International Research Journal of Biochemistry and Bioinformatics (ISSN-2250-9941) Vol. 2(2) pp. 046-057, February, 2012
Available online http://www.interesjournals.org/IRJBB

Full length Research Paper

Characterization of soils and response of potato (*Solanum tuberosum* l.) to application of potassium at Angacha in southern Ethiopia

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Accepted 28 November, 2011

An experiment was conducted at Angacha Research Station in Kembata Tembaro Zone of SNNPRS to characterize the soils of the research station and evaluate the response of potato (Solanum tuberosum L.) to potassium fertilizer. A pedon with 2 m x 2 m x 1.5 m volume was opened and horizons were described in situ. Samples were collected from all identified horizons for laboratory analysis. Increasing rates of K (0, 40, 80, 120, 160, 200, 240, 280, and 320 kg ha^{-1} as KCl) in RCBD with four replications were used in the experiment. Recommended rates of N and P, 111 and 39.3 kg ha^{-1}, respectively were applied to all treatments. Urea (46-0-0) and DAP (18-46-0) were used as sources of N and P. N was applied in split at planting and after tuber initiation (as side dressing). The physico-chemical characteristics of the soil showed that the soil has good soil fertility status but organic carbon (OC) content was medium (1.56%). The soil type of the research station was identified to be Alfisols. Organic carbon (OC), total N, and K contents of the soil, ranging between 0.5 and 1.56%, 0.06 and 0.25%, and 0.19 and 0.37 Cmol (+) kg^{-1}, respectively, and decrease with depth, whereas the available P content is the same (40 ppm) throughout the horizons. The composite soil sample contains moderate organic carbon (1.6%), whereas the total N (0.26%), available P and K contents are high. The potato tuber yield ranged between 43.97 t ha^{-1} at application of 200 kg K ha^{-1} and 53.33 t ha^{-1} at application of 280 kg K ha^{-1}. Application of K did not significantly influence potato tuber yield, N, P and K concentrations both in leaf and tuber, exchangeable and available potassium in the soil. However, a yield advantage of 11.4% (5.47 t ha^{-1}) was obtained from the application of 280 kg K ha^{-1} over the control, although the difference is not statistically significant. These parameters neither showed increasing or decreasing pattern with increased K application. Therefore, it is concluded that soil fertility management practices based on the findings should focus on maintaining and increasing OC content of the soil and monitoring for balances among nutrients. Based on the current finding, application of K for potato at Angacha is not required. However, since the experiment is conducted only for one year, it should be repeated to draw a sound conclusion. Besides, as potato is highly K demanding crop, periodic checking of the K status of the soil and crop response to it is important.

Keywords*:* Argillic, potassium fertilization, potato tuber yield, exchangeable potassium.

Background and justification

Of the essential elements, potassium (K) is the third most likely, after nitrogen and phosphorus, to limit plant productivity (Brady and Weil, 2002). It plays a critical role in lowering cellular osmotic water potentials, thereby reducing the loss of water from leaf stomata and increasing the ability of root cells to take up water from the soil (Havlin *et al*., 1999) and maintain a high tissue water content even under drought conditions (Marschner, 2002). Potassium is essential for photosynthesis, nitrogen fixation in legumes, starch formation, and the translocation of sugars. It is also important in helping plants adapt to environmental stress (Havlin *et al*., 1999). As a result of several of these functions, a good supply of this element promotes the production of plump grains and large tubers. When K is deficient, growth is retarded, and net retranslocation of K^+ is enhanced from mature leaves and stems, and under severe deficiency these organs become chlorotic and necrotic (Marschner, 2002). Potassium deficiency causes lodging to crops (Mengel and Kirkby, 1987). K deficient plants are highly sensitive to fungal attack (Marschner, 2002), bacterial attack, and insect, mite, nematode and virus infestations (Havlin *et al*., 1999). Potassium deficiency affects nutritional and technological (processing) quality of harvested products particularly fleshy fruits and tubers. In potato tubers, for example, a whole range of quality criteria are affected by the potassium content in tuber tissue (Marschner, 2002).

In order to maintain the fertility level of the soil, the amount of K^+ taken up by crops (kg K ha^{-1}) and that lost by leaching should at least be balanced by K fertilizers. The response to K^+ uptake by crops depends to a considerable extent on the level of N nutrition. Generally, the better the crop is supplied with N the greater the yield increase due to K supply. On the other hand, applied N is only fully utilized for crop production when K supply is adequate (Mengel and Kirkby, 1987).

In Ethiopia due to the belief that the soils are developed from K-rich parent material, attention is not given to potassium fertilization. It is only P and N fertilizers that are being used in the country. But, the belief is based on the work done before three decades by Murphy **(**1959; 1968**)**, which indicated that the available potassium content of most Ethiopian soils is high. The intensive cropping and the increased use of nitrogen fertilizer after this long period might have lowered the availability of K in the soil. A study conducted in Nazareth on tomato in 1981/82 indicated that there was a strong trend of yield increase with increased levels of potassium fertilizers (IAR, 1987). Moreover, vegetables demand high amount of nutrients including potassium for their proper growth (IAR, 1987). In potato plants, for example, an increase in potassium is correlated with an increase in tuber yield and potassium content of leaves (Marschner, 2002).

