Crops Response to Balanced Nutrient Application in Northwestern Ethiopia

Tadele Amare[1]*, Zerfu Bazie[1], Erkihun Alemu[1], Asmare Wubet[1], Birhanu Agumas[2], Mengistu Muche[1], Tesfaye Feyisa,[2] Desalew Fentie[3] and Mequanint Andualem[3]

[1]Adet Agricultural Research Center, P.O.Box 08, Bahir Dar, Ethiopia,

[2]Amhara Agricultural Research Institute (ARARI), P.O.Box 527, Bahir Dar, Ethiopia,

[3] Finote-selam Research sub-center

[*]Corresponding author email: tadele17b@yahoo.com

Abstract

Enhancing crop productivity through soil fertility management mainly by the use of synthetic fertilizers has got prior attention in Ethiopia. Recently a soil fertility map of the Amhara National Regional State developed by Ethiopian Ministry of Agriculture and Natural Resources (MoANR) and Agricultural Transformation Agency (ATA) indicates that in addition to the conventional nitrogen and phosphorus containing fertilizers (urea and DAP), the demand of potassium, sulfur, zinc, boron and other micronutrients containing synthetic fertilizers. This research was designed to validate the developed soil fertility map with a response of major cereal crops (maize, Teff, and wheat) at Burie-womberma, Debre-Elias, Enemey, South Achefer, and Yilmana Densa districts to the application of potassium, zinc and boron-containing fertilizers depicted on the map. The findings of the research showed that nitrogen and phosphorus are still the most yield-limiting nutrients. The response to potassium was observed under rare cases that did not fit with the developed soil fertility map, but the finding was verified for one year and those rare cases were not observed. Application of zinc and boron-containing fertilizers didn't show any significant yield advantage, indicating that fertilizers containing NPS nutrients with a major focus of NP are sufficient. Under the Vertisols (Bichena), NPSZnBK (nitrogen, phosphorus, sulfur, zinc boron and potassium) containing fertilizer was showing a yield advantage over NP fertilizer, but upon verification of the findings of the two-years experiments with simple treatments there was no significant effect of the potassium, zinc and boron fertilizer over NPS alone. Based on the findings of this research, zinc, boron, and potassium are not yield limiting nutrients for the study areas and crops. Therefore, potassium, zinc and boron fertilizers recommended by the fertility map of the region shall not be used anywhere without research-based field verification and recommendations. Furthermore, we recommend monitoring on the status of plant nutrients in the soil and crop responses to potassium, zinc and boron fertilizers every 5 to 10 years.

and ATA, 2016). The map shows 100% of the soil in the region needs nitrogen, phosphorus and sulfur fertilizers; 94% of the soil needs potassium and boron fertilizers while for zinc and copper fertilizers 50.8% and 0.7%; respectively.

Developing the soil fertility map of the country strongly supports the efforts towards sustainable soil fertility management including for location-specific fertilizer recommendations. However, the ground truth for the developed soil fertility map must be verified and supported by field experiments prior to its broad recommendations and applications so as to avoid unnecessary use of fertilizers. Therefore, this research was carried out to validate the response of crops to potassium, zinc, and boron that are recommended by the soil fertility map of the region developed by MoANR and ATA (2016).

Materials and Methods

Description of the study area

Densa and Womberma districts of the western Amhara Region where maize; Teff and wheat productions are prominent. The districts are among the most productive areas of the country. The responses of maize (South Achefer and Womberma), bread wheat (Debre Elias and Womberma) and Teff (Enemey and Yilmana Densa) were studied. Maize and wheat were tested under the Nitisols while Teff was tested both on Nitisols and Vertisols.

Soil fertility map of ANRS and treatment set up

The soil fertility map of the Amhara National Regional State was developed by the Ministry of Agriculture and Natural Resources (MoANR) in collaboration with Ethiopian Agricultural Transformation Agency (ATA) in 2013 for selected districts and in 2016 for the whole districts of the region (Figure 1). The responsibility of the Amhara Regional Agricultural Research Institute (ARARI) was to validate the response of major cereal crops to potassium, zinc, and boron-containing fertilizers (Table 1) proposed by the developed soil fertility map of the region. This paper presents the research work for the northwestern parts of the region. Economically recommended urea and di-ammonium phosphate (DAP) fertilizer rate for each crop was included in the treatment set up and compared with potassium, zinc and boron-containing fertilizers. The recommended nitrogen rate was kept constant (Table 1, Table 2). Nitrogen was applied half at planting and half at about 30 to 45 days after planting while the whole dose of other nutrients was applied at planting. Crop management practices were kept uniform for all treatments. The experiment was conducted for two consecutive rainy seasons (2014/15 and 2015/16).

