Composition of Mineral Nutrients in Leaves of Potato (*Solanum tuberosum* L.) Cultivated on Farmers Field: The Case of Six Districts in West Shoa Zone, Ethiopia

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Abstract

Plant nutrient deficiency could be one of the potential problems attributed to low potato productivity. The nutrient status of potato crop grown on farmers' field in six selected districts of West Shoa Zone, was examined. Leave samples collected at vegetative growth stage were analysed for various nutrient contents (N, P, K, S, Mg, Ca, Zn, Mn, Cu, B, Mo). The leaf nutrient concentration (P, K, Mg, Ca, Zn, Mn, Cu, B and Mo) were determined using Inductively Coupled Plasma Optical Emission Spectrophotometer (ICP-OES), whereas N, C and S were determined by CNS analyzer. Results showed that the concentration of phosphorus and potassium in potato leaf did not vary much among the districts that ranged from 2.8 to 3.3 and from 31-35 mg/g dry matter for P and K, respectively. About 97 and 75% of the surveyed fields showed P and K deficiencies in potato leaves, respectively. At 75% of the surveyed fields, plants showed insufficient potassium concentration in the leaf when compared to the optimum range described in literatures. The average nitrogen and sulphur concentration in potato leaf were also in a narrow range of 61-63 and 4.1-4.5 mg g^{-1} d.m, respectively for all the districts and results obtained confirmed that plants were well supplied with N and S. Plants at all the surveyed fields of all the districts were also well supplied with Ca and Mg, since no field showed insufficiency of these nutrients. The micronutrients concentrations in the leaf tissue were in the optimum range and/or even above for most micronutrients.

Key words: Nutrient concentration, potato leaf, macronutrients, micronutrients, optimum range

Introduction

Potato (*Solanum tuberosum* L.) is one of the most important food security crops in Ethiopia (Gildmacher *et al*., 2009). It is also additionally considered as cash crop, especially in the highlands and the mid altitude areas of the country (Yigzaw Dessalegn *et al*., 2008). Potato has a short cropping cycle and a large production per unit area in a given time. It also provides more nutritious food per unit land in less time and often under more adverse condition (Elmar, 2013). The production of the crop has increased tremendously and its use has been diversified (as french fries, chips and crisp) in Ethiopia. Despite the increasing importance of the crop for household food security and income generation in Ethiopia, the national average yield ranges between 8 and 10 tons (t) per hectare (ha), which is much lower than the yields obtained in the

Sudan (17 t ha^{-1}) and Egypt (26 t ha^{-1}) (Haverkort *et al*., 2012).

Potato has higher demand for nutrients than most other vegetables and cereal crops (MAFF, 2000). According to Elmar (2013), the huge difference between actual and potential potato yield in sub-Saharan Africa including Ethiopia was mainly attributed to insufficient nutrient supply to the crop. Balanced and optimum application of the essential nutrients are highly indispensable to secure higher crop yield as well as higher crop nutritional quality. The application of fertilizers increased yield as well as nutrient concentrations in potato and hence nutritional qualities of the crop (Rocha *et al*, 1997; Allison *et al*., 2001). However, in Ethiopia, nutrient deficiencies in potatoes are not uncommon due to absence or sub-optimal fertilizers application (Gildemacher *et al*., 2009; Haverkort *et al*., 2012). Nigussie Dechassa (2012), for instance, has reported N and P deficiency in potato cultivated in the Eastern highlands of Ethiopia. Such low concentration of essential nutrients (N and P) in plant tissue resulted in low yield on farmers' field in the Eastern highlands of Ethiopia (Mulatu *et al*., 2005) and this was mainly ascribed to poor fertilization strategy resulting in serious nutrient in-balances on the farmer's field (Nigussie Dechassa, 2012). The central highlands of Ethiopia, where farmers grow potato twice a year, suffer the most from soil fertility decline this being further aggravated by the absence of the concept of maintenance fertilization coupled with crop residue removal from the field for various purposes. As a result, lower yield and poor quality potato have been reported on farmers' field (Gebremedhin *et al*. 2013) with the yield level varying with field sites depending on farmers' soil management practices (personal communication). Moreover, potato growers pay less attention to soil fertility management, which was a major factor that has long been affecting the yield of the crop in the country (Gildemacher *et al*., 2009; Elmar, 2013). Poor soil fertility management results in low nutrient uptake and subsequently in limited translocation of these nutrients to the active sites where it is used for various metabolic activities, thereby reducing growth, yield as well as processing quality of tubers (White *et al*., 2009).