Potato grows satisfactorily at an altitude of over 1000 m and economic yields are only obtained at elevation greater than this, although recently produced cultivars perform well at low elevations at 400-2000 m in tropical highlands (Tindall, 1983). A rainfall ranging between 500 and 750 mm, with even distribution during the growing period is generally considered necessary for optimum growth. Unlike most vegetables, acid soils that are fertile, loose and well drained are ideal for growing potatoes and there is usually no need to apply lime to soil unless it's pH is below 4.8 (Greensill, 1978; Cotner, 1985).

The yield of potato in sub-Saharan countries is only 4 to 7 tons ha^{-1}, whereas in Europe 30-40 tons ha^{-1} is obtained (FAO, 1991). One of the reasons for low productivity of potato in Sub-Saharan Africa is that the farmers do not have means to use the necessary fertilizers (FAO, 1991). The potato crop is heavy user of mineral nutrients (Hartmann *et al*., 1988). Patent and Bilderback (1982) indicated that a deficiency of potassium could cause problems. Tubers with too little potassium may become soggy and unappealing when cooked.

Response to fertilizer and rates of applications vary widely with location, climate, and soil type (Hartmann *et al*., 1988). In an area of similar climate and vegetation, differences between soils may be found due to differences in the parent material (Buol *et al*., 2003). A study conducted on four types of Hararghae highland soils by Tsedale (1983) indicated that as applied potassium in the soil was increased, different tuber yield responses were observed the highest being obtained from application of 210 kg ha^{-1}. The yield was decreased under the three types of soils, but increased under one type of soil.

Characterization of soils is fundamental to all soil studies, as it is an important tool for soil classification, which is done based on soil properties. Soil characterization also helps to document soil properties at research sites, which is essential for the successful transfer of research results to other locations (Buol *et al*., 2003). Therefore, it is important to characterize the soil of the research site and further investigate the soil type although the soil of the area is broadly said to be Ultisols (Ministry of Agriculture, 1995).

According to Central Agricultural Census Commission (CACC, 2003 Part I), the average agricultural population density of Angacha Woreda is 7 persons ha^{-}

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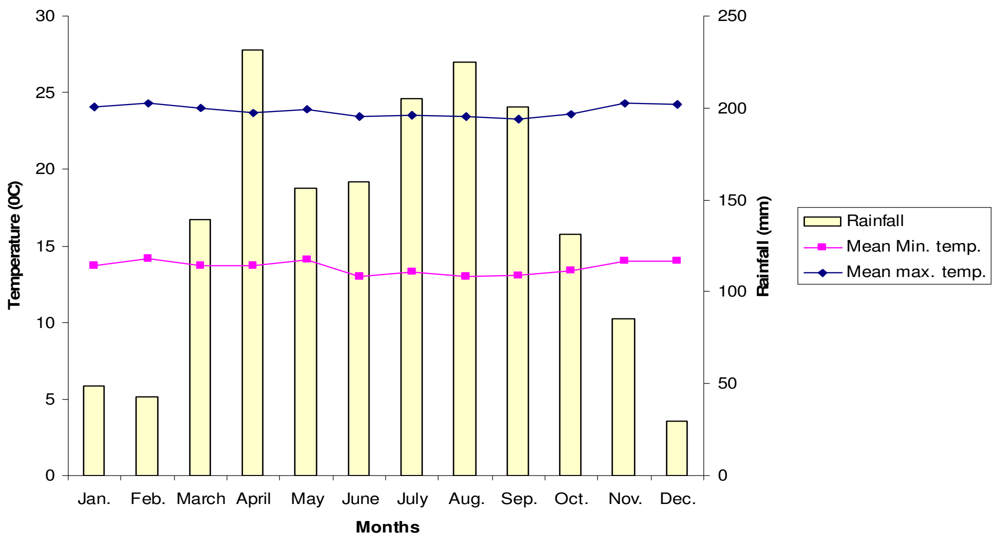

Figure1. Mean Annual Rainfall, Mean Maximum and Minimum Temperature at Angacha (ten years average)

[1]. Potato as a high yielding crop is very important in contributing to food security for this high population density. Potato is widely grown at Angacha. According to CACC (2003 Part II. B), the production of potato in the Woreda is 30265.32 t yr^{-1} (10.5 t ha^{-1}), which accounts for 51% of the production in the Zone (Kembata Tembaro Zone). Out of this production 47.47% goes to house hold consumption whereas 15.61% is used to make cash. The soils of the site are continuously cropped to potatoes without fertilizer K application, which might have reduced their nutrient K content. Thus increased K fertilization for potato production may be required as heavy cropped soils respond well to larger applications of K fertilizer (Hatmann *et al.*, 1988). However, the fertilizer should not be applied to the soil for the production of the crop before knowing whether K is deficient in the soil or not. The surest way to demonstrate a need for a nutrient suspected of being deficient is to apply it as a fertilizer and see what happens (Troeh and Thompson, 1993). Research on determination of the optimum level of K has never been carried out on the site. In order to make site-specific recommendation of K for potato production, characterization of the soil at the site and nutrient rate experiment are required. This study was therefore initiated with the objectives to characterize the soil of Angacha research station, and evaluate the response of potato to increasing levels of K application.