BH540 and BH660 for maize, TAY for wheat and kuncho for Teff were the varieties used for the study. For maize, the population was 44 444/ha with a spacing of 30 cm between plants and 75 cm between rows. Wheat and Teff were planted in rows with seed rates of 125 kg/ha and 10 kg/ha, respectively. A randomized complete block design was used for all the crops. Major agronomic data including grain yield were collected. The grain weight and moisture content of wheat and maize were simultaneously taken and finally adjusted to 12.5% moisture content. Collected data were subjected to the analysis of variance (ANOVA) using SAS software (SAS, 2003).

Soil sampling, preparations and analysis

Composite soil samples were collected at depths of 0-20 cm before planting for each site. Samples were air dried, ground using pestle and mortar. Soil pH was determined in a 1:2.5 soil to water suspension following the procedure outlined by Sertsu and Bekele (2000). Soil organic carbon content was determined by wet digestion method using the Walkley and Black procedure (Nelson and Sommers, 1982). Total nitrogen was determined using the Kjeldahl method (Bremner and Mulvaney, 1982) while the available phosphorus was determined following the Olsen procedure (Olsen and Sommers, 1982). The exchangeable potassium was measured by flame photometer after extraction of the samples with 1N ammonium acetate at pH 7 following the procedures described by Sertsu and Bekele (2000).

Figure 1. Recommended fertilizers for Amhara National Regional State (MoA and ATA, 2016)

Table 2. Formulas and the nutrient contents

Formula	Formulation (% nutrient composition)	Source of fertilizer
1 (NPS)	19N-38P_2O_5-7S	19 N-38 P_2O_5+7S
2 (NPSB)	18.1N-36.1-P_2O_5-6.7S- 0.71B	95 kg NPS+4.9 kg Borax
3 (NPSKB)	13.7N-27.4P_2O_5-14.4K_2O-5.1S-0.54B	72.2 kg NPS+24.1kg KCl+3.7 kg Borax
4 (NPSZnB)	16.9N-33.8P_2O_5 -7.3S-2.23Zn-0.67B	90 kg NPS +5.5kg ZnSO4+4.5 Kg Borax
5 (NPKSZnB)	13N-26.1P_2O_5-13.7K_2O-5.6S-1.72Zn-0.51B	68.7 kg NPS+22.9kg KCl+4.84kg ZnSO4 + 3.5 Borax
6 (Formula 4 modified)	17.5 N-34.9P_2O_5-7.6S - 2.23Zn -0.25B	89.38 kgNPS+6.4kg ZnSO4+1.7 kg Borax
7 (Formula 5 Modified)	13N-26.1P_2O_5-14.8K_2O-5.6S-1.72Zn-0.25B	68.7kg NPS+24.74 kg KCl+4.9kg $ZnSO_4$+1.7 kg Borax

Table 2. Treatment setups for the test crops at specific districts

Fertilizer formula	**Fertilizer types and amounts (kg/ha) ***						
	Maize		Teff			Wheat	
	South Achefer	Burie-Womberma	Yilmana Densa		Bichena	Burie-Womberma	Debre Elias
	Nitisols	Nitisols	Nitisols	Vertisols	Vertisols	Nitisols	Nitisols
1 (NPS)	250 (176)	250 (176)	-	-	-	-	150 (260)
2 (NPSB)	150 (220)	150 (220)	150 (50)	100 (50)	100 (146)	150 (260)	150 (260)
3 (NPSKB)	-	-	-	-	-	-	200 (262)
4 (NPSZnB)	150 (220)	150 (220)	150 (53)	100 (53)	100 (137)	150 (260)	150 (260)
5 (NPKSZnB)	150 (235)	150 (235)	200 (47)	150 (47)	150 (132)	150 (275)	-
6(Formula 4 modified)	250 (185)	250 (185)	200 (32)	150 (32)	150 (117)	200 (245)	200 (262)
7(Formula 5 Modified)	250 (208)	250 (208)	200 (33)	200 (33)	200 (118)	200 (263)	200 (262)

* Numbers in parenthesis indicate the amount of urea in kg/ha top-dressed in addition to the specified amounts of formula. The vacant (-) indicates that specific formula was not used.

