzed for pH and EC (1:2.5) (lime to water ratio) using a glass electrode pH meter and electrical conductivity meter, respectively. Moisture content was determined following Hesse [31] method. To determine the Ca and Mg contents of the liming materials, first CaO and MgO content were analyzed following the method described by Yule and Swamson [32] and Ca and Mg content were calculated by multiplying percent CaO and MgO by factors of 0.7147 and 0.6031, respectively, whereas calcium carbonate equivalence (CCE) was determined using Issam and Antoine [33] method.

Table 2. *Some chemical property of the Wukro and Sheba liming materials*

Liming material	pH	EC (dS m^{-1})	Ca (%)	Mg (%)	CCE (%)	Moisture content (%)
Wukro lime	10.16	12.85	48.00	trace	120	0.5
Sheba lime	9.38	0.65	27.50	0.99	70	3.0

EC = Electrical conductivity, CCE = Calcium carbonate equivalent

Fineness factors of both the liming materials were calculated (Table 3) from the percentage of lime passed through 20, 60 and 100-mesh number of a sieve analyzer. Relative neutralizing values (RNVs), the percentage of each liming materials that are supposed to react with soil acidity in the first year of application, were determined (Table 3) by multiplying the lime fineness factor and its respective calcium carbonate equivalent [34]. The quantities of lime required per hectare, to be used in the pot experiment, were determined on the bases of the method described by Cornell Nutrient Analysis Laboratory (CNAL) [35]. Finally, the amount of actual lime per hectare for each liming materials was adjusted based on the formula suggested by NRCCA [34] assuming 15 cm soil depth and the pH of which need to rise to 6.5.

Table 3. *Percentage of lime passed through different mesh wire-screen sieve, fineness factor (FF), moisture factor (MF) and relative neutralizing value (RNV) of the Wukro and Sheba liming materials*

Liming material	% of liming material passed			FF	MF	RNV (%)
	#20 Sieve	#60 Sieve	#100Sieve			
Wukro lime	55.13	41.41	29.29	0.46	1.005	50.70
Sheba lime	90.33	29.80	10.52	0.42	1.030	34.00

2.3. Experimental Design and Procedures

The experiment consisted of a factorial combination of three lime levels (without lime, Wukro lime at the rate of 5771 kg ha^{-1} and Sheba lime at the rate of 8607 kg ha^{-1}) and four N and P fertilizer levels (no NP, 46 kg ha^{-1} N, 20 kg ha^{-1} P and 46 kg ha^{-1} N + 20 kg ha^{-1} P). The treatment combinations were arranged in a complete randomized block design with 4 replications.

Forty eight (30 x 60 cm) polyethylene pots filled with 3 kg acidic soils per pot were prepared. All the treatments were received same amount of nitrogen (N) and phosphorus (P) fertilizers in the form of urea and triple superphosphate (TSP), respectively. The NP fertilizer rates are the blanket recommendation of 46 kg ha^{-1} N and 46 kg ha^{-1} P_2O_5 which is a common practice for cereal crops throughout the country. The amount of lime, urea and TSP (g pot^{-1}) was determined by multiplying the recommended lime and fertilizers rate (kg ha^{-1}) and 3 kg soil pot^{-1} and divided by 2000000 kg soil ha^{-1}. Improved bread wheat variety; Galama (HAR- 604) was used as a test crop. Six wheat plants were grown per pot which was watered after planting and maintained at field capacity and all management practices (watering, planting, weeding and harvesting) were done by hand.

2.4. Agronomic Data Collection, Plant Tissue Sampling and Analysis

Plant height was determined by measuring the lengths of the plants from the ground level to the top of the spike just before physiological maturity. At physiological maturity, the plants were harvested close to the ground level by hand, get air dried in an open dry environment for 7 days and total biomass was determined by weighing the shoots along with the seeds using sensitive balance. Grain yield per pot was determined after cautiously separating the grain from the straw, cleaned and adjusted to 12.5% seed moisture content using a hand seed moisture tester instrument. The dry matter percentage in plant tissues was determined by taking 2 gram air dried plant samples from the threshed plants (straw and grain) of 10 pots collected randomly and heating to 105^{O}C for a period of 2 hours. Root length was measured after harvest by immersing the soil with crop residue in the polyethylene in to water in a bucket and dispersed and roots per pot were weighed after dried in an open air.