Materials and Methods

Description of the Study Site

The study was conducted at Angacha research station, which is located in Southern Nations Nationalities and People's Regional State (SNNPRS), Kembata Tembaro Administrative Zone. It is located at about 260 km South of Addis Ababa and 2 km south to Angacha town, found at 7^0 03' N and 38^0 29' E and altitude 2381m asl. The mean annual rainfall is 1656 mm with a bimodal pattern that extend from February to September. The peak rainy months are April, July, August and September (Figure 1). The mean annual maximum temperature is 24 ^{0}C and monthly values range between 23 and 24 ^{0}C (Appendix Table 3). The mean annual minimum temperature is 14 ^{0}C and monthly values range between 13 and 14 ^{0}C (Appendix Table 3). The coldest months are June and August, whereas February is the hottest month (Figure 1).

Treatments and Experimental Design

Potato variety "Tolcha" was used as a test crop to evaluate its response to increasing levels of K. The treatments used were 0, 40, 80, 120, 160, 200, 240, 280, and 320 kg K ha^{-1}.

The treatments were arranged in RCBD with four replications. Four rows, each having 10 plants, were used on 3m x 3m plot. A distance of 1 and 1.5 m were left between plots and blocks, respectively. N and P at rates of 111 and 39.3 kg ha^{-1} levels, respectively, were applied to all treatments. N was applied in split, at planting and after tuber initiation (as side dressing). All doses of P and K were applied at planting time following in row application method. DAP, Urea and KCl were used as sources of NPK. All cultural practices, such as weeding, earthening up, etc., were carried out equally for all treatments. The potato was harvested four months after planting. Flowering and maturity dates (when 50% of the plants were at respective phenological stage), stem number and tuber yield were recorded.

Soil Characterization and Sampling

A 2 m x 2 m x 1.5m soil pit was excavated at a representative spot in the Research station. The soil profile was described in situ following guidelines for soil description (FAO, 1990).

Soil samples were collected from every identified horizon of the profile. Besides these, 30 soil samples were randomly collected from surface layer (0-30 cm) and composited before planting. At harvest, composite samples were also collected from surface layer of every plot.

Plant Sampling

Third to sixth leaves (20 leaves per plot) from the tip, and potato tuber were collected for analysis of K, N, and P. Then the samples were washed with distilled water to remove dust and other contaminants. The washing was made quick to avoid leaking of some elements like Ca and K. The washed samples were then put into an oven at 65 ^{o}C for 48 hours. The oven dried plant samples were finely ground to pass 200 mesh for analysis.

Laboratory Analyses

All Laboratory analyses were done following the procedures in laboratory manual prepared by Sahlemedhin and Taye (2000). The soil samples were air-dried and ground to pass a 2-mm sieve and 0.5 mm sieve (for total N) before analysis. Soil texture was determined by Bouyoucos hydrometer method. The pH and electrical conductivity of the soils were measured in water (1: 2.5 soil: water ratio). Organic carbon content of the soil was determined following the wet combustion method of Walkley and Black. Total nitrogen (wet digestion) procedure of Kjeldahl method. The available phosphorus content of the soil was determined by Bray II method. Exchangeable cations and the cation exchange capacity (CEC) of the soil were determined following the 1 N ammonium acetate (pH 7) method. The exchangeable K and Na in the extract were measured by flame photometer. Ca and Mg were measured using EDTA titration method. The available potassium was determined by Morgan's extraction solution and potassium in the extract was measured by flame photometer. Exchangeable acidity of the soil was determined by leaching exchangeable hydrogen and aluminum ions from the soil samples by 1 N potassium chloride solution.

Nitrogen content of potato leaf and tuber was determined by wet digestion procedure of Kjeldhal method. The phosphorus content of the plant leaf and tuber was determined colorimetrically using vanadate method from the solution obtained through wet digestion. The potassium content of the plant leaf and tuber was measured using flame photometer from the solution obtained through wet digestion.

Data were statistically analyzed using the PROC ANOVA function of SAS and means were compared using LSD at a probability level of 5%.