Results and Discussion

Maize

As shown in Table 3, Table 4 and Table 5, maize did not respond to applied fertilizers containing potassium, zinc, and boron. On the other hand, the yield was highly variable within short distances for both Achefer and Burie-Womberma districts where a single soil type (Nitisols) is dominating with similar rainfall patterns of each district. A rare observation of response to potassium, zinc, and boron-containing fertilizers could not support for general recommendations as it was observed in Aferefida of south Achefer. At Aferefida in south Achefer, the maximum yield of maize (7350 kg/ha) was obtained from higher rates of potassium (Table 4) which was a rare case for the two years across all the study sites that maize response to applied potassium was observed. Of course, the exchangeable soil potassium of Aferefida site was lower (0.43meq/100g soil) than Ahuri (1.12 meq/100g soil) a very nearby site; both of them are above 0.25 meq/100g which is the critical value based on ammonium acetate extraction (IPI, 2016). At this site, the second highest yield (6310 kg /ha) was obtained from the lowest rate of phosphorus but with the addition of potassium. Nevertheless, this response was a single observation that was not repeated across our experimentation (Table, 3, 4, and 5). Moreover, intensive research verification with simple treatment setups (with and without potassium, zinc, and boron) showed a non-significant result (Tadele et. al., 2018). The overall result of the research is in line with findings reported by Tadele et al. (2008), but it did not support the soil fertility map developed by the MoANR and ATA (2016) for the Amhara Region. It rather intended to respond for higher rates of nitrogen and phosphorus fertilizer rates. A recent ongoing research result on maize (unpublished) in south Achefer showed that a grain yield of maize greater than 10000 kg/ha with nitrogen and phosphorus alone (with 150 kg N/ha and 125 kg P_2O_5).

Therefore, potassium application does not pay any significant yield increase of maize as the supply of the soil is presently sufficient. However, research should continue monitoring on the state of soil potassium and maize response to potassium application in case it becomes a yield-limiting nutrient sometime in the future. Experiences from countries including China show that potassium fertilizer application started very late as compared to nitrogen and phosphorus fertilizers (Portch and Jin, 2009; Zhang, 2014); while The Netherlands reached 100 kg/ha K_2O

on average in 1936 (Isherwood, 2010). Crop productivity in Ethiopia is still limited by nitrogen and phosphorus nutrients than potassium.

The yield of maize was not increased by the addition of the micronutrients (Boron and Zinc) for all sites for the two cropping seasons that also fail to prove the deficiency of the micronutrients mapped for the study areas (MoANR and ATA, 2016). The finding is in line with yield response of maize to applied micronutrients in Pakistan that only increased marginal yield (6950 kg/ha with control, 7230 kg/ha with micronutrient) as reported by Khan *et al.* (2014). Severe deficiency of micro-nutrients including boron and zinc mostly occurs for soils with higher pH values (Singaraval *et al.*, 1996) and (Zayed *et al.*, 2011) claims rice productivity in rice growing countries shows a reducing trend mainly because of micro-nutrients deficiency. In contrast, the soils where the present study carried out are Nitisols and their pH ranges from slightly acidic to acidic that does not limit the availability of micro-nutrients except molybdenum.

Table 3. Maize (Variety - yield response to balanced fertilizer t South Achefer (Year 2014/15)

The northwestern parts of the region including the districts where the present research was carried out are characterized by high rainfall amounts and good distributions. Nevertheless, maize productivity is still below the expected potential of the area because of the low rate of fertilizer application. Hence, increased production and productivity of crops including maize will be realized through judicious management and utilization of nitrogen and phosphorus containing synthetic fertilizers.

