Quantifying optimum lime requirements to increase the productivity of potato (*Solanum tubersum* L.) in West Amhara, Ethiopia

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Abstract

A field study was conducted to determine the optimum rate of lime for potato production at Banja and Machakel. The experiment comprising twelve levels of lime rates (0%, 11.1%,12.5%,14.3%,16.7%,20%,25%,33.3%,50%,75%,100%,125%) with common 138N and 69P_2O_5 laid out in randomized complete block design (RCBD) with three replications. The study showed that the application of different rates of lime was not significantly affected the yield of Potato. But the Application of 14.3% lime rate at Banja gives 6.41 and 4.51 t ha^{-1} tuber yield advantage over the control at year one site one and year two and site two (Y1S1&Y2S2) respectively. Similarly, the application of 20% lime at Machakel provides 4.04, 1.13 and 0.94 tuber yields than the control treatment at Y1S1, Y2S1&Y2S2 respectively. On the contrary, soil properties changed by the application of lime. This might be due to the reclamation activity of lime through the substitution of aluminum (Al+3) and (H+1) with (CaCO3) on soil exchangeable site that makes the formation of aluminum hydroxide and water than free hydrogen and aluminum. Based on this finding the application of minimum lime rate 14.3% at Banja and 20% at Machakel is important for acid reclamation with recommended fertilizer (138N, 69P2O5) for potato production. But for concrete recommendation we suggest further research on lime residual effect and time of application with the different lime requirement calculation methods.

Key Words: Potato, lime, soil Physico-chemical properties

Introduction

Potato was one of the P D M R U V W U D W H J L F F U R S V W R W K H 8 Q L W H G 1 Goals of achieving food security and eradicating poverty. More, 2008 was recognized as the year of potato by the United Nations. Its contribution to food security with a stable price might be continued as price of potato mainly depends on local demand and supply than global trade. It is a short cycle and early maturing additional advantages of double cropping and crop intensification than other crops that take longer days for maturity. Ethiopia has a vast potential to increase the production and productivity of potato, especially in the highlands (Gebremehdin et al., 2012; Haverkort et al., 2012). About 70% of the cultivated land in Ethiopia is suitable for potato production (FAO, 2008) but only 2% of the potential has been used (Adane et al., 2015). About 40% of potato producers in the country are in the South Gonder, North Gonder, East Gojam, West Gojam, and Agew Awi zones of the Amhara region (Adane et al., 2015) where the Adet Agricultural Research center is mandated for this potential. Potato is the fourth crop globally in terms of production and area coverage. It also ranks first among root and tuber crops in Ethiopia (CSA, 2016). Potato is cheap and nutritive food security crop, because of its high production per unit area and time with good nutritive values than other major cereal crops. However, the productivity of potato in Ethiopia is below 10 tons per hectare (Adane et al., 2015; Asresie et al., 2015; Haverkort et al., 2012). On the contrary, Gebremehdin et al., 2012 indicated that released potato varieties have high yielding potentials of up to 54 tons/ha in Ethiopia under farm conditions. Furthermore, Haverkort et al., (2012) reported up to 64 tons/ha around Shashemene area. We also recently assured that the achievable potentials of potato with nutrient management (Gudene variety) are above 40 tons/ha (unpublished data). Soil fertility is one of the factors that limit agricultural productivity in Ethiopia including potato (Adane et al., 2012; Degefu and Mengistu, 2017; Tadele et al., 2018). Then can further improve the productivity of potato through acid soil management? Soil acidity is one of the challenges of crop production in the high rainfall areas of the country where potato is the staple crop (Getachew et al., 2021). About 30% R I W K H Z R U O G ¶ V consists of acid soils (<pH 5.5), and as much 50% of the w R U O G ¶ V S R W H Q W are acidic (Kochian et al., 2004). Due to Transportation costs and labor intensiveness, farmers are not interested to apply fully calculated lime rate at once on their farmland. However, Birhanu et al., (2016), reported that 25% of the lime calculated based on the exchangeable acidity applied in row at planting gave an equivalent bread wheat yield with a full dose. Hence, based on this finding, wider demonstration activities were conducted on the row application of lime by Adet Agricultural