Analysis of plant tissue for nutrient concentration serves as a tool for targeting high yield through strategizing fertilization program since yield and tuber quality in potato is strongly influenced by tissue nutrient concentrations (Maier *et al*, 1994). Moreover, plant tissue analysis provides a clear picture of plant nutritional status and help to determine whether or not a fertilizer programme is adequate to meet nutrient requirements of crops to attain optimum yield and better nutritional quality (Westermann *et al*., 1994; Rocha *et al*., 1997; Fageria, 2009). Thus, results obtained from such studies can help in managing the nutritional status of the crop during growth to achieve high tuber yield and quality (Westermann *et al*., 1994). The basic principle in utilizing results of plant tissue analysis for strategizing fertilization program is that each crop has critical nutrient concentrations below which a yield reduction may occur due to deficiency thus, demanding fertilizer addition and above which toxicity may occur (Prummel and Barnau-Sijthoff, 1984) requiring no further fertilization. The data obtained from the plant tissue analysis studies are usually interpreted through comparing the tissue nutrient concentrations determined for the crop with the established critical values from literature (Nigussie Dechassa, 2012).

Deficient, adequate, sufficient, high, excess or toxic concentration ranges of nutrients in different parts of potato plant at different sampling times have been determined and described by several workers (Bergmann, 1992; Walworth and Muniz, 1993; Gupta *et al.*, 1995; Rocha *et al.*, 1997) and such information can serve as a reference to classify the nutrient concentration in potato leaf sampled in the current study. According to Nigussie Dechassa (2012), the critical nutrient range described by Walworth and Muniz (1993) and by Bergmann (1992) is more reliably used for interpreting nutrient concentration data in plant tissue.

Different plant parts usually have different nutrient concentration. Moreover, nutrient concentration is also influenced by the age of the sampled tissue and type of crop cultivar (Walworth and Muniz, 1993) and thus careful selection of best representative plant parts and sampling stage are very important for proper diagnosis to avoid misinterpretations in defining the nutritional status of a given crop. Reis Jr. and Monnerat (2000) confirmed that analysing petioles and leaf blades together gives a better diagnosis than when these plant parts are analysed separately to evaluate the nutritional status of the potato crop. It was with this assumption that similar leaf parts (Leaf blade + Petioles) were used for the purpose of the current study. The objective of the study was therefore, to evaluate the leaf nutrient concentration of potato grown under farmers management in view of the critical ranges described by Walworth and Muniz (1993) and Bergmann (1992) at six districts of Western Shoa Zone to generate preliminary information that would help develop suitable fertilizer recommendation strategy for higher and sustainable crop yield in the sub-region.

Materials and Methods

Description of the study area and leaves samplings

The study was conducted during the *Belg* cropping season (March-June) of 2012. All the study districts were located in the highland parts of West Shoa Zone (Figure 1). In terms of climatic condition, the study area is characterized as given in Table 1.

Table 1: Important meteorological and other data of the study area.