Plant (grain and straw) tissue samples from each pot were collected after threshing and dried in an oven at 65 C^0 to constant weight. The dried material of each plant part was ground and sieved with 0.5 mm mesh, for analysis of N and P concentrations. The tissue N content was determined by micro-Kjeldahl method as describe by Buresh *et al*. [36] whereas the P content was determine by the method described by Chapman and Pratt [37] and Olsen and Sommers [38].micro-Kjeldahl method as describe by Buresh *et al*. [36] whereas the P content was determine by the method described by Chapman and Pratt [37] and Olsen and Sommers [38].

Grain and straw N and P uptakes were determined by multiplying the N and P concentrations of each plant part by their respective dry matter weights. Agronomic efficiency (AE) and apparent recovery efficiency (ARE) of the N and P fertilizers were calculated [39] as:

$$AE\ (kg\ kg^{-1}) = \frac{Gf - Gu}{Na}$$

where Gf is the grain yield of the fertilized plot (kg), Gu is the grain yield of the unfertilized plot (kg) and Na is the quantity of P or N fertilizer applied (kg).

$$ARE\ (\%) = \frac{(Nf - Nu)}{Na} \times 100$$

where Nf is the N or P uptake (grain plus straw) of the fertilized pot (kg), Nu is the N or P uptake (grain plus straw) of the unfertilized plot (kg) and Na is the quantity of N or P fertilizer applied (kg).

To calculate the agronomic efficiency and apparent recovery efficiency of the combined application of NP fertilizers, the sum of the quantities of N and P fertilizers applied and the sum of the N and P uptakes, respectively, were considered.

2.5. Data Analysis

Analysis of variance was carried out on yield and yield components for all the treatments to determine response of wheat to the applied NP fertilizers and liming materials using the generalized linear models procedure of the Statistical Analysis System (SAS) [40].

3. Results and Discussion

3.1. Wheat Plant Height, Root Length and Root Weight Response

The analysis of variance (ANOVA) results (Table 4) showed that mean grain yield, total biomass yield, N and P uptakes were significantly (P ≤ 0.05) affected by the main effects of fertilizer, lime and their interaction effects while plant height, root weight, root length, plant tissue N and P contents were appreciably (P ≤ 0.01) affected only by the main effects of fertilizer and lime applications.

***Table 4**. Analysis of variance (ANOVA) for the response of considered wheat yield parameters to the applied fertilizers, lime and their interaction*

Plant parameter	Mean squares for source of variation			
	Fertilizer (3)	Lime (2)	Fertilizer x Lime (6)	Error (36)
Grain yield (g pot^{-1})	19.507**	16.733**	1.657*	0.504
Total biomass (g pot^{-1})	109.280**	98.156**	7.248*	2.215
Plant height (cm)	1423.354**	1231.188**	11.437ns	28.215
Root weight (g pot^{-1})	3.795**	3.681**	0.256ns	0.224
Root length (cm)	36.354**	40.771**	2.667ns	2.247
Plant N content (%)	0.128**	0.120**	0.008ns	0.012
Plant P content (%)	0.013**	0.0146**	0.000ns	0.001
N uptake (mg pot^{-1})	28809.009**	31589.221**	2961.429**	428.840
P uptake (mg pot^{-1})	923.484**	682.972**	93.89**	20.893

Figures in parentheses = Degrees of freedom;* = Significant at P ≤ 0.05; ** = Significant at P ≤ 0.01; ns = Non-significant

The soils which received only recommended N + recommended P fertilizers (NP) showed increments in plant height by 38, 40 and 22%; root weight by 58, 68 and 22% and root length by 19, 15 and 8% over the control, only N and only P fertilizers, respectively (Table 5). The substantial increment in plant height, root weight and root length as a result of the only NP application could be ascribed to the N and P fertilizers synergistic effect. This explanation also agrees with that of Pervaiz *et al.* [41] who revealed that phosphatic fertilizers increased efficiency of nitrogen fertilizers.