Research Center and was successful with the production of wheat in areas where it has been out of production (Asmamaw et al., 2020). This result has been scaled up to end users (farmers) that are getting a high rate of acceptance. This method significantly reduces the amount of lime which has a problem for the adoption of the lime technology by the farmers. Due to the large area coverage of acid soils in Ethiopia, it is also difficult for the government to supply the total lime required. That is why using only 25% by row application at planting is the best approach to increase the rate of adoption and productivity of crops. Accordingly, the question of other crops to develop the rate of lime with row application at planting has been requested by the stakeholders including the bureau of agriculture. The recommendation given for wheat may not be equally work for other crops. One of the targets of the growth and transformation of the program of the soil and water research directorate is also to improve the productivity of crops in the highland through soil fertility management including acid soil management. Therefore, the research was initiated to improve the productivity of potato through the application of optimum lime rate both economically and biologically.

Objective

- To determine the economical and biological optimum micro dozing level of lime for potato production in highly acidic areas of North West Amhara region

Materials and methods

Description of the study area

The expeU L P H Q W Z D V F R Q G X F W H G D W % D Q M D D Q G 0 D F K D N H O West Amhara region Ethiopia. The site is located southwest 175 and 230 km away from Bahir-Dar respectively. Geographically the sites at Banja lies at (10^0 55'00'' latitude and 37^0 05'00' longitude) and Gozamen (Û O D W L W X G H 10^0 16'46'' longitude) D Q G The study areas receive a mean annual rainfall of 2348 and 1700 mm with an altitude of 2312 and 2200m above sea level respectively. Major Crops grown in the area include Potato, Barley, Wheat, Oat, Teff, Faba Bean, and Triticale.