Table 4. Maize (Variety - yield response to balanced fertilizer t South Achefer (Year 2015/2016)

6038
6078
5538
6086
5816
6664
6662

Table 5. Maize (Variety BH 540) yield response to balanced fertilizer at Womberima (Year 2014/2015)

	Grain yield (kg/ha)					
Treatments	Sebadar	Bolden	Markuma	Wegedad	Marweld	Mean
NP (200 Urea/ha+200 kg DAP/ha)	3890	3090	4390	7080	6120	4914
250 kg/ha Formula 1+176 kg/ha Urea	5280	4180	4570	7120	5890	5408
150 kg/ha Formula 2 + 220 kg/ha Urea	5010	3100	5540	7200	5990	5368
150 kg/ha Formula 4 + 220 kg/ha Urea	6270	3670	5460	7220	4470	5418
150 kg/ha Formula 5 + 235 kg/ha Urea	4760	4050	5250	6820	5940	5364
250 kg/ ha Formula 6+185 kg/ha Urea	4060	5000	5920	7750	5550	5656
250 kg/ha Formula 7+ 208 kg/ha Urea	5360	4010	5580	6870	6450	5654
LSD (0.05)						NS
CV (%)						24.8

Bread wheat (*Triticum aestivum*)

fertilizer. For some of the study sites, the recommended NP fertilizer was better than the ones with potassium, zinc and boron-containing fertilizers (Table 6 and 7) indicating that nitrogen and phosphorus are still the most yield-limiting nutrients than other nutrients including potassium. The verification of research with simplified treatments showed no significant yield advantage of potassium, zinc, and boron over NPS alone (Tadele et al., 2018)

There was no response to applied micro-nutrients; not supporting the soil fertility map developed for the districts. If micronutrients including zinc and boron were a very deficit as stated by the soil fertility map of the studied districts, the yield could be significantly affected as they are essential to plant nutrients. Malakouti (2008) reported that the yield of crops like durum wheat (*Triticum durum* L.) could be increased by about 50% using micro-nutrients and under very severe deficiency of the micronutrients; there could be a situation of no harvest.

Table 6. Response of bread wheat for different blended fertilizers at Womberma

Treatment	Grain yield (Kg/ha)									
	Year1					Year 2				
	Bolden	Markuma	Wegedad	Marwold	Mean	Bolden	Markuma	Wegedad	Sebadar	Mean
NP (260 kg Urea +150 kg DAP/ha) *	4170	4280	4970	4110	4383	2510	4370	3640	2900	3355
150 kg/ha Formula 2+260 kg Urea/ha	3700	4400	5440	4150	4423	2100	4490	3230	3100	3230
150 kg/ha Formula 4+260 kg Urea/ha	3710	3830	5080	2960	3895	2500	4570	3510	3050	3408
200 kg/ha Formula 6+245 kg Urea/ha	3540	4040	5240	3290	4028	2280	4510	3830	3310	3483
150 kg/ha Formula 5+275 kg Urea/ha	3730	2150	4900	4030	3703	2300	4550	3490	3220	3390
200 kg/ha Formula 7+263 kg Urea/ha	3510	3600	5120	3930	4040	2260	4460	3120	3230	3268
LSD (0.05)					NS	LSD (0.05)				NS
CV (%)					20	CV (%)				27

Table 7. Response of bread wheat for different blended fertilizers at Debre Elias

	Grain yield (kg/ha)*											
	Year 1						Year 2					
Treatments	Abe.1	Yek.	D/E.Z1	D/E.Z2	Abe.2	Mean	Abe.1	Yek.	D/E.Z1	D/E.Z2	Abe.2	Mean
NP (260 kg Urea+150 kg DAP/ha)	4800	4380	4230	3960	3110	4096	4190	4340	4070	3240	4070	3982
150 kg/ha Formula 2 + 260 kg Urea/ha	5780	3920	5110	2000	2110	3784	2950	6010	3680	3600	4320	4112
150 kg/ha Formula 4 +260 kg Urea/ha	5320	3520	4580	1840	2150	3482	3280	4390	3490	3380	4060	3720
200 kg/ha Formula 6 + 245 kg Urea/ha	5650	3270	4030	2530	1980	3492	3580	4640	2720	3320	4080	3668
150 kg/ha Formula 5+275 kg Urea/ha	5180	3690	4220	2520	2700	3662	3630	3880	3580	2300	3760	3430
200 kg/ha Formula 7+ 263 kg Urea/ha	4990	3720	3790	2070	2450	3404	4020	4330	4180	2700	4020	3850
LSD						NS	LSD					NS
CV (%)						35	CV (%)					19

* Are the study sites where: Abe.1= Abeshma 1, Yek.= Yekegat, D/E.Z1= Debre Elias zuria 1, D/E.Z2 = Debre Elias zuria 2 and Abe.2= Abeshma