Results and Discussion

Physico-chemical Properties and Classification of Soils of Angacha Research Station

The soil of the Research Station that covers an average of 5 ha is well drained and permeable that occurs on land of 6% slope (Appendix Table 1). The color of the surface soil is light reddish brown when dry and dark reddish brown when moist. The color changed to grayish with depth (Table 1). Its organic carbon (OC) content ranged between 0.5 and 1.56% and decreases with depth (Table 2). The moist color value and chroma, OC content and PBS meet Mollic epipedon criteria. The results of the particle size analysis indicated that the textural classes of the soil of the research station are clay loam at upper horizons and silty loam at Bt_2 horizon (Table 2). This could be probably due to clay migration within the profile. Clay content in the soil ranged from 30 to 42% and increased with depth. These Bt_1 and Bt_2 horizons are more than 30 cm thick and have apparent cation exchange capacity (CEC_7) values of 40 and 31 cmol kg^{-1} clay, respectively. The Bt horizons contained 38 and 42 percent clay, which are more than 1.2 times as much clay as the A horizon above. The soil is very deep (>150 cm) and has an angular blocky structure with

Table 1. Selected Morphological Properties of the Soil Profile at Angacha Agricultural Research Station

Horizon symbol	Depth (cm)	Color		Texture	Structure	Consistency			Boundary
		Dry	Moist	(Feel method)		Dry	Moist	Wet	
A	0-69	5YR6/3	5YR3/2	Clay Loam	Angular blocky	Slightly hard	Friable	Slightly sticky-very plastic	Clear weavy
Bt_1	69-96	5YR6/2	5YR3/2	Clay Loam	Angular blocky	Slightly hard	Friable	Slightly sticky-very plastic	Clear weavy
Bt_2	96-150+	5YR7/2	5YR4/2	Clay Loam	Angular blocky	Slightly hard	Friable	Slightly sticky-very plastic	Clear weavy

Table 2. Selected Physicochemical Properties of the Soil Profile at Angacha Agricultural Research Station

Depth (cm)	Particle size distribution (%)			Textural Class	pH (H_2O)	EC (dS m^{-1})	N (%)	OC (%)	C/N	Exchangeable bases (cmol(+) kg^{-1})					EA cmol(+) kg^{-1}	BSP (%)	ESP (%)	Avl.P mg/kg	Av.K mg/kg
	Sand	Silt	Clay							Na	K	Ca	Mg	CEC					
0-69	34	36	30	CL	6.46	0.051	0.25	1.56	6.24	0.4	0.37	12.0	1.5	18.08	0.015	78.9	3.91	40	94
69-96	24	38	38	CL	6.62	0.049	0.11	0.5	4.55	0.4	0.19	10.6	1.4	15.24	0.099	82.6	8.33	40	94
96-150+	16	42	42	SL	6.56	0.16	0.06	0.65	10.80	0.4	0.28	8.3	1.4	12.88	0.023	80.6	6.76	40	94

CL- Clay Loam, SL- Silty Loam, EC-Electrical conductivity, OC- Organic carbon, C/N- Carbo to Nitrogen ratio, EA- Exchangeable acidity, BSP- Base saturation percentage, ESP- Exchangeable sodium percentage, Avl. P- Available phosphorus, Av. K- Available potassium.

good porosity and clear textural boundary. Based on these features and the clay films (argillans) detected in these horizons, the sub surface horizons are termed as argillic.

The base saturation percentage (BSP) is greater than 50% by ammonium acetate at pH 7 throughout the profile. According to Buol *et al.* (2003), the 50% base saturation determined by the ammonium acetate method (CEC_7) is roughly equivalent to 35% base saturation by sum of cations ($CEC_{8.2}$). Thus, the argillic horizons had base saturation greater than 35%.

The profile has an A and Bt horizons with accumulation of enough clay in the Bt horizons. There is also relatively high base status in the argillic horizon. Besides these, the OC content in the mineral horizons is relatively low. The properties qualify the soil as an order of Alfisol of the soil Taxonomy with a suborder and great group of Udalfs and Hapludalfs, respectively. The equivalent FAO/Unesco soil classification is Haplic Luvisol.

The pH of the soil is moderately acidic (Herrera, 2005) with values ranging between 6 and 6.62. This pH value indicates that there is no toxicity of aluminum, manganese and hydrogen; rather cations such as K, Ca and Mg are abundant (Fall, 1998). The pH values increased with soil depth because less H^+- ions are released from decreased organic matter decomposition, which is caused by decreased organic matter content with depth and this is in agreement with Buol *et al.* (2003). The electrical conductivity of the soil ranged between

Table 3. Exchangeable and available K, soil available P (Bray II), total N and OC as influenced by increasing K application on soils at Angacha