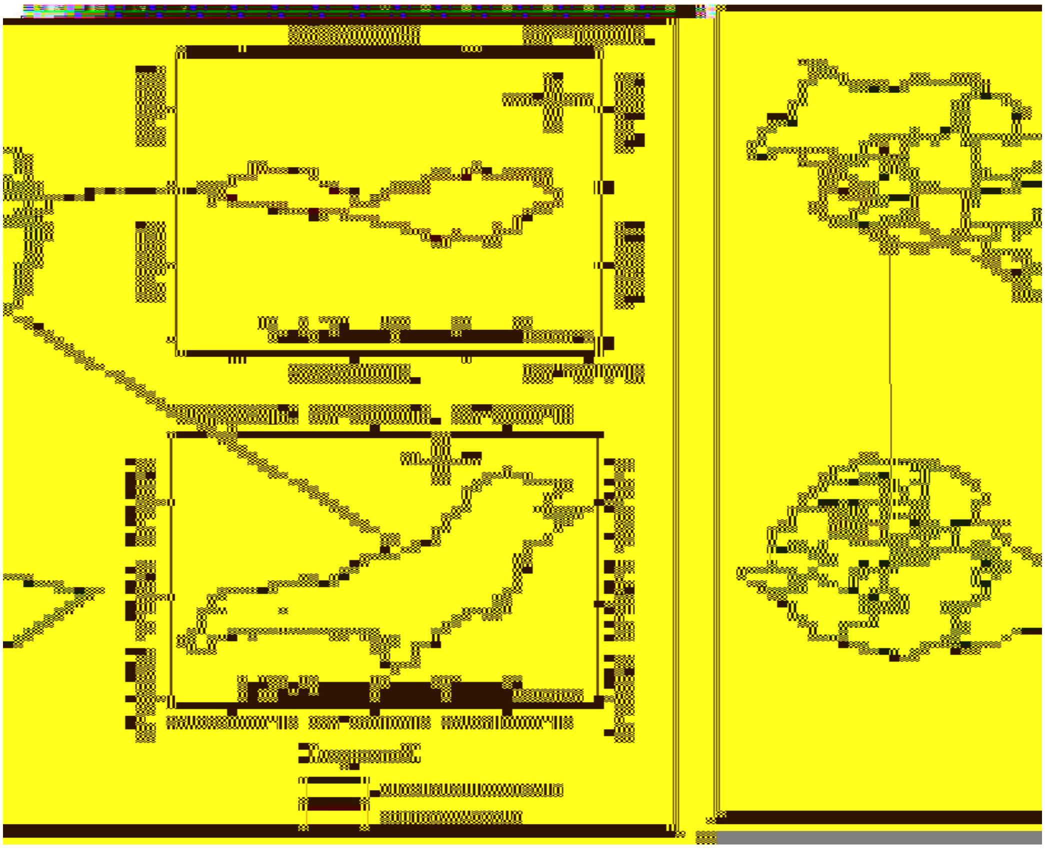

Figure1.Geographical location of the study Area

Soil sampling and experimental procedure

Before and after planting, representative soil samples were collected from 0-20 cm depth in a random sampling method from 10 spots in the field by using auger. All samples were mixed together and one composite sample was formed. The composite sample was grounded using a mortar and pistil as well as passed through 2mm sieve for analysis of soil texture, exchangeable acidity, CEC, pH, and available P whereas 0.5 mm sieve was used for determining the soil organic carbon (OC) and total N. Bulk density was determined by core sampling method. Major chemical properties of soil such as exchangeable acidity, OC, pH, CEC, total N and available P were analyzed following the compiled laboratory manual of Sahlemedhin and Taye (2000). Soil pH was measured in water at the ratio of 1:2.5 using glass electrode pH meter. The soil OC content was determined following the wet digestion method as outlined by Walkley and Black which involves digestion of the OC in the soil samples with potassium dichromate ($K_2Cr_2O_7$) in sulphuric acid solution. AvP was determined by Olsen extracting method. Total N content in the soil sample was determined following the Kjeldahl method CEC was determined by extracting the soil samples by ammonium acetate (1N NH_4OAc) followed by repeated washing with ethanol (96%) to remove the excess ammonium ions in the soil solution. Percolating the NH4+saturated soil with sodium chloride would displace the ammonium ions adsorbed in the soil and the ammonium liberated from the distillation was titrated using 0.1N NaOH. Simultaneously, the core samples per site were collected for the determination of the bulk density which is important for the calculation of the amount of lime as shown below. The soil samples were air-dried, ground, and sieved according to standard procedures. The exchangeable acidity (sum of exchangeable Al^{+3} and exchangeable H^{+}) of the collected soil samples were determined at Adet Agricultural Research Center Laboratory. Following the determination of the exchangeable acidity of the samples, the lime requirement was calculated with the following formula and applied in rows at planting.

$$\text{Lime}(\text{CaCO3})\text{kgh}^{-1} = \frac{\text{Exacidity}(\text{cmolkgha}-1)*0.2\text{m}*10000\text{m2}*\text{BD}(\text{Mgm}-3\ )*1000}{2000}*1.5$$

Accordingly, the optimum rate of lime for the production of potato was examined based on the following treatments. Fertilizers with a rate of 138N and 69 P_2O_5 were uniformly applied. Nitrogen was applied by three splitting: one third at planting, one third at about 30 days after planting and the remaining was at the beginning of flowering. The total phosphorus was applied at planting with the following treatments:

1) Full amount of Equation 1+25% (125%)
2) Full amount of Equation-1 (100%
3) Three-fourth of Equation-1 (75%)
4) Half of Equation-1 (50%)
5) One-third of Equation-1 (33.3%)
6) One-fourth of Equation-1 (25%)
7) One-fifth of Equation-1 (20%)
8) One-sixth of Equation-1 (16.7%)
9) One-seventh of Equation-1 (14.3%)
10) One-eighth of Equation-1 (12.5%)
11) One-tenth of Equation-1 (11.1%
12) Control (without lime) (0%)

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications carried out under rain fed condition while potato variety Gudene was used as a test crop. The total area of each plot was 3 m x 4.5 m (13.5 m^2) having 1m space between plots and blocks. The spacing between plants was 0.3m and each plot consisted of six rows at 0.75m interval. Data were collected from the middle four rows.