Teff

Teff is one of the dominant cereal crops in northwestern parts of the Amhara National Regional State. It grows well both in the Vertisols and Nitisols. This paper presents the findings of two years of research on the response of Teff to potassium, zinc, and boron for both Nitisols and Vertisols. At Yilmana Densa district, the response of Teff to potassium, boron and zinc-containing fertilizers was insignificant (Table, 8) which did not support the 100 kg/ha potassium chloride recommendation by IPI (2016) and (MoAR and ATA, 2016). At Enemey, there was yield gain by the addition of balanced fertilizers over nitrogen and phosphorus use alone; which was significant in the first year (Table, 9); however, there was no significant difference in the second year (Table 10). However, under our verification taking NPS fertilizer as standard, there was no yield difference with the presence or absence of potassium, zinc and boron-containing fertilizers (Tadele et al., 2018). Therefore, similar to maize and wheat, potassium, zinc, and boron are not yet yield limiting for Teff in the study areas.

Table 8. Response of Teff for different blended fertilizers at Yilmana Densa (Nitisols)

Treatments	
NP (130kg DAP/ha +36 kg Urea/ha)	
150 kg/ha Formula 2+ 50 kg/ha Urea	
150 kg/ha Formula 4+ 53 kg/ha Urea	
200 kg/ha Formula 5+ 47 kg/ha Urea	
200 kg/ha Formula 6 +32 kg/ha Urea	
200 kg/ha Formula 7+ 33 kg Urea	
LSD	
CV (%)	

Table 9. Response of Teff for different blended fertilizers at Enemay Vertisols (Year 1)

	Grain yield (kg/ha)				
	Year1				
Treatments	Weyra	Yerez	Yezerezer	M/Birhan	Mean
NP (140 kg/ha Urea + 87 kg/ha DAP)	1960	2690	2370	1700	2180
00 kg/ha Formula 2+146 kg/ha Urea	2240	2880	2880	3220	2805
100 kg/ha Formula 4+137 kg/ha Urea	2410	2540	2520	3570	2760
150 kg/ha Formula 6 +117 kg/ha Urea	1970	2140	2620	3630	2590
150 kg/ha Formula 5 +132 kg/ha Urea	2330	3230	3180	3100	2960
200 kg/ha Formula 7 + 118 kg/ha Urea	2240	2620	2750	3210	2700
LSD (0.05)					755
CV (%)					19.1

Table 10. Response of Teff for different blended fertilizers at Enemay Vertisols (Year 2)

Treatments	Grain yield (kg/ha)				
	Year 2				
	Weyra	Yerez	Yezerezer	M/Birhan	Mean
NP (140 kg/ha Urea + 87 kg/ha DAP)	1500	2160	2930	2420	2253
100 kg/ha Formula 2+146 kg/ha Urea	2200	1990	3060	3280	2633
100 kg/ha Formula 4+137 kg/ha Urea	1770	2260	2460	3140	2408
150 kg/ha Formula 6 +117 kg/ha Urea	2350	1710	2440	3020	2380
150 kg/ha Formula 5 +132 kg/ha Urea	2130	1500	3020	3220	2468
200 kg/ha Formula 7 + 118 kg/ha Urea	2190	1820	3200	3470	2670
LSD (0.05)					NS
CV (%)					26.8

Soil analysis results

In general, the response of crops to potassium, zinc and boron-containing fertilizers did not agree with the recommendation made by the fertility map of the Amhara National Regional State (MoANR and ATA, 2016). The exchangeable potassium (cmol(+)/kg) for the study sites was ranged south Achefer (0.77 to 1.40), Debre Elias (1.3 to 1.45), Enemay (1.22 to 1.44), Yilmana Densa (0.91 to 1.31) and Burie-Womberma (0.93 to1.34). For all the sites the lowest values are above three times the critical values of exchangeable potassium (0.25 cmol/kg) based on ammonium extraction methods (IPI, 2016) indicating a finding of crop responses was strongly justifiable.