Rates of K (kg ha^{-1})	Exchangeable K (cmol (+) kg^{-1})	Available K (cmol (+) kg^{-1})	Available P (mg kg^{-1})	Total N (%)	OC (%)
0	0.45cd	0.56c	61.30	0.26	1.59ab
40	0.49cd	0.88abc	59.00	0.25	1.47bcd
80	0.54abcd	0.58c	61.30	0.25	1.34d
120	0.50bcd	0.78bc	59.00	0.28	1.36bcd
160	0.58abc	0.90abc	54.00	0.28	1.47bcd
200	0.65a	0.88abc	56.30	0.27	1.51bc
240	0.52bcd	0.74c	58.00	0.27	1.52abc
280	0.51bcd	1.2a	60.00	0.26	1.51bc
320	0.62abc	1.2a	55.00	0.28	1.69a
Before planting	0.84	1.00	65.00	0.26	1.60
CV (%)	16.03	18.00	11.96	11.23	7.77
LSD (5%)	0.13	0.38	NS	NS	0.17

0.05 in Bt_1 horizon and 0.16 dS m^{-1} in Bt_2 horizon indicating that it has no salinity problem (McWilliams, 2003). Higher concentrations of bases (K, Ca and Mg) are observed in the surface horizon meeting one of the requirements of Alfisols (Buol *et al*., 2003).

The total N content of the soil ranged between 0.06% in Bt_2 horizon and 0.25% in A horizon (Table 2). Its content decreased with depth due to decreased organic matter content down the profile that is in agreement with Buol *et al*. (20003). The C: N ratio of the soil ranged between 6.24 at the A horizon and 10.8 at theBt_2 horizon.

According to Landon (1991), the cation exchange capacity (CEC) of the soil is medium ranging between 12.88 and 18.08 cmol (+) kg^{-1} of soil. The value decreases with depth. This range of CEC indicates that the dominant clay mineral of the soil is illite as Buol *et al*. (2003) indicated the CEC range for soil dominated by this clay mineral to be between 10 and 40 cmol(+) kg^{-1} of soil. Alfisol is one of the soil orders in which this mineral is an important constituent of clays (Tan, 1993). According to this author, K^+ ions exert electrostatic bond in the interlayer of illite and link the unit layers together not to expand up on addition of water. As a result of this, illite is potassium reservoir (Landon, 1991) and known to be potassium rich (Keene *et al*., 2004). The exchangeable potassium of the soil ranged between 0.19 and 0.37 cmol (+) kg^{-1} of soil. The value decreased from 0.37 cmol (+) kg^{-1} of soil at A horizon to 0.19 cmol (+) kg^{-1} of soil at Bt_1 horizon but started to increase at Bt_2 horizon. The soil has low available potassium (Landon, 1991), which is similar throughout the profile being in agreement with Foth (1990). The low availability might be attributed to fixation.

The exchangeable sodium content of the soil is 0.4 cmol (+) kg^{-1} of soil throughout the profile. The exchangeable sodium percentage (ESP) ranged between 3.9 and 8.3, which indicates that the soil has no sodicity problem (Herrera, 2005). Higher ESP values were obtained at bottom horizons than the upper one, which could be attributed to adsorption of Ca and Mg at the soil surface. The exchangeable acidity is also low ranging between 0.02 at A horizon and 0.10 cmol (+) kg^{-1} of soil at Bt_2 horizon. The soil has no exchangeable aluminum throughout the profile and hence acquired its exchangeable acidity only from the exchangeable H.

Influence of Potassium application on Soil Chemical Properties

Available Potassium

The highest (1.2 cmol (+) kg^{-1}) and lowest (0.56 cmol (+) kg^{-1}) available K were obtained from application of the highest rate of K (320 kg K ha^{-1}) and control (0 kg K ha^{-1}), respectively. The available potassium contents of the experimental soil both before planting (1 cmol (+) kg^{-1}) and at harvest (ranging between 0.56 and 1.2 cmol (+) kg^{-1}) were higher than the critical level (0.15 cmol (+) kg^{-1}) reported by Cox and Urbe (1992). However, the values obtained from the present experiment are in line with that of Tariku and Tekalign (1999), who reported available K range between 0.22 and 1.5 cmol (+) kg^{-1}. Application of potassium fertilizer increased the amount of available potassium (Table 3) although the increasing trend was not linearly related to the rate of application. In the treatments with application of 280 and 320 kg K ha^{-1}, equal amount of available K, which was higher than that of all the other treatments and the b value

Table 4. Effects of increasing K application on Potato Tuber Yield and Stem Number

Rates of K (kg K ha^{-1})	Tuber yield (t ha^{-1})	Stem number/plot
0	47.86abc	72ab
40	47.14abc	68ab
80	48.06abc	74a
120	47.89abc	68ab
160	50.98ab	71ab
200	43.97c	56b
240	46.44bc	56b
280	53.33 a	83a
320	50.23abc	71ab
CV (%)	9.29	16.87
LSD (5%)	6.577	17.00

Values followed by the same letter (s) within a column are not significantly different

before planting, was obtained. In the other treatments the available potassium contents were reduced as compared to the value obtained before planting with the greatest reduction in the control treatment. The increment due to application of 280 and 320 kg K ha^{-1} was significantly different from the control as well as 80, 120 and 240 kg K ha^{-1} applications. Available K was highly correlated with exchangeable K (r= 0.41**) and significantly correlated with applied K (r= 0.33*). It was also positively correlated with leaf K concentration, tuber K concentration, available P, leaf P concentration, total N, leaf N concentration, OC, pH, EA, and tuber yield, whereas its correlation with tuber P concentration, tuber N concentration, Ca, Mg and stem number was negative (Table 6).