Data collection

Collected agronomic data

Number of tubers per plant was measured at harvesting by counting tubers from randomly selected five plants and averaged for a single reading. Total tuber yield was measured by harvesting both fresh marketable and non-marketable tubers from the net middle plot area of 3m x 3m to avoid border effects

Statistical Analysis

All data were subjected to analysis of variance by using SAS software program version 9.4(SAS Institute, 2002). List significant test (LSD) at 0.05 probability level was employed to separate treatments means when significant differences exist (Gomez and Gomez, 1984).

Results and discussion

Soil Chemical Properties before and after planting at Banja and Machakel

Results of soil chemical analysis before and after harvest from each experimental site was presented in Table 1,2&3. The soil analysis result of before planting revealed that the soil was acidic with a exchangeable acidity 2.78, 1.52 and 3.55cmol kg^{-1} and pH 5.03,5.30&5.13 at Banja, on first year site one and second year site one and two respectively. Similarly, the laboratory analysis result for the composite soil sample from Machakel district also indicated that the soil was highly acidic with the exchangeable acidity of 6.09, 6.44& 5.12 cmolkg^{-1} and pH values 4.8,4.76& 4.73 for site one(first year) and for site 1 and 2 (second year) respectively; which is out of the critical range of optimum soil exchangeable acidity and low pH for crop production (Tekalign 1991).

On the other hand, after harvest soil pH and exchangeable acidity was affected by the application of different lime rates in table 3&4 at Banja and Machakel districts respectively. These might be due to the chemical reaction of the applied calcium carbonate (CaCO$_3$) on aluminum (Al^{+3}) and hydrogen (H^{+1}) in the soil exchangeable site. And make them unavailable in soil solution through a substitution reaction of Aluminum and Hydrogen by Ca^{+2} that makes decreasing the exchangeable acidity by increasing soil pH. The result was in line with the finding of Athanase (2013) who reported that the application of different lime sources and rate affected on exchangeable acidity and soil pH. And the same author concluded that the application of 4.2tha^{-1} Rusizi lime decreased exchangeable Acidity a by unit of 2.67 cmolkg^{-1} as compare to control treatment.

Table1. Soil physical and chemical properties across locations for Year 1 and 2 before planting

Campsite sample	pH	Ex H^{+1}	Ex Al^{+3}	Ex A (cmol kg^{-1})	BD (gcm^{-3})	TN%	OC%	Av P (mg kg-1)	CEC (cmol kg-1)	LR(tha^{-1})
Banja										
Y1S1	5.03	1.14	1.64	2.78	1.2	0.28	3.55	15.64	27.70	5.1
Y2S1	5.30	0.34	1.18	1.52	1.27	0.19	2.67	17.43	30.92	2.9
Y2S2	5.13	1.25	2.3	3.55	1.30	0.12	1.57	10.15	29.04	6.9
Machakel										
Y1S1	4.80	1.27	4.82	6.09	1.23	0.12	1.71	15.04	28.56	10.3
Y2S1	4.76	1.11	5.33	6.44	1.16	0.17	2.47	9.36	24.80	11.2
Y2S2	4.73	0.32	4.79	5.12	1.27	0.18	1.91	4.94	20.72	9.7

Y1S1= year one site one, Y2S1=year two site one, Y2S2=year two site two LR= calculated lime requirement each site and Ex A=exchangeable acidity
Calculated lime per site