Only P received soils showed significant (P ≤ 0.01) increment in plant height and root length over the soils received N alone and the control (Table 5). This might be credited to the neutral nature of the triple superphosphate fertilizer used which does not have appreciable lowering effect in soil pH [17]. In connection with this, Muraoka [42] has revealed that the application of P fertilizers resulted in excellent crop responses in the Brazil P-deficient acidic soils. On the other hand, the lower response to the application of N fertilizer alone could be likely because of the acidic nature of the urea fertilizer used. Nanthi and Mike [43] has also reported that the application of N fertilizers, such as urea and ammonium sulfate, to acidic soils can produce H^+ ions through oxidation of NH_4^+ ions to NO_3^- ions and recommend to apply 43 kg lime for each 25 kg ha^{-1} N applied to neutralize the acidity produced.

Statistical results revealed that average plant height, root length and root weight of wheat respond significantly ($P \leq 0.01$) to the applied Wukro and Sheba limes (Table 6). About 26 and 27% plant height, 52 and 41% root weight and 15 and 11% root length increment had registered by the soils received only Wukro and Sheba limes over the control, in that order.

The significant wheat plant height, root weight and root length response to the lime applied soils over the control is because of the lime's ability to neutralize acidic soil toxicity effect and increase soil nutrient availability by enhancing mineralization. Strong positive correlations of plant height with root weight and root length, respectively, were also observed (Table 8). The explanation is in agreement with that of Kamprath and Foy [44]; [6] who reported that organic N and P mineralisation in acid soils, are stimulated mainly through liming and resulted in significant crop production increment.

Table 5. *Effects of N and P fertilizers application on plant height, root length and root weight (Mean ± SE) response*

Recommended N and P (kg ha^{-1})	Plant height (cm)	Root weight (g pot^{-1})	Root length (cm)
N/P (0/0)	59.42±1.53c	1.91±0.14bc	20.42±0.43c
N (46)	58.92±1.53c	1.80±0.14c	21.08±0.43c
P (20)	67.67±1.53b	2.48±0.14b	22.58±0.43b
N/P (46/20)	82.25±1.53a	3.02±0.14a	24.33±0.43a

Means within a column followed by the same letter(s) are not significantly different at P 0.05

However, wheat plant height, root weight and root length did not show any significant ($P > 0.05$) variation among the soils received Wukro and Sheba limes alone (Table 6). This non significant variation is attributed to the adjusted lime recommendation which is made to have more or less same relative neutralizing values. When different agricultural liming materials with the same amount of effective neutralizing value is applied and mixed thoroughly with the soil, the pH change in the zone of application will be the same [10].

Table 6. *Plant height, root length and root weight (Mean ± SE) of wheat response to Wukro and Sheba lime applications*

Liming material (kg ha^{-1})	Wheat yield parameters		
	Plant height (cm)	Root weight (g pot^{-1})	Root length (cm)
Without lime	56.94±1.33b	1.76±0.12b	20.31±0.37b
WL (5771)	71.88±1.33a	2.68±0.12a	23.38±0.37a
SL (8607)	72.38±1.33a	2.48±0.12a	22.62±0.37a

WL = Wukro lime; SL = Sheba lime; Means within a column followed by the same letter are not significantly different at P 0.05

3.2. Grain and Biomass Yield of Wheat

Soils which received only NP fertilizers, Wukro and Sheba limes showed significant augmentation by about 78, 76 and 96% in grain yield and by 60, 62 and 65% in total biomass over the control, respectively. On the other hand, the applications of combined NP fertilizers along with Wukro and Sheba limes (NP + Wukro lime and NP + Sheba lime) revealed significant augmentation over control by about 239 and 233% in grain yield and by 174 and 172% in total biomass yield, respectively (Table 7). As a result of the application of NP + Wukro lime and NP + Sheba lime, the grain yield obtained by application of only NP rise by about 86 and 90%. Similarly, the grain yield obtained by the application of Wukro and Sheba limes alone had increased by 88 and 73% when applied in combination with NP. Strong positive correlations of grain yield with biomass, plant height, and root weight and root length (Table 8) were also observed. However, interaction effect did not bring any significance grain as well as total biomass yield disparity in between the soils received NP + Sheba lime and NP + Wukro lime.

The significant increment of wheat grain yield by the combined application of NP fertilizers along with lime, and to some extent, only N and P together with lime might show liming does not only enhance soil organic N and P mineralisation in acid soils but also it facilitates uptakes of the applied inorganic N and P fertilizers by the crop. Significant maize yield increment by combined application of lime along with NP fertilizers was also reported in Araka, south Ethiopia [45].