Exchangeable Potassium

Application of K fertilizer increased the exchangeable K over the control, although the increment is significant only in some treatments (Table 3). The highest exchangeable K was obtained from the application of 200 kg K ha^{-1}, whereas the lowest was obtained from the control (with no K application). Three rates of K application (160, 200 and 320 kg ha^{-1}) resulted in significantly higher exchangeable K than the control. The exchangeable K value (0.65 cmol (+) kg^{-1}) at application of 200 kg K ha^{-1} is significantly higher than the control (0.45 cmol (+) kg^{-1}) and the treatments with 40, 120, 240 and 280 kg K ha^{-1}. Exchangeable K did not increase with increasing rates of applied K indicating the applied K was either taken up by plants, remained in soil solution, removed by leaching or fixed on clay surface (Havlin *et al.*, 1999; Rehm and Schmitt, 2002). The exchangeable K did not linearly increase with increasing rates of applied K, although it was positively correlated with applied K (Table 7). In all treatments, the exchangeable K values were found to be below the level recorded before the trial was commenced (Table 3). The greatest reduction occurred in the control treatment, whereas the lowest reduction was obtained from the application of 200 kg K ha^{-1} (Table 3). Exchangeable K was significantly correlated with tuber K concentration (r= 0.38*). It was positively correlated with leaf K concentration, leaf P concentration, tuber P concentration, tuber N concentration, total N, CEC, EA and tuber yield, whereas its correlation was negative with available P, leaf N concentration, Ca and Mg (Table 7). A significant negative correlation was also obtained between exchangeable K and potato stem number (r= 0.36*).

Response of Potato to Potassium Fertilization

Potato Tuber Yield

The highest tuber yield (53.33 t ha^{-1}) was obtained from application of 280 kg K ha^{-1} and this result is similar to that reported by Tawfik (2001). The treatment had 5.47 t ha^{-1} (11.4%) yield advantage over the control (47.86 t ha^{-1}), although the difference was not statistically significant. However, the yield obtained from application of 280 kg K ha^{-1} was significantly different from 200 and 240 kg K ha^{-1} (Table 4). The lowest tuber yield (43.97 t ha^{-1}) was obtained from application of 200 kg K ha^{-1}. None of the potassium rates resulted in significantly higher tuber yield than the control in this study making it different from previous study by Roberto and Monnerat (2000).

Table 5. N, P, K concentrations of potato leaves and tubers as influenced by increasing K application

Rates of K (kg ha^{-1})	Concentrations in Tissues (%)					
	Leaves			Tubers		
	N	P	K	N	P	K
0	7.78	0.58b	6.58	2.92a	0.43b	1.22cd
40	7.62	0.61ab	6.98	2.54ab	0.43b	0.93d
80	7.82	0.60ab	7.48	2.23b	0.43b	1.38abcd
120	7.43	0.59ab	7.43	2.63ab	0.48ab	1.35bcd
160	7.35	0.64ab	7.08	2.41ab	0.43b	1.33bcd
200	7.40	0.63ab	7.70	2.51ab	0.53a	1.75ab
240	7.59	0.65ab	6.98	2.50ab	0.48ab	1.83a
280	7.96	0.67a	7.30	2.62ab	0.43b	1.68abc
320	7.95	0.65ab	6.73	2.62ab	0.43b	1.40abc
CV (%)	11.78	8.87	12.26	15.27	8.77	14.3
LSD (5%)	NS	0.08	NS	0.57	0.06	0.47

Values followed by the same letter (s) within a column are not significantly different
NS - not significant

The yield increment in treatments with application of 80, 120, 160, 280 and 320 kg K ha^{-1} over the control did not follow the increasing pattern of the rate of potassium application. Treatments with application of 40, 200 and 240 kg K ha^{-1} resulted in lower yield than the control. Potato tuber yield was highly correlated with stem number (r= 0.50**) and positively correlated with applied K (Table 7). Most factors that influenced stem number also influenced tuber yield. The exchangeable K, available K, leaf and tuber K concentration at which the highest yield was obtained were 0.51 cmol (+) kg^{-1}, 1.18 cmol (+) kg^{-1}, 7.3 %, and 1.675 %, respectively. The lowest yield was obtained at the exchangeable, available, leaf, and tuber K of 0.65 cmol (+) kg^{-1}, 0.56 cmol (+) kg^{-1}, 7.7%, and 1.75%, respectively.

Phenology and Stem Number of Potato

Potassium fertilization did not affect time of emergence, flowering and physiological maturity. In all treatments, the crop emerged at the same time. The treatments did not show difference in days to 50% flowering. Days to 50% physiological maturity are also similar for all treatments.