Table2 Soil chemical properties at Banja sites after haresting for year1 and2

	Y1S1				Y2S1				Y2S2			
Treatment	pH	Ex H^{+1}	$ExAl^{+3}$	ExA ($cmolkg^{-1}$)	pH	Ex H^{+1}	$ExAl^{+3}$	ExA ($cmolkg^{-1}$)	pH	Ex H^{+1}	$ExAl^{+3}$	ExA ($cmolkg^{-1}$)
125%lime	6.05	0.0	0.12	0.12	5.40	0.33	0.0	0.33	6.53	0.18	0.0	0.18
100%lime	6.80	0.0	0.59	0.59	5.15	0.53	0.0	0.53	6.20	0.26	0.0	0.26
75%lime	6.89	0.0	0.20	0.20	4.80	0.55	0.54	1.09	6.97	0.11	0.0	0.11
50%lime	6.56	0.0	0.09	0.09	4.83	0.77	0.0	0.77	6.51	0.15	0.0	0.15
33.3%lime	5.93	0.15	0.58	0.73	5.26	0.34	0.46	0.80	5.87	0.26	0.0	0.26
25%lime	6.48	0	0.15	0.15	4.98	0.52	1.01	1.53	6.02	0.16	0.0	0.16
20%lime	4.78	3.6	0.05	3.6	4.89	0.49	1.18	1.67	5.67	0.19	0.0	0.19
16.7%lime	6.08	0.27	0.31	0.58	4.94	0.60	1.25	1.85	5.88	0.22	0.0	0.22
14.3%lime	5.72	0.75	0.15	0.90	4.74	0.69	1.52	2.21	5.78	0.31	0.0	0.31
12.5%lime	4.96	2.27	0.33	2.61	4.85	0.42	1.20	1.62	6.72	0.16	0.0	0.16
11.1%lime	5.13	2.15	0.08	2.23	4.76	0.56	1.65	2.21	5.90	0.21	0.0	0.21
0%lime	4.76	5.15	0.04	5.19	4.82	0.43	1.47	1.90	5.46	0.74	0.0	0.74

Y1S1= year one site one, Y2S1=year two site one, Y2S2=year two site two and ExA=exchangeable acidity

Table3 Soil chemical properties at Machakel sites after haresting for year 1 and 2

	Y1S1				Y2S1				Y2S2			
Treatment	pH	Ex H^{+1}	ExAl^{+3}	ExA (cmolkg^{1})	pH	Ex H^{+1}	ExAl^{+3}	ExA (cmolkg^{1})	pH	Ex H^{+1}	ExAl^{+3}	ExA (cmolkg^{1})
125%lime	5.53	0.81	1.96	2.77	5.47	0.05	1.60	1.65	7.03	0.39	0.0	0.39
100%lime	5.12	0.27	3.63	3.90	5.40	1.03	4.16	5.19	6.83	0.21	0.0	0.21
75%lime	5.17	0.71	3.57	4.29	4.88	0.27	4.46	4.73	6.78	0.12	0.0	0.12
50%lime	5.20	0.88	3.52	4.40	4.86	0.46	3.47	3.93	6.15	0.19	0.0	0.19
33.3%lime	5.07	0.40	4.01	4.41	4.84	1.11	3.86	4.97	6.09	0.18	0.0	0.18
25%lime	4.74	0.50	4.64	5.14	4.82	0.37	3.69	4.06	6.27	0.20	0.0	0.20
20%lime	4.89	0.33	4.55	4.88	4.47	0.82	4.42	5.24	6.42	0.12	0.0	0.12
16.7%lime	4.76	0.68	4.46	5.14	4.76	0.92	3.50	4.42	5.76	0.23	0.0	0.23
14.3%lime	4.79	0.25	4.65	4.90	4.93	0.42	4.27	4.69	5.14	0.29	1.27	1.56
12.5%lime	4.76	0.53	4.61	5.14	4.69	0.55	4.10	4.65	4.80	0.62	2.25	2.87
11.1%lime	4.70	0.53	4.60	5.13	4.77	0.87	4.07	4.94	4.99	0.43	1.89	2.32
0%lime	4.78	0.54	4.61	5.15	4.87	0.43	4.78	5.21	4.76	0.56	4.42	4.98