Application of P alone did not show any significant disparity in grain yield from the soils which received NP, N + Wukro lime, N + Sheba lime, Wukro lime, Sheba lime, P + Wukro lime, P + Sheba lime alone. Likewise, it did not demonstrate any important ($P > 0.05$) difference in biomass yield versus the soils which received only NP, N + Wukro lime, N + Sheba lime, Wukro lime and Sheba lime. This could be accredited to the neutral nature of the triple superphosphate fertilize and might imply, in addition to the application of lime, heavy application of P in the form of TSP fertilizers in the acidic soils of the Tsegede highlands could be another alternative to improve wheat production although needs further field research. Fageria *et al*. [46] also pointed out that with application of high rate of P fertilizers, soil sorption sites are satisfied and P level increase to sufficiency for crop production.

***Table** 7. Interaction effect of fertilizers and liming materials on grain yield (Mean ± SE) of wheat crop*

Recommended N and P (kg ha^{-1})	Liming material (kg ha^{-1})			Mean
	Without lime	Wukro lime (5771)	Sheba lime (8607)	
		Grain yield (g pot^{-1})		
N/P (0/0)	2.09±0.36d	3.69±0.36bc	4.11±0.36bc	3.30
N (46)	2.56±0.36d	3.53±0.36bc	3.43±0.36bc	3.18
P (20)	3.15±0.36c	4.29±0.36bc	4.11±0.36bc	3.85
N/P (46/20)	3.73±0.36bc	6.95±0.36a	7.09±0.36a	5.92
Mean	2.88	4.62	4.69	
		Total biomass yield (g pot^{-1})		
N/P (0/0)	6.65±0.74f	10.80±0.74cd	10.94±0.74cbd	9.46
N (46)	7.62±0.74ef	9.77±0.74d	9.74±0.74ed	9.04
P (20)	9.45±0.74ed	12.39±0.74cb	13.03±0.74b	11.62
N/P (46/20)	10.63±0.74cd	18.11±0.74a	18.19±0.74a	15.64
Mean	8.59	12.77	12.98	

Means across rows and columns followed by the same letter(s) are not significantly different at P □ 0.05; LSD (0.05) = 1.0176 (grain yield); LSD (0.05) = 2.1343 (total biomass yield)

Noticeable wheat performance and root length difference (Figure 1) were also observed in the soils which received Sheba lime + NP and Wukro lime + NP over the control. The shorter wheat root length observed in the control soils might be accredited to the toxicity effect of high exchangeable Al (about 300 mg kg^{-1}) in the experimental soil which is above the critical level (0.5 to 0.8 mg kg^{-1}) for sensitive cereal crops [47]. This toxic effect could likely restrict the root growth and reduces the soil volume to be explored by the roots thereby decreases the uptake efficiency of water and nutrients. In agreement with this Parker *et al*. [48] reported that an activity of Al ions of less than 54 mg kg^{-1} in a solution growth medium for wheat and sorghum caused reduction in plant root growth.

***Figure 1.** Picture of wheat root length difference grown in acidic soils received Sheba lime (SL) + NP(left), Wukro lime (WL) + NP fertilizers (middle) and no lime and fertilizer ($L_oN_oP_o$) (right) fertilizers*

Table 8: *Simple correlation coefficients (r) between average yield and yield parameters of wheat grown on acidic soils applied with NP fertilizers, Wukro and Sheba liming materials*

Parameter	TB	GY	PLH	RW	RL	NC	PC	NU
GY	0.96**							
PLH	0.92**	0.93**						
RW	0.85**	0.77**	0.77**					
RL	0.67**	0.65**	0.68**	0.68**				
NC	0.26ns	0.31*	0.23ns	0.20ns	0.44*			
PC	0.70**	0.67**	0.63**	0.67**	0.63**	0.37*		
NU	0.97**	0.95**	0.88**	0.82**	0.72**	0.49*	0.73*	
PU	0.90**	0.88**	0.80**	0.80**	0.70**	0.37*	0.91**	0.92**

