Research Findings

Photo by E. Sokolowski.

The Effect of Potassium on the Yields of Potato and Wheat grown on the Acidic Soils of Chencha and Hagere Selam in Southern Ethiopia

Wassie Haile[(1)] and Tekalign Mamo[(2)]

Introduction

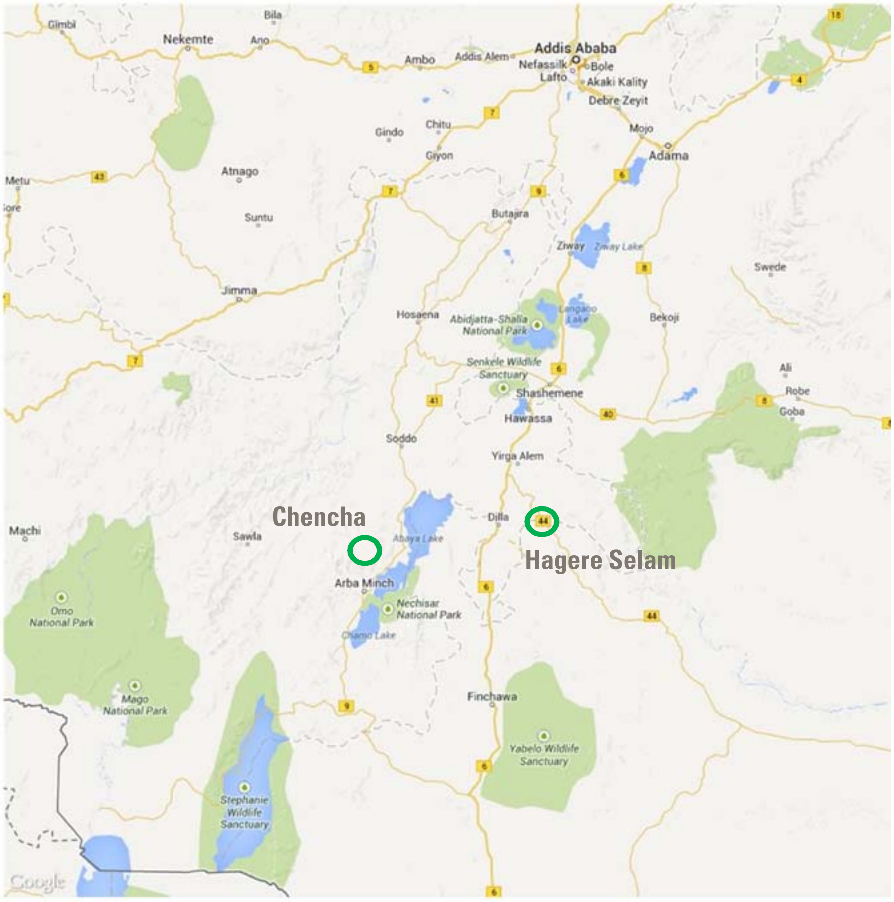
Agriculture is the basis of the Ethiopian economy and the main source of livelihood of the population. The potential for developing agricultural production is high but despite this, Ethiopia is currently unable to produce enough food to meet the demands of its ever increasing population. According to the International Food Policy Research Institute (IFPRI, 2010), 5-7 million people in Ethiopia are chronically food insecure. The reasons for this are diverse and complex but declining soil fertility and soil degradation is a primary factor. Four decades ago, nitrogen (N) and phosphorus (P) were identified as being the most deficient nutrients in almost all Ethiopian soils. As a result, application of fertilizers containing N and P (urea and DAP) began in the late 1960s, producing dramatic increases in the yields of several crops. Consequently, the use of urea and DAP have been by far the most widely adopted inputs by farmers, causing a steady year-on-year increase in the consumption of these fertilizers.

[(1)]Department of Plant and Horticultural Sciences, College of Agriculture, Hawassa University, P.O. Box 05, Hawassa, Ethiopia, wassiehaile@yahoo.co.uk
[(2)]Ministry of Agriculture, P.O. Box 62347, Addis Ababa, Ethiopia, tekalignmamo@gmail.com

Map 1. Map of the African Continent and Ethiopia.