Y1S1=year one site one, Y2S1=year two site one, Y2S2=year two site two and ExA=exchangeable acidity

Effect of different lime rates on Potato total tuber yield at Banja and Machakel

The analysis of variance revealed that the tuber yield of potato is not significantly different at ($P < 0.05$) due to lime application rate across different testing sites (Tables 4 and 5). Even if the application lime rate reaches 125% t ha^{-1} L W G R H V Q R W give a significant tuber yield as compared to other lower rate treatments including control. Although the result is statistically not significant some treatments have a yield advantage as compared to the control that gives the lowest fresh total tuber yield in both areas of Banja and Machakel (Tables 4 & 5). For instance, in Banja, the application of 14.3% of recommended lime gives 4.57 and 6.41 t ha^{-1} tuber yield advantage as compared to control on Y1S1 and Y2S2 respectively. Similarly, in Machakel, the application of 20% full recommended lime gives 4.04, 1.13 & 0.94 t ha^{-1} total tuber yield advantage over control treatment @Y1S1, Y2S1 and Y2S2 respectively. This might be due to the neutralization activity of lime that helps to plant get nutrients in the plant root system, especially phosphorus deliver into the soil solution beyond its sorption by Aluminum and Iron in acidic soil conditions In addition, non-significant results in all lime-applied treatments as compared to the control and even with each other might be from the biological acid tolerance capacity of potato as compared to other crops like Barley, Faba bean, wheat, and Maize. The finding in line with the study of Natalia et al., (2019) who revealed that the Supplement of dolomitic limestone did not increase plant growth and tuber yield of potato even when soil correction was performed with calcitic limestone to elevate the base saturation to 60%. Another study conducted by Hajduk et al., (2016) indicated that Liming had no statistically significant impact on potato tuber yields even if the mean value of potato yield from non-limed and limed fields varied depending on mineral NPK nutrition; the yield from the non-limed field ranged from 19.3 to 29.7 t ha^{-1}. While the limed field was 20.6-32.5 t ha^{-1}

Table4. Effect of lime rates on Potato tuber yield and yield components of at Banja

Treatment	Y1S1			Y2S1			Y2S2		
	MY (tha-1)	UMY (tha-1)	TY (tha-1)	MY (tha-1)	UMY (tha-1)	TY (tha-1)	MY (tha-1)	UMY (tha-1)	TY (tha-1)
125%lime	12.82	0.63	13.44	20.52	2.22	22.74	13.37	0.3	13.67
100%lime	11.7	0.24	11.94	21.78	4.15	25.93	13.5	0.29	13.79
75%lime	11.89	0.57	12.46	19.89	2.78	22.67	13.44	0.2	13.64
50%lime	12.3	0.4	12.70	17.15	1.85	19.00	18.14	0.28	18.42
33.3%lime	10.74	0.19	10.93	16.59	2.41	19.00	17.72	0.33	18.05
25%lime	11.56	0.38	11.94	18.41	2.37	20.78	10	0.31	10.31
20%lime	10.52	0.35	10.87	16.93	1.7	18.63	14.89	0.3	15.19
16.7%lime	11.78	0.22	12.00	19.37	2.07	21.44	14.39	0.76	15.15
14.3%lime	13.93	0.62	14.55	18.74	2.07	20.81	16.78	0.24	17.02
12.5%lime	11.7	0.23	11.93	18.96	3.04	22	17.78	0.25	18.03
11.1%lime	10.74	0.72	11.46	19.56	2.74	22.3	14.59	0.16	14.75
0%lime	9.63	0.35	9.98	14.44	2.33	16.77	10.17	0.44	10.61
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV(%)	22.3	80.6	22.1	25.2	90,0	23.1	30.2	45.6	29.8