* = Significant at P ≤ 0.05; ** = Significant at *P* ≤ 0.01; TB = Total Biomass (g pot^{-1}); GY = Grain yield (g pot^{-1}); PH = Plant height (cm); RW = Root weight (g pot^{-1}); RL = Root length (cm); NC = Plant N content; PC = Plant P content; NU = N uptake (mg pot^{-1}); PU = P uptake (mg pot^{-1})

3.3. Nitrogen (N) and Phosphorus (P) Uptakes

Nitrogen uptake was higher in the only NP fertilizers applied soils over the control, P and N fertilizers alone by 66, 25 and 18%, respectively, (Table 9). The uptake of N also increased in the soils limed with only Wukro and Sheba limes by 80 and 81% than the non-limed soils. Moreover, application of combined NP fertilizers along with Wukro and Sheba limes revealed significant N uptake increment by about 241 and 237% over the control and by 50 and 47% over the NP fertilizer only, in that order.

As it is indicated in the upper sections, the increment of N uptake in the soils applied with only NP fertilizers is resulted from the synergistic effect of N and P application. Similarly, the N uptake improvement as a result of lime application could be related to the change in physical, chemical and biological activities of the acidic soil. In connection with this, Crawford [49] reported that liming of soils of pH less than 5 results in increased heterotrophic microbial activity, resulting in greater availability of mineral forms of N (NH_3 and NO_3) for uptake by plants. The observed strong positive correlation of N uptake with root weight (r = 0.82**) and length (r = 0.72**) (Table 8), could be an evidence for the wheat root proliferation as a result of positive liming effect on soil acidity thereby improves the wheat N uptake efficiency.

In the soils which received only NP fertilizers, P uptake was significantly greater by about 93, 148 and 93% over the control, only N and P fertilizers, in that order. It was also higher by 91 and 93% in the soils applied with only Wukro and Sheba limes over the control where as lime type difference did not bring any significant variation in the P uptake (Table 9).

The wheat P uptake increment in the limed soils is likely attributed to the raise of solublized soil P in the soil solution. In line with this, reports have indicated that since liming enhances soil available P, the yield benefit from liming likely resulted, at least partly, from enhanced P nutrition [50-52].

Table 9. *Interaction effect of N and P fertilizers and liming materials on N and P uptakes (Mean ± SE) by wheat crop*

Recommended N and P (kg ha^{-1})	Liming material (kg ha^{-1}) Without lime	Wukro lime (5771)	Sheba lime (8607)	Mean
	Nitrogen (N) uptake (mg pot^{-1})			
N/P (0/0)	84.22±10.354d	151.89±10.354bc	152.46±10.354bc	129.52
N (46)	112.00±10.354cd	156.62±10.354bc	149.81±10.354bc	139.48
P (20)	118.73±10.354c	168.12±10.354b	176.24±10.354b	154.36
N/P (46/20)	140.15±10.354c	287.00±10.354a	283.75±10.354a	236.97
Mean	113.77	190.91	190.56	
	Phosphorus (P) uptake (mg pot^{-1})			
N/P (0/0)	6.35±2.285ed	12.25±2.285bcd	12.13±2.285bcd	10.25
N (46)	4.95±2.285d	9.79±2.285cde	11.31±2.285cde	8.68
P (20)	6.37±2.285ed	15.35±2.285bc	17.88±2.285b	13.199
N/P (46/20)	12.28±2.285bcd	34.99±2.285ab	36.28±2.285a	27.85
Mean	7.49	18.10	19.40	

Means across rows and column followed by the same letter(s) are not significantly different at P > 0.05; LSD (0.05) = 29.698 (N uptake); LSD (0.05) = 6.555 (P uptake)

In addition to that, the application of combined NP fertilizers along with WL and SL revealed significant increment P uptake by about 451 and 471% over the control and by 195 and 185% over the NP only (Table 9). Significant positive correlations of P uptake with root weight (r = 0.80**) and root length (r = 0.70**) (Table 8) also observed which might likely indicate the reduction of acid soil toxicity effect by lime and facilitate the growth of wheat root and P uptake efficiency.

Application of P fertilizer with lime did not bring any significant difference in P uptake as compared to the soils received only NP and NP + Sheba lime. In general, P uptake efficiency and response of wheat grain yield to P fertilizer in these acidic soils seem less influenced by lime application as compared to that of nitrogen fertilizer.