Fertilizers containing N and P are the only ones currently being used in Ethiopia. There has been a long established understanding, for example, that Ethiopian soils are rich in potassium (K) and so there is no need for the application of fertilizers containing K (Murphy, 1968). Such studies have meant that little attention has been paid to the status of K in Ethiopian soils. More recent evidence, however, suggests the likelihood of K deficiency in some Ethiopian soils for the following reasons: extensive deforestation that has occurred in the last four decades (Pound and Jonfa, 2005), a high incidence of soil erosion, crop nutrient removal, and continuous cropping, and inadequate and imbalanced use of organic and inorganic fertilizers (Bishaw and Abdulkadir, 1990).

In recent years, studies on the nutrient status of Ethiopian soils other than N and P have increased and emerging reports are confirming that nutrients, such as K, are beginning to limit crop growth. For instance, Deressa *et al.* (2013) collected 353 soil samples from five districts of east Wollega, western Ethiopia, and found that the levels of K and calcium (Ca) in all soils was below the optimum level for adequate crop production. The findings of Abegaz (2008) who studied the K content of three soil types from the Atsbi-Wonberta district of Tigray, northern Ethiopia, in 2003 also showed that K was deficient in a Luvisol under barley production. Abiye *et al.* (2004) reported that K applied in the form of K_2SO_4 significantly increased the uptake of N in the grain and straw of wheat as well as increasing grain yield on the Vertisols of central Ethiopia.



Map 2. Experimental sites in Chencha and Hagere Selam, South Ethiopia.
Source: Map data @2013 Google; adapted by IPI.

In southern Ethiopia, in the early 2000s, multi-location experiments on different crops were conducted with the objective of determining the optimum N and P rate for crop production. In fact, little or no response was found in some areas with acidic soils. Interestingly, however, and by contrast, the results of an experiment conducted for two years (2006-2007) on the acidic soil in Chencha, southern Ethiopia (see Map 2) - comparing the effects of NP, NPK, farm yard manure (FYM), NP + FYM and NPK + FYM on potato production - revealed that the NPK treatment dramatically and significantly increased the fresh total tuber yield of potato to 30.9 mt ha^{-1} from 6.27 and 8.09 mt ha^{-1} in the control and NP treated plots respectively. In other words, application of K along with NP increased the tuber yield of potato respectively by 392 and 282 percent over the control and NP treatments (Wassie *et al.*, 2009). This observation greatly strengthened our suspicion that K could be a limiting nutrient in these areas and it was decided to conduct extensive on-station and on-farm research on the response of potato and wheat to K fertilization along with NP (urea and DAP) fertilizers in areas of southern Ethiopia with acidic soils.

This paper presents the findings on the response of potato and wheat to K fertilizers over five years (2007-2011) on the acidic soils in Chencha and Hagere Selam (see Map 2). Based on the studies, the aim was to make recommendations for scientists and policymakers, with respect to the use of K fertilizers as an important additional input for crop production in these and other similar areas of Ethiopia, and to indicate future directions on aspects of soil K research in Ethiopia.

Materials and methods

The effect of K fertilizer on tuber yield of Irish potato in Chencha's acidic soils

The experiment was conducted at the Chencha sub-center of Awassa Agricultural Research Center for two years (2007-2008). The center is located at 37˚ 6' E and 6˚ 13' N, at an altitude ranging from 2,800 to 3,005 meters with a mean annual rainfall of 1,500 mm. The chemical properties of the soil in the study area were as follows: pH (4.8), organic carbon (2%), N (0.3%), P (3.2 mg kg^{-1}) and exchangeable K (0.028 Cmol kg^{-1}). The treatments used were increasing levels of K (K_2O; 0, 30, 60, 90, 120, 150, 180, 210, 240, 270 and 300 kg ha^{-1}) applied in the form of KCl as muriate of potash (MOP). The experiment was laid out in a randomized complete block (RCB) design with three replications. The potato variety - CIP392618-511 - was planted in a plot size of 3.75 x 3.9 m with intra and inter row spacing of 30 and 70 cm respectively. N and P fertilizers were applied uniformly to all plots at 110 and 40 kg ha^{-1} in the form of urea and triple superphosphate (TSP) respectively. The N application was split, half at planting and the remaining half 45 days later. Recommended agronomic practices were applied. Data on total tuber and marketable tuber yield were collected.