Y1S1= year one site one, Y2S1=year two site one, Y2S2=year two site two, MY=marketable tuber yield, UMY=unmarketable tuber yield and TY =total tuber yield

Table5. Effect of lime rates on Potato tuber yield at Machakel

Treatment	Y1S1			Y2S1			Y2S2		
	MY (tha-1)	UMY (tha-1)	TY (tha-1)	MY (tha-1)	UMY (tha-1)	TY (tha-1)	MY (tha-1)	UMY (tha-1)	TY (tha-1)
125%lime	10.1	0.67	10.78	6.2	0.88	7.1	7.19	0.42	7.61
100%lime	8.96	0.22	9.19	8.1	0.71	8.82	5.59	0.66	6.27
75%lime	10.1	0.96	11.04	7	0.7	7.74	5.41	0.26	5.67
50%lime	9.41	0.26	9.67	8.8	0.92	9.73	6.59	0.3	6.89
33.3%lime	8.89	1.7	10.59	8.7	0.86	9.57	6.3	0.61	6.91
25%lime	9.44	0.52	9.96	7.3	0.74	8.0	6.37	0.42	6.79
20%lime	10	0.85	10.89	9.7	0.58	10.3	6.56	0.45	7.01
16.7%lme	9.67	0.93	10.59	6.6	0.78	7.33	5.93	0.56	6.49
14.3%lime	7.96	0.89	8.85	8.4	0.64	9.01	5.41	0.78	6.19
12.5%lime	7.15	1.93	9.07	8.8	0.43	9.21	6.52	0.16	6.68
11.1%lime	8.52	0.52	9.04	9.4	0.89	10.3	6	0.83	6.83
0%lime	5.67	1.19	6.85	7	0.36	7.36	5.78	0.29	6.07
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV(%)	20.2	79.5	18.6	22.3	37.3	21.2	27.1	69.4	28.1

Y1S1= year one site one, Y2S1=year two site one, Y2S2=year two site two, MY=marketable tuber yield, UMY=unmarketable tuber yield and TY =total tuber yield

Conclusion and recommendation

It is concluded that the application of lime rates on acidic soils of Banja and Machakel did not significantly improve the tuber yield of Irish potato as compared with control treatment on experimental fields of each district. However; the application of 14.3% lime at Banja gives 6.41 and 4.51 t ha^{-1} tuber yield advantage over the control at Y1S1&Y2S2 respectively. Similarly, the application of 20% lime at Machakel provides 4.04, 1.13 and 0.94 t ha^{-1} tuber yields than the control treatment at Y1S1, Y2S1&Y2S2 respectively. The soil was affected due to the application of different lime rates on selected soil properties such as decreasing exchangeable acidity (exchangeable aluminum and hydrogen concentration). This might be due to the reclamation (neutralization) activity of lime through the substitution chemical reaction of ($CaCO_3$) with aluminum (Al^{+3}) and (H^{+1}) on soil exchangeable site that makes the formation of aluminum hydroxide and water than free hydrogen and aluminum. So in the study areas further cost to lime for potato production is not necessary or by using recommended fertilizer it enabled to produce potato but in order to fulfill the principle of reclamation acidic soil for production of subsequent crops it is important to use the minimum rate of lime. Based on this application of 14.3% of the lime rate at Banja and 20% of the lime rate at Machakel with recommended fertilizer (138N,69P2O5) would be important for potato production. But for concurrent suggestion and recommendation is vital to do further research findings on lime like its long-term residual effect and time of application with the different lime requirements calculation methods by including potential verities. In addition, it is also important to do integrated nutrient management in permanent plots in order to back up the depletion of soil organic matter

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