3.4. Agronomic and Apparent Recovery Efficiency

Generally, highest agronomic efficiency had recorded in the soils treated with P fertilizer in combination with Wukro and Sheba limes (Table 10). The soils received N + Wukro lime, P + Wukro lime and NP + Wukro lime gave 208, 108 and 197% higher agronomic efficiency and N + Sheba lime, P + Sheba lime and NP + Sheba lime showed 186, 91 and 206% higher agronomic efficiency than the soils received only N, P and NP fertilizers, respectively. Likewise, agronomic recover efficiency was maximum in the soils received NP along with Wukro and Sheba limes as compared to the other treatments. Increment by about 2.7 and 2.5, 17.8 and 22.4 and 3.7 and 3.7 fold in agronomic recover efficiency of N, P and NP in the presence of WL and SL over the soils applied with only N, P and NP fertilizers, respectively, had registered.

This remarkable augmentation in agronomic efficiency and apparent recovery efficiency of NP fertilizers by wheat crop might show, lime in addition to its ability of ameliorating acidic soils it also improves the uptake efficiency of applied inorganic fertilizers. Different reports are also revealed that the availability and recovery efficiencies of fertilizers are greatly affected by lime amendment due to their effects in nutrient dynamics [18, 20, 53].

Table 10. *Agronomic efficiency and apparent recovery efficiency of N and P fertilizers by wheat crop in acidic soils of the Tsegede highlands as affected by Wukro and Sheba lime applications*

Treatments	N and P (g pot^{-1})	N content (%)	P content (%)	N uptake (g pot^{-1})	P uptake (g pot^{-1})	AE (g g^{-1})	ARE (%)
$N_0P_0 + L_0$	0.00	1.28	0.09	0.085	0.006	-	-
N_0P_0 + WL	0.00	1.41	0.11	0.153	0.012	-	-
N_0P_0 + SL	0.00	1.41	0.11	0.154	0.012	-	-
N + L_0	0.15	1.47	0.06	0.112	0.005	3.13	18
N + WL	0.15	1.61	0.10	0.157	0.010	9.63	48
N + SL	0.15	1.56	0.12	0.152	0.011	8.95	44
P + L_0	0.07	1.26	0.07	0.119	0.007	15.14	1
P + WL	0.07	1.35	0.12	0.168	0.015	31.43	14
P + SL	0.07	1.35	0.14	0.176	0.018	28.89	17
NP + L_0	0.22	1.32	0.12	0.140	0.012	7.43	28
NP + WL	0.22	1.59	0.19	0.288	0.035	22.10	106
NP + SL	0.22	1.56	0.20	0.283	0.036	22.72	104

N = Nitrogen fertilizer; N_0 = Without nitrogen fertilizer; P = Phosphorus fertilizer; P_0 = without phosphorus fertilizer; L_0 = Without lime; WL = Wukro lime; SL = Sheba lime; AE = *Agronomic efficiency; ARE = Apparent recovery efficiency*

4. Conclusions

Acidic soils received combined application of NP + Wukro lime and NP + Sheba lime showed significant grain yield increment as well as higher N and P uptake over those separately applied N and P fertilizers and lime levels. Moreover, significant wheat yield response and NP uptake were also observed due to application of only lime over the non-limed soils. However, difference in liming material did not show any significant variation in wheat yield, N and P uptake which may imply that if any liming material is adjusted to have the required relative neutralizing value; it has similar acid soil ameliorating effect. The significant increment of wheat yield by combined application of NP fertilizers along with lime implies, liming is not only enhancing soil organic N and P mineralisation in acid soils but also it speeds up the uptake efficiency of applied NP fertilizers.

Hence, application of NP fertilizers along with lime seems paramount importance to improve wheat crop production on these acidic soils. Besides, grain yield response and uptake efficiency of P fertilizers even in the absence of lime seem respond better than that of nitrogen fertilizers. Thus, in addition to the combined application of lime and NP fertilizers, heavy application of P in the form of TSP fertilizers could be another alternative to achieve sustainable wheat crop production on acidic soils of the Tsegede highlands as well as elsewhere with similar agro-ecology areas. However, further field studies on heavy application of P fertilizer intended to determine the optimum rate that must be applied to reclaim soil acidity and combined with N fertilizer are essential.

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