On-farm verification of the effect of K fertilizer on potato in Hagere Selam's acidic soils

The experiment was conducted on 24 farmers' fields in Hagere Selam in 2010. The treatments used were: control (zero fertilizer), NP (110:40:0) and NPK (110:40:100 N, P_2O_5 and K_2O; kg ha^{-1}) with urea, TSP and KCl being used as sources of N, P and K respectively. The N application was split, half applied at planting and the remaining half one month later. P and K fertilizers were band-applied at planting. The experiment was laid out in a RCB design, replicated across 24 farmers' fields. Four different varieties of Irish potato, namely Zengena, Guassa, Jalleni and Tolcha, were planted as test crops. Each variety was planted in a plot size of 3.75 x 3.9 m with intra and inter row spacing of 30 and 70 cm respectively. Prior to planting, composite soil samples were taken from the fields of participating farmers and their physicochemical properties analyzed. Data on total tuber yield, marketable yield, number of tubers per plot and other relevant information were collected. Farmers' days were also organized and the effect of K on potato was demonstrated.

On-farm verification of K fertilizer on wheat in Hagere Selam

Following the impressive and positive results that were obtained due to K fertilization at Hagere Selam in previous years, further on-farm verification and demonstration of the effect of K fertilizers on the yield of wheat was conducted in the 2011 cropping season as part of nationally coordinated trials. Treatments included (kg ha^{-1}): 50 urea + 100 DAP; 50 urea + 100 DAP + 50 K_2SO_4; 50 urea + 100 DAP + 43.33 KCl; and 50 urea + 100 DAP + 43.33

Photo 1 (left) and Photo 2 (right). Potato control plot (left) and plot that received NPK (right), (110:40:100 kg ha^{-1} of N, P_2O_5 and K_2O, respectively). Hagere Selam, Ethiopia. Photos by Wassie Haile.

KCl + 50 $CaSO_4$. Bread wheat (Degello variety) was planted at a rate of 150 kg ha^{-1} in 5 x 5 m plots. The seeds were planted in rows 20 cm apart. The experiment was laid out in a RCB design, replicated across ten farmer's fields. The recommended agronomic practices for wheat production were applied. Data on yield and yield components of wheat were collected.

Statistical analyses

Data on total and marketable tuber yields of potato and the grain and straw yield of wheat, collected from both on-station and on-farm experiments in different locations and seasons, were subjected to analysis of variance (ANOVA) using SAS software (SAS, 2000) to detect variations among treatments of each experiment. Parameters, for which the ANOVA found to be significant, resulted in further separation work using the least significant difference (LSD) method at 0.05 probability level.

Table 1. The effect of different K levels on the tuber yield of Irish potato on the acidic soil of Chencha.

K application rate	Tuber yield			
	2007		2008	
	Total yield	Marketable yield	Total yield	Marketable yield
kg K_2O ha^{-1}	*mt ha^{-1}*			
0	15.6 d†	13.4 d	24.5 c	21.3 d
30	21.7 d	19.7 d	25.7 bc	22.8 cd
60	38.0 c	34.6 c	29.7 c	26.5 cd
90	40.0 c	36.9 c	35.7 abc	32.9 abcd
120	50.8 ab	41.8 ab	36.5 abc	34.6 abcd
150	57.2 a	55.9 a	50.3 a	49.2 a
180	49.3 abc	47.5 ab	42.8 bc	41.4 abc
210	54.8 a	51.8 a	45.2 ab	42.7 ab
240	52.3 ab	49.7 a	44.9 abc	42.6 ab
270	51.4 ab	48.8 a	33.3 abc	31.6 abcd
300	51.3 ab	48.5 ab	44.1 abc	41.6 abc
LSD (0.05)	12.3	11.7	20.3	19.2
CV (%)	16.0	16.7	32	32.3

Note: †Means followed by the same letter are not statistically different from each other at 0.05 probability level.