The problem of the map with potassium may be associated with the introduction of 0.7:1 correction factor exchangeable potassium to exchangeable magnesium based on (Loide, 2004). The research finding of (Loide, 2004) was about liming materials and their effects on the respective exchangeable base ratios including potassium to magnesium which is less relevant to our system. Interestingly, more than 90% of the region is in the range of optimum without the introduction of the correction factor; then 94% of the soil of the region converted to potassium deficiency with the correction factor (MoANR and ATA, 2016). Moreover, the critical limits used to map the map are the major ones that affect the quality of the map. For example, MoANR and ATA, (2016) used a wider range as well as higher values of exchangeable potassium (190 - 600 mg/kg equivalent to 0.49 to 1.54 cmol/kg).

The pH of the soil for the study sites was below 6 except for Enemay that ranges from 6.8 to 7.4. Therefore, the cost of sustainable soil health in addition to crop responses must be considered upon applying zinc and boron based on the soil fertility map of the region (MoANR and ATA, 2016) under these acidic soils as the cumulative effect of these nutrients matter. The soil organic carbon content for most of the soils was below 2% which is the critical point (Murphy, 2014) that rather needs an integrated soil fertility management. The total nitrogen was in the range from less than 0.1% to 0.29% (low to very low ranges), while the available phosphorus for most of the sites was below 10 ppm.

Conclusions

The research was conducted in agriculturally potential districts of the northwestern Amhara National Regional State (Burie-womberma, Debre-Elias, Enemay, South Achefer, and Yilmana Densa) to evaluate the response of major cereal crops (maize, wheat and Teff) to fertilizers that contain boron, potassium and zinc plant nutrients. The findings of the research for crops under all districts with respect to the addition of fertilizer including potassium containing ones did not show any significant yield advantage that did not justify the recommendations made by the recently developed soil fertility map of the region. The soil fertility map of the region jumped into conclusions and recommendations of fertilizers with less or no ground truth of crop responses for potassium, zinc and boron fertilizers. Recommending fertilizer without any yield advantage will hurt the economy of the country in general and the poor Ethiopian farmers in particular. Fertilizer recommendation for nutrient maintenance and build up without any yield advantage could not be accepted by our poor and subsistence farmers. Accordingly, the northwestern parts of the Amhara National Regional State should focus only on urea and NPS fertilizers. There is no option for NPS as DAP is completely out of the Ethiopian market. We do not have any proof of NPS is better than DAP. Assessment on the long-term effect of fertilizer types including NPS on soil acidity shall be considered. It will not be sure with this research finding how long will the soil support to supply sufficient amounts of potassium and micro-nutrients and hence continuous assessment of the status of soils for these nutrients and crop responses are critically important.

Acknowledgements

The authors would like to thank for the two reviewers for sparing their time and for their critical comments and suggestions. We also thank Amhara Agricultural Research Institute (ARARI) and Adet Agricultural Research Center for the logistic matters. Our final thank goes to farmers for allowing us to do intensive research on their farms.

References

Asgelil, D., Taye, B. & Yesuf, A. (2007). The status of micro-nutrients in nitisols, vertisols, cambisols and fluvisols in major maize, wheat, Tefff and citrus growing areas of Ethiopia. *Proceedings of Agricultural Research Fund*: 77-96.

Astatke, A., Mamo, T., Peden, D. & Diedhiou, M. (2004). Participatory on-farm conservation tillage trial in the ethiopian highland vertisols: The impact of potassium application on crop yields. *Experimental agriculture* 40(3): 369-379.

Berry, L. (2003). Land degradation in Ethiopia: its impact and extent in Berry L, Olson J. and Campbell D (ed): Assessing the extent, cost and impact of land degradation at the national level: findings and lessons learned from seven pilot case studies. *Commissioned by global mechanism with support from the World Bank*: 1-12.

Bremner, J. M. & Mulvaney, C. (1982). Nitrogen total 1. *Methods of soil analysis. Part 2. Chemical and microbiological properties* (methodsofsoilan2): 595-624.

Ethiopian main index. (2018). https://theodora.com/wfbcurrent/ethiopia/ethiopia_people.html

Haile, W. (2011). Response of Irish potato (Solanum tuberosum) to the application of potassium at acidic soils of Chencha, Southern Ethiopia. *International Journal of Agriculture and Biology* 13(4).

Hailu, H., Mamo, T. & Keskinen, R. (2017). Response of wheat (Triticum aestivum L.) to phosphorus and potassium fertilization on Vertisols in Ethiopia's central highlands. *Electronic International Fertilizer Correspondent (e-ifc)* (49): 15-28.