Similar to tuber yield, the highest and lowest numbers of stems were obtained from application of 280 and 200 kg K ha^{-1}, respectively. Stem number of the potato was influenced by the application of K fertilizer (Table 5). Most of the K treatments gave lower stem number than the control. But the stem number did not follow a decreasing or increasing trend with increasing rates of K application. Although the highest stem number (83) was obtained from the application of 280 kg K ha^{-1}, it was not significantly higher than the control. Treatments with 40, 120, 160, 200, 240 and 320 kg K ha^{-1} resulted in lower stem number than the control. Stem number was positively correlated with applied K (Table 7).

Nutrient Concentrations in Tissue

Concentration of Potassium in Tissue

Application of K fertilizer generally increased both leaf and tuber K concentrations (Table 5). However, the K

Table 6. Correlation between soil parameters, tissue nutrients concentrations, Tuber yield and stem number

	Kex	Kav	KL	KT	Pav	PL	PT	TN	NL	NT	OC	CEC	pH	EA	Ca	Mg	Y	Stem no.
Kap	0.31	0.33*	0.05	0.44**	-0.21	0.46**	0.14	0.20	0.06	-0.06	0.29	-0.16	0.01	0.47**	-0.26	-0.01	0.20	0.04
Kex	1	0.41**	0.17	0.37*	-0.17	0.07	0.05	0.30	-0.04	0.06	0.34*	0.07	0.38*	0.27	-0.07	-0.18	0.01	-0.36*
Kav		1	0.05	0.11	0.04	0.2	-0.09	0.11	0.04	-0.12	0.25	0.00	0.25	0.31	-0.04	-0.08	0.21	-0.01
KL			1	0.03	-0.15	-0.12	0.12	-0.24	-0.11	0.00	-0.08	0.07	-0.20	0.08	0.06	0.02	-0.11	-0.11
KT				1	-0.23	0.33*	0.25	0.05	0.12	0.05	0.06	-0.07	0.06	0.07	-0.12	0.22	0.08	-0.26
Pav					1	-0.06	-0.09	-0.18	0.18	0.06	-0.03	0.23	0.06	-0.13	0.10	0.03	-0.16	-0.003
PL						1	-0.04	0.00	-0.01	-0.18	0.02	-0.36*	0.01	0.17	-0.26	0.26	0.12	-0.11
PT							1	0.13	-0.03	-0.03	-0.12	0.25	0.02	-0.19	-0.23	-0.04	-0.28	-0.33*
TN								1	-0.09	0.04	0.11	0.03	0.54***	-0.05	-0.13	-0.03	0.14	0.03
NL									1	0.19	-0.08	-0.16	0.00	-0.23	0.11	-0.18	0.24	-0.01
NT										1	0.26	-0.13	-0.04	-0.20	0.17	-0.08	-0.06	-0.19
OC											1	0.10	0.18	0.13	-0.02	0.07	-0.02	-0.01
CEC												1	0.27	-0.07	0.34*	0.07	-0.32	-0.17
PH													1	-0.03	0.21	-0.02	0.04	-0.22
EA														1	-0.24	-0.08	0.02	-0.10
Ca															1	0.01	-0.12	0.10
Mg																1	0.20	0.06
Y																	1	0.50**

*, **, ***-Significant at 0.05, 0.01 and 0.001 probability levels, respectively. Kap-applied K, Kex-exchangeable K, KL- leaf K concentration, KT- tuber K concentration, Pav-available P, PL-leaf P concentration, PT- tuber P concentration, TN- total N, NL- leaf N concentration, NT- tuber N concentration, OC- organic carbon, CEC- cation exchange capacity, EA-exchangeable acidity, Y- tuber yield

fertilization did not significantly influence concentration of potassium in leaf, which is in line with the report by Cripps *et al*. (1989). The K concentrations in both leaves and tubers did not have either an increasing or decreasing pattern with the increasing rate of K application. The highest leaf K concentration (7.70%) was obtained from the application of 200 kg K ha^{-1}. However, this value was not significantly higher than the values obtained from the other rates of K application. The highest rate of K application (320 kg K ha^{-1}) gave the lowest leaf K concentration (6.73%). According to Decuypere (2002), who reported optimum tissue K levels varying from 2-5%, the leaf K concentration in all treatments including the control is above the optimum indicating high uptake of K by the crop. Pushparajah (1997) also classified leaf K concentration as low (< 1.25%), medium (1.25-1.5%), high (1.5-1.65%) and very high (> 1.65%). According to this classification, the leaf K concentration in this study is groped as very high.