Results and discussion

The effect of K fertilizer on the tuber yield of Irish potato in Chencha's acidic soils

Applications of increasing levels of K significantly increased the total and marketable tuber yield of potato in both years (Table 1 and Fig. 1). Increasing levels of K from 30 up to 150 kg ha^{-1} significantly increased the tuber yield. In the 2007 cropping season, K applied at 150 kg ha^{-1} increased the marketable tuber yield from 13.4 mt ha^{-1} in the control to 55.9 mt ha^{-1}. The corresponding increase in the 2008 cropping season was from 21.3 mt ha^{-1} to 49.2 mt ha^{-1}.

On average, this rate of K increased the yield by approximately 36 mt ha^{-1} compared with the control treatment that received only optimum amounts of N and P. This increase is significantly higher than that typically obtained in India (Grewal *et al.*, 1991), and in other typical response-to-K experiments. This shows that potato yields in Ethiopia, at K deficient conditions, are extremely low, and that the application of K causes a dramatic increase in yields, with obvious positive economic results. We also assume that the significant increase in the yield of potato is not only due to the direct biochemical and physiological roles of K in plants, but also due to its positive interaction with other essential plant nutrients, particularly N (Gething, 1993; Milford and Johnson, 2012).

On-farm K fertilizer application effect on potato at Hagere Selam

Application of K fertilizer significantly increased the total and marketable tuber yields of potato on farmers' fields in Hagere

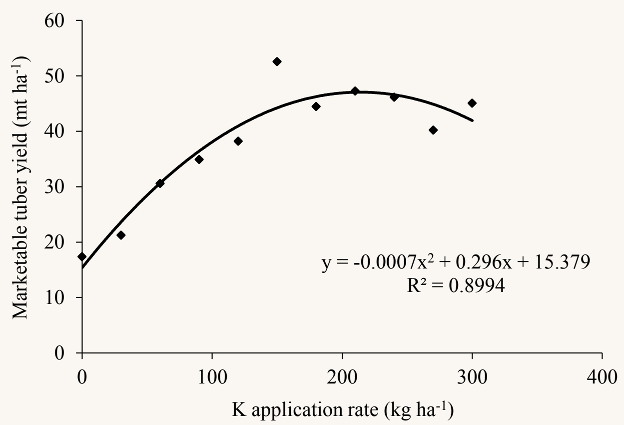


Fig. 1. The effect of increasing levels of K fertilizer on the marketable tuber yield of potato over two years (2007-2008) on acidic soils of Chencha, southern Ethiopia.

Selam in the 2010 growing season (Table 2). When averaged over 24 farmers' fields, K applied at 100 kg ha^{-1} in the form of KCl increased the total and marketable tuber yields by 208 and 252 percent over the control, respectively. The corresponding increases over NP treatments were 52 and 55 percent respectively. These results are consistent with the findings of Adhikary and Karki (2006) who studied the effect of different levels of K applied as basal and top dressed on potato grown in soil with an exchangeable K value of 0.167 me/100 g of soil in Nepal. They found that the yield of potato was significantly increased from 16.63 mt ha^{-1} in the control to 24.75 mt ha^{-1} in plots treated with 100 kg ha^{-1} K (50 kg basal and 50 kg top dressed). Moreover, most of the yield increase between NP and NPK treatment (approximately + 8 mt ha^{-1}, or + 50 percent) is an increase in marketable yield, hence the proportion of the unmarketable yield in the NP treatment is much higher. This has a positive effect on the economics of K application.

The four varieties of potato used in the study area also varied significantly in their performance. The highest tuber yield was produced by the variety Zengana, followed by Jallenie and Guassa. Tolcha was found to have the lowest yield (Table 2).

Table 2. The effect of NP and NPK fertilizers, varieties and their interaction on the tuber yield of potato grown on the acidic soils of Hagere Selam in 2010.