IPI (International Potash Institute). (2016). Technical manual on potash fertilizer: Use for soil fertility experts and development agents. DOI 10.3235/978-3-905887-22-8

Isherwood, K. (2010). Fertilizer use in Western Europe: types and amounts. *Interdisciplinary and Sustainability Issues in Food and Agriculture-Volume III*: 315.

Khan, H., Amin, M., Akbar, N., Saleem, M. & Iqbal, A. (2014). Impact of zinc and manganese application to increase productivity of autumn planted maize (zea mays L.). *Cercetari Agronomice in Moldova* 47(4): 65-70.

Loide, V. (2004). About the effect
potassium and magnesium in liming of acid soils. *Agronomy research* 2(1): 71-82.

Malakouti, M. J. (2008). The effect of micronutrients in ensuring efficient use of macronutrients. *Turkish Journal of Agriculture and Forestry* 32(3): 215-220.

Ministry of Agriculture and Natural Resources and Agricultural Transformation Agency of Ethiopia. (2016). Soil Fertility Status and Fertilizer Recommendation Atlas of Amhara National Regional State, Ethiopia: 297 pages.

Murphy, B. (2014). W,(2014) Soil Organic Matter and Soil Function Review of the Literature and Underlying Data. *Department of the Environment, Canberra, Australia*.

Murphy, H. (1968). A report on fertility status and other data on some soils of Ethiopia. Expt. *Bull* 44.

Nega, B. & Degfe, B. (1999). Annual Report on the Ethiopian Economy. *Vol. I* 2000.

Nelson, D. & Sommers, L. E. (1982). Total carbon, organic carbon, and organic matter 1. *Methods of soil analysis. Part 2. Chemical and microbiological properties* (methodsofsoilan2): 539-579.

Olsen, S. & Sommers, L. (1982). Phosphorus. p. 403 430. AL Page et al.(ed.) Methods of soil analysis. Part 2. Agron. Monogr. 9. ASA and SSSA, Madison, WI. *Phosphorus. p. 403 430. In AL Page et al.(ed.) Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.*: -.

Portch, S. & Jin, J. (2009). Fertilizer use in China: Types and amounts. *Encyclopaedia of Life Support Systems, Agricultural Sciences; Lal, R., Ed*: 247-256.

Scoones, I. & Toulmin, C. (1999). Policies for soil fertility management in Africa. *Policies for soil fertility management in Africa.*

Sertsu, S. & Bekele, T. (2000). Procedures for soil and plant analysis. National Soil Research Center. *Ethiopian Agricultural Research Organization, Addis Ababa, Ethiopia. 110p*.

Singaraval, R., Balasundaram, S. & Johnson, K. (1996). Physicochemical characteristics and nutrient status of coastal saline soils of Tamil Nadu. *J. Ind. Soc. Coastal Agric. Res* 14(1&2): 59-61.

Statistical Analysis System (SAS). (2003). SAS Institute Inc., Statistical Analysis System, Cary, NC, USA.

Tadele Amare, Tesfaye Feyisa and Yihenew G.Silassie. (2008). Response of Maize, Malt Barley and Tomato to Potassium. Proceedings of the 3rd Annual Regional Conference on Completed Natural Resources Management Research Activities 1-4 September 2008.

Tadele Amare, Amlaku Alemayehu, Bitewlgn Kerebih, Zerfu Bazie, Erikhun Alemu, Assefa Derebe, Tesfaye Feysa, Sefinew Wale and Dessalegn Getaneh. (2018). Verification of crop response to potassium, boron and zinc nutrients. Presented as completed research in the annual research review of Amhara Regional Research Institute (ARARI). Held from Feuary 26, 2018 to March 4, 2018, Bahir Dar, Ethiopia.

Zayed, B., Salem, A. & El Sharkawy, H. (2011). Effect of different micronutrient treatments on rice (Oriza sativa L.) growth and yield under saline soil conditions. *World J. Agric. Sci* 7(2): 179-184.

Zeleke, G., Agegnebu, G., Abera, D. & Rashid, S. (2010).Fertilizer and Soil Fertility Potentials in Ethiopia: Constraints and Opportunities for Improvement. Paper prepared by the International Food Policy Research Institute for the

Zhang, W. (2014). Fertilizer situation in China. Fertilizer outlook and technology conference,