District	Annual Average total Rain fall (mm)	Annual temperature range (°C)	Altitude (masl)
Jeldu	812-699	17-25	1900-3206
Tikur-Inchini	1000-1800	6-24	2200-3023
Jibat	800-1500	18-24	1600-3200
Cheliya	900-1400	10-25	1500-3051
Ejere	900-1200	22-28	2060-3185
Welmera	**760-1062**	**7-24**	**2200-2400**

Source: West Shoa Zone Agriculture Office

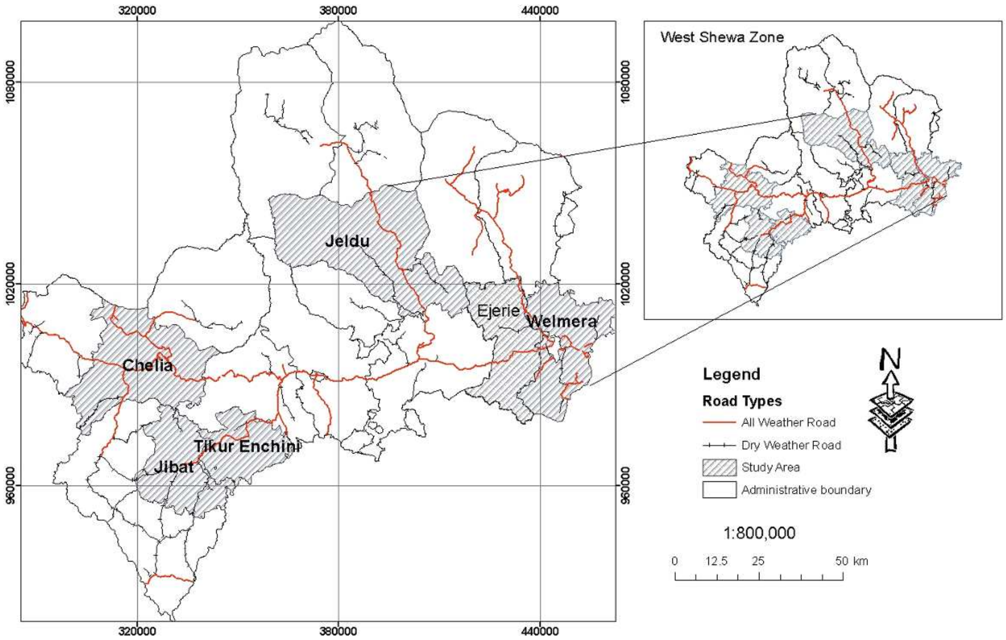

Figure 1. Map of the study districts in West Shoa Zone.

Six districts in West Shoa Zone having most of their kebeles situated in the mid to highland areas were purposively selected based on their potential for potato production. However, potato leaf samples were randomly collected at every 3 to 5 km of the selected villages. The selected districts were Jeldu, , Tikur-Inchini, Jibat, Cheliya, Welmera and Ejere. The numbers of sampled fields were 10 for Jeldu, and Cheliya each and 10 for both Welmera and Ejere and 10 for both Tikur-Inchini and Jibat together, with a total of sampled fields being 40.

Fully expanded 5th leaf counted from top as suggested by Walworth and Muniz (1993) were collected into a paper bag in a zig-zag manner from 15-20 plants per field at vegetative growth stage (just before flowering) of the crop. The samples were then oven dried at 65^{O}C for 48 hrs before grinding. The commonest potato varieties whose leaf samples were collected were Gudene, Jalene, Menagesha, Wochecha, Guassa and local varieties of the respective sites.

Determination of mineral nutrient concentration in leaf tissue

Ground leaf samples were analysed for various nutrient contents (N, P, K, S, Mg, Ca, Zn, Mn, Cu, B, Mo, Na). Fifty mg ground potato leaf samples was ashed over night in a Muffle furnace at a temperature of 480^{O}C and was extracted using 1:3 diluted nitric acid solution. After the content was filtered through whatman filter paper, the nutrient concentration in the aliquate was directly measured using Inductively Coupled Plasma Optical Emission Spectrophotometer (ICP-OES, Spectroflame EOP, Spectro analytical Instruments, KLVE). N, C and S contents in the potato leaf samples were determined by CNS auto analyzer (Elementar Vario EL III). In the case of nitrogen, 10-15 mg dried plant sample was weighed into aluminium foil and burned at a temperature of 1200°C whereas in the case of sulphur 15-20 mg dried plant sample was weighed into the same aluminum foil and a similar amount of tungsten (III) oxide was added as a reaction catalyzer in the presence of oxygen supply after which it was completely burned at a similar temperature of 1200°C.