Treatment ($N-P_2O_5-K_2O$)	Total yield	Marketable yield	Un-marketable yield
kg ha^{-1}	----------*mt ha^{-1}*----------		
Control (no fertilizer)	7.9 c†	6.2 c	1.7 b
NP (110:40:0)	16.0 b	14.0 b	2.0 a
NPK (110:40:100)	24.4	21.8 a	2.6 a
LSD	3.07	3.04	0.42
Varieties			
Guassa	16.6 b	11.7 c	4.9 a
Jallenie	20.4 a	18.5 b	1.9 b
Tolcha	3.80 c	3.3 d	0.49 d
Zengana	23.6 a	22.5 a	1.1 c
LSD	3.53	3.51	0.48
Fertilizer X varieties	**	**	**
CV (%)	22.5	25.0	23.6

Note: †Means followed by the same letter are not statistically different from each other at 0.05 probability level. **Significance at the 0.01 probability level.

The effect of K and sulfur (S) on yield of wheat in Hagere Selam

The grain and biomass yields of wheat were found to be significantly affected by different treatments (Table 3). The highest biomass and grain yield of wheat was obtained from 50 urea + 100 DAP + 43.33 KCl + 50 $CaSO_4$. The next highest yield was obtained from 50 urea + 100 DAP + 50 $CaSO_4$. However, there were no differences between the grain yield of wheat in the rest of the treatments, indicating that S could also be a limiting nutrient in the area.

Table 3. The effect of K and S applied singly or in combination on the yield of wheat grown on different soil types in southern Ethiopia in 2011.

Treatment	Mean biomass yield	Mean grain yield
kg fertilizer	----------*mt ha^{-1}*----------	
50 urea + 100 DAP	5.23 c†	1.82 c
50 urea + 100 DAP + 50 K_2SO_4	9.44 b	3.76 ab
50 urea + 100 DAP + 43.33 KCl	10.11 b	2.74 b
50 urea + 100 DAP + 50 $CaSO_4$	10.597 b	4.02 ab
50 urea + 100 DAP + 43.33 KCl + 50 $CaSO_4$	13.1 a	4.87 a
CV (%)	9.6	29.1

Note: †Means followed by the same letter are not statistically different from each other at 0.05 probability level.

The observed increase in the biomass and grain yields of wheat on farmers' fields in Hagere Selam confirms previous findings from on-station experiments indicating a significant response of wheat to K fertilization. Photos 3 and 4 (p. 8) show wheat growth with urea and DAP (Photo 3) as compared to urea, DAP and KCl (Photo 4).

Conclusions

The results of several studies conducted over the past five years on potato and wheat, both on-station and on farmers' fields in acidic soils in Chencha and Hagere Selam, southern Ethiopia, have revealed that the yields of these crops were significantly increased by the application of K fertilizers. These findings provide very strong evidence that the soils of these areas are low in available K. The positive response to K application in these areas was also consistent with previously published results showing significant responses to K fertilization by potato, wheat and barley. Thus, these findings provide practical evidence disproving long-standing assumptions that Ethiopian soils are rich in K. This is further substantiated by emerging evidence from central, northwestern and northern Ethiopia where positive responses to K by wheat, potato and barley have been reported.

Additionally, several recently published and unpublished studies indicate that exchangeable soil K values determined for some soils from all corners of Ethiopia, are below critical levels expected to support adequate crop production. However, conclusions based merely on soil test K levels are inadequate to accurately predict plant available soil K because this is a function of the interactive effect of different forms of K in the soil (Römheld and Kirkby, 2010). In this respect, soil parent material, clay types and their proportions, as well as intensity of cultivation, climate and crop species all play a role. Thus, establishing soil critical K levels requires not only the study of soil K but also soil and crop interactions which require greenhouse and field experiments. Potato requires high levels of K, removing much higher amounts than other crops, and thus is a good indicator of K availability (http://www.ipipotash.org/presentn/kinmp.php). For Chencha and Hagere Selam, it is beyond doubt that soil available K is deficient. Application of K fertilizers is therefore recommended for enhanced and sustained crop production

Photo 3 (left) and Photo 4 (right). Wheat plot that received urea and DAP (left) and with addition of KCl (right). Hagere Selam, Ethiopia. Photos by Wassie Haile.

in these areas. For those areas of Ethiopia in which low soil test K levels have been reported, further extensive and intensive laboratory, greenhouse and field crop response investigations are recommended. More work on other crops is needed to assess the response to K in these regions.

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