Application of 240 kg K ha^{-1} resulted in the highest tuber K concentration (1.83%). This value is significantly higher than the value of tuber K concentration in the control (1.2%) and all treatments that received less than 160 kg K ha^{-1} except that of 80 kg K ha^{-1}. The highest rate of K pplication (320 kg K ha^{-1}) did not result in significantly higher tuber K concentration than the control. The tuber K concentration obtained from the highest rate of K application was 1.4%. The lowest tuber K concentration was obtained from the application of 40 kg K ha^{-1}. Leaf K concentration had positive correlation with applied K, tuber K concentration, tuber P concentration, CEC, EA, Ca and Mg. Its correlation was negative with available P, leaf P concentration, total N, leaf N concentration, OC, pH, tuber yield and stem number (Table 7). Both tuber yield and stem number are lowest at highest leaf K concentration. Tuber K concentration was highly correlated with applied K (r= 0.44**) and significantly correlated with leaf P concentration (r= 0.33*), respectively. Tuber K concentration was positively correlated with tuber P concentration, total N, leaf N concentration, tuber N concentration, OC, pH, EA, Mg, available P, CEC, Ca and potato stem number.

Concentration of Nitrogen in Tissue

The highest leaf N concentration (7.96%) was obtained from application of 280 and 320 kg K ha-1. The highest tuber N concentration (2.92%) was obtained from the application of 0 kg K ha-1, whereas the lowest leaf and tuber N concentrations were obtained from the application of 160 and 80 kg K ha-1, respectively (Table 6). There is no statistically significant difference in N concentration of leaf among treatments, whereas significant difference in N concentration of tuber was obtained among treatments. Treatments with application of 80, 280 and 320 kg K ha-1 gave higher leaf N concentration than the control. The other treatments with application of 40, 120, 160, 200 and 240 kg K ha-1 resulted in lower leaf N concentration than the control. According to Pushparajah (1997), who classified leaf N as low (< 3.2%), medium (3.2-3.5%), high (3.5-3.7%) and very high (> 3.7%), the leaf N concentration is rated as very high.

On the other hand, all treatments with application of K resulted in lower tuber N concentration than the control. The control gave significantly higher tuber N concentration than the treatment with application of 80 kg K ha-1. The increasing or decreasing pattern of leaf N contents was not linear with application of K fertilizer. The leaf N concentration was positively correlated with applied K, tuber N concentration, Ca and tuber yield (Table 6). On the other hand, it had negative correlation with OC, CEC, EA, Mg and stem number. The N concentration in tuber was positively correlated with OC and Ca. It was negatively correlated with applied K, CEC, pH, EA, Mg, tube yield and stem number. The negative correlation between N concentration in tuber and tuber yield could be attributed to less deposition of carbohydrate in tuber with high concentration of N in tuber (Havlin et al., 1999).

Concentration of Phosphorus in Tissue

The highest tuber (0.53%) and leaf (0.67%) P concentrations were obtained from the application of 200 and 280 kg K ha^{-1}, respectively. The lowest leaf P concentration was found at the application of 0 kg K ha^{-1}, whereas the lowest tuber P concentration was found at the application of 0, 40, 80, 160, 280 and 320 kg K ha^{-1} (Table 6). Application of 200 and 280 kg K ha^{-1} significantly increased the tuber and leaf P concentrations over the control, respectively. Application of K fertilizer increased leaf P concentration, which is in line with the report by Kanziwera *et al*. (2001). All rates of K application resulted in higher leaf P concentration than the control, although, the increment of leaf P concentration was not linearly related to the rate of K application. Moreover, except for the treatment with application of 280 kg K ha^{-1}, there is no significant leaf P concentration difference between the treatments with application of K and the control. The leaf P concentration in all treatments including the control was greater than the plant P concentration range (0.1-0.5%) mentioned by Havlin *et al*. (1999), which is rated as very high as Pushparajah (1997) grouped leaf P as low (< 0.19%), medium (0.20-0.25%), high (0.26-0.28%) and very high (> 0.28%). The tuber

P concentration did not linearly increase with increasing application of potassium fertilizer. The two highest rates of K application (280 and 320 kg K ha^{-1}) gave the lowest tuber P concentration. Leaf P concentration was highly correlated with applied K (r= 0.46**) and negative significantly correlated with CEC (r= -0.36*). The K rates at which the highest and the lowest leaf P concentration were obtained were 280 and 0 kg K ha^{-1}, respectively. The leaf P concentration was positively correlated with OC, pH, EA, Mg and tuber yield and its correlation with tuber P concentration, leaf N concentration, tuber N concentration, Ca and stem number was negative (Table 7). Tuber P concentration was significantly correlated with stem number (r= 0.33*). It was positively correlated with applied K, total N, CEC and pH, whereas the correlation with leaf N concentration, tuber N concentration, OC, EA, Ca, Mg and tuber yield was negative.

CONCLUSION

The soil of Angacha Research Station has good soil fertility status and pH range, where nutrients are easily available for satisfactory crop production. However, soil organic matter content is medium. Therefore, soil fertility management practices should focus on maintaining and increasing OC content of the soil and monitoring for balances among nutrients.

Application of K, as revealed by all parameters considered, is not required for potato production at Angacha research Station area. However, as potato is a highly K demanding crop, periodic checks for K status of the soil and the response of the crop to K are necessary.

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