Statistical analysis

Descriptive statistics (mean, range, percentage) were used to explore the data. Concentrations of mineral nutrients in the leaf tissue were compared against the ranges reported for potato by Walworth and Muniz (1993) and Bergmann (1992) to classify them into optimum, deficient or excess. For some nutrients, the Pearson correlation coefficients were also determined through running correlation analysis using sigma plot version 10 in order to evaluate linear relationships between mineral nutrient concentrations in leaf tissue and content of the same nutrient in the soil.

Results and Discussion

Concentration of macronutrients in potato leaf

The mean phosphorus (P) concentration in potato leaf (petiole + leaf blade) (Table 2) did not differ much among the districts, since the mean values of each district were in a very close range (2.8-3.3 mg/g d.m). Compared to the optimum phosphorus concentration range described by both Walworth and Muniz (1993) (4.8-5.7 mg/g d.m), and Bergmann (1992) (4-6 mg /g d.m), the leaf P concentration were in the P deficiency range for all the districts except for one site (Alle Ula Dhabi) in the Cheliya district as compared to the optimum P concentration range described by both Walworth and Muniz (1993) (4.8-5.7 mg/g d.m) and Bergmann (1992) (4-6 mg/g d.m) (Annex 1). About 97.5% of the study sites showed leaf P concentration in the deficiency range, indicating the seriousness of low P availability in the soil as it was confirmed by soil analysis (data not shown). There was a huge gap between the leaf P concentration determined in this study and the optimum value indicated in such literatures as Walworth and Muniz (1993) and Bergmann (1992) for the crop. This might partly explain the lower tuber yield record on farmers' field at each district (ranged between 11-26 t ha^{-1} for cultivar Jalene) and (range between 34-46 t ha^{-1} for cultivar Gudene) as reported by Gebremedhin *et al*. (2013). In agreement with this finding, Nigussie Dechassa (2012) also reported P deficiency (at 60% of the surveyed villages), in potato leaf samples collected from the Eastern highlands of Ethiopia. The lower leaf P concentration in this study could be attributed to the lower soil available P content (70.6% of the surveyed field sites having Olsen P below the target value) emanated from P fixation due to the extremely acidic nature of the soil (Tesfaye Balemi *et al*., 2015). The significant positive relationship between leaf P concentration and Olsen P depicted in Figure 2a also indicate that there is a close relationship between the two parameters indicating that the lower leaf P concentration in the present investigation was clearly due to lower soil available P. Therefore, the only strategy to enhance the tissue P concentration in these potential potato growing farms is to apply sufficient amount of phosphorus fertilizers until the Olsen P value of the soils lie in the target range. Otherwise the yield of potato in those farms will always be limited since P is highly essential for the major plant metabolic activities such as photosynthesis and respiration (Marschner, 1995), which are known to considerably influence crop yields.

The average potassium (K) concentration in potato leaf was also in a very close range at all districts (31-35 mg/g d.m) (Table 2). At 75% of the surveyed field sites, plants showed insufficient potassium concentration in the leaf when compared to the optimum range (36.2-37.2 mg/g.d.m) described by Walworth and Muniz (1993). However, when compared against the relatively higher leaf K concentration in potato leaf (5.0-6.6 mg/g.d.m) described as optimum range for the crop by Bergman (1992), 97.5% of the surveyed field sites in the present study showed the leaf K concentration in the deficiency range with only one site (Ilu Barga) in Welmera district showing a leaf K concentration in the sufficient range (Annex 1). This observation is slightly different from the report of Nigussie Dechassa (2012), who observed sufficient leaf K concentration in potato grown in the Eastern highlands of Hararge although the leaf K concentration he observed was closer to the lower than to the upper optimum range. Since the results of the soil analysis showed that 90% of the surveyed sites had ammonium acetate extractable potassium content above the target value (data not presented), the low potassium content in the plant tissue in the present study might be attributed to potassium leaching from the plant leaf following heavy rain as suggested by Rosolem *et al*. (2005). In view of the fact that leaf K leaching does not reflect K deficiency, the low yield on farmers' field in the study areas, therefore, cannot be attributed to potassium deficiency. Leaf K concentration showed significant positive correlation with soil available K (Figure 2B), however, this relationship does not necessarily show that the lower leaf K concentration was due to low available K content of the soil but probably reflects that similar amount of leaf K leaching has occurred at all field sites.

The average nitrogen (N) concentration in potato leaf (Table 3) was also in a narrow range (61-63 mg g^{-1} d.m) for all the districts. Results obtained indicated that the plants were well supplied with N, since at 85% and 100% of the surveyed field sites; the leaf nitrogen concentration determined in this study was in the optimum range (60-64 mg/g.d.m) described by Walworth and Muniz (1993) and by Bergmann (1992) (50-65 mg/g d.m). Therefore, the lower tuber yield on farmers' field in the study areas (Gebremedhin *et al.*, 2013) cannot be attributed to lower leaf nitrogen concentration, a nutrient which plays a key role in influencing yield through affecting vegetative growth components such as leaf area, shoot growth and also crop quality through influencing protein bio-synthesis (Marschner, 1995). The result of the present study contrasted the report of Nigussie Dechassa (2012), who observed insufficient N concentration in potato leaf samples collected from the Eastern Haragre highlands. The leaf nitrogen concentration in the current study, however, did not show significant positive relationship with soil available N contents (NH_4^+ and NO_3^-) (Figure 3a), probably due to the dynamic nature of these available forms, which are vulnerable to various loss from the soil system.

Similar with nitrogen concentration in potato leaf (Table 3) the leaf sulphur (S) concentration was also in a narrow range (2-5 mg g^{-1} d.m) for all the districts. Results obtained indicated that the plants were well supplied with S, since at 100% of the surveyed field sites, the leaf sulphur concentration was in the optimum range described by Walworth and Muniz (1993). Therefore, the yield reduction on farmers' field cannot be attributed to lower leaf sulphur concentration, a nutrient which is very important in chlorophyll and protein formation (high nutritional quality) as well as in enhancing crop vegetative growth that ultimately influence yield (Marschner, 1995). Similar with the trend observed for nitrogen, the leaf sulphur concentration, however, did not show significant positive relationship with soil total sulphur content (Figure 3b), which is difficult to explain.

The average calcium (Ca) and magnesium (Mg) concentration in plant leaf were very close across the districts (13.5-16.9 for Ca and 5.5-7.1 for Mg) (Table 4). The Ca concentration in plant leaf, almost at all sites, was higher than the optimum range for the crop given by Walworth and Muniz (1993), with narrow optimum range. However, compared to the optimum range given by Bergmann (1992), which offers a wide optimum range, slightly higher leaf Ca concentration than the optimum range was observed only at two sites (at Alle Ula dabi) in Cheliya district and (at Robgebiya) in Welmera District. The results of the present study probably indicate that Bergmann's optimum Ca concentration range is more accurate than that of Walworth and Muniz (1993). Plants at all sites of all the districts were well supplied with Ca since no site showed insufficiency of these nutrients when referred against the optimum range described by both Walworth and Muniz (1993) and Bergmann (1992).

The Mg concentration in plant leaf at all sites were in the optimum range compared even to the extended upper limit range given by Bergmann (1992), except at Tullu kosoru-3 in Cheliya district and at Robgebiya and Illu Aga, in Ejere district, where it was slightly above the optimum range. Thus, similar with Ca, plants at all field sites of all the districts were well supplied with Mg since no site showed insufficiency of this nutrient when referred against the optimum range described by both Walworth and Muniz (1993) and Bergmann (1992). Thus, the lower yield report in potato on farmers' field in the study area cannot be related to constraints of these two macronutrients, which are important in cell wall strengthening and membrane stabilization and hence in conferring plant resistance against fungal and bacterial infection in the case of Ca and in serving as an integral component of chlorophyll molecule and also playing a key role in photosynthesis through enzyme activation and promoting photophosphorylation in the case of Mg (Marschner, 1995). Similar with the present finding, Nigussie Dechassa (2012) also did not observe deficiency of these macronutrients in potato as a yield limiting factor in the Eastern Ethiopian highlands.

Table 2. Phosphorus and potassium concentration in potato leaf collected from different districts in West Shoa Zone.

Sl. No	Name of district	No of fields sites sampled	P (mg/g d.m)		K (mg/g.d.m)	
			ranged	average	ranged	average
1	Jeldu	11	2.3-3.9	3.0	23.9-34.3	30.9
2	Tikur-Inchini and Jibat	10	2.2-3.6	2.8	30.2-44.4	35.3
3	Cheliya	10	2.5-4.7	3.3	13.3-47.7	32.9
4	Welmera and Ejere	10	2.3-4.0	3.1	25.5-53.0	32.4
		Optimum range		4.8-5.7[1]		36.2-37.2[1]
				4-6[2]		50-60.6[2]

Optimum range was adopted from (Walworth & Muniz, 1993)[1] and (Bergmann, 1992)[2]

Table 3. Nitrogen and sulphur concentration in potato leaf collected from different districts in West Shoa Zone.

Sl.No	Name of district	No of fields sites sampled	N (mg g^{-1} d.m)		S (mg g^{-1} d.m)	
			Range	Average	Range	Average
1	Jeldu	11	57-69	62	3.8-5.4	4.4
2	Tikur-Inchini and Jibat	10	57-65	61	3.9-4.3	4.1
3	Cheliya	10	56-66	62	3.9-4.9	4.4
4	Welmera and Ejere	10	58-70	63	3.9-4.9	4.5
		Optimum range		60-64[1]		2-5[1]
				50-65[2]		-

Optimum range was adopted from (Walworth & Muniz, 1993)[1] and Bergmann, 1992)[2]

Concentration of micro-nutrients in potato leaf

The average zinc (Zn) concentration in plant leaf in the study area ranged between 30-42 µg/g.d.m (Table 5). The average Zn concentration in plant leaf was slightly higher for Welmera, Ejere and Cheliya districts (42 and 37 µg/g.d.m, respectively) as compared to that of Tikur-Inchini and Jibat as well as Jeldu districts (30 and 32 µg/g.d.m, respectively). The leaf Zn concentration recorded at all field sites in the current study was in the optimum range compared to the optimum leaf Zn concentration range described by both Walworth and Muniz (1993) and Bergmann (1992), which were 21-70 µg/g.d.m and 20-80 µg/g.d.m, respectively. Thus, Zn, a highly essential micronutrient for plant metabolic activities being an integral component of many enzymes, is not a yield limiting nutrient at all the study areas.

The average manganese (Mn) concentration in plant leaf in the study area ranged between 91-137 µg/g.d.m (Table 5). The average Mn concentration in plant leaf was slightly higher for Cheliya and Jeldu districts (137 and 128 µg/g.d.m, respectively) as compared to that of Welmera-Ejere and Tikur-Inchini-Jibat districts (91 and 108 µg/g.d.m, respectively). At two field sites in Jeldu district (Chilanko-2 and Kolu Gelan-2) and two other field sites in Chliya district (Tullu Kosoru-2 and Tullu Kosoru-3), which altogether make up 10% of the surveyed field sites, a higher manganese concentration than optimum for the crop as described by Walworth and Muniz (1993) was recorded (Annex 1). Especially, at the later two field sites, the leaf Mn concentration was closer to the toxic level for the crop. This indicates that there could be a possibility of encountering manganese toxicity to the crop at those sites, unless corrective measures are taken. The higher Mn level in potato leaf tissue was related to lower soil pH as confirmed from the significant negative relationship observed between soil pH and leaf Mn concentration (figure 2). In the other four districts (Tikur-Inchini, Jibat, Welmera and Ejere) however, leaf Mn concentration did not exceed the optimum range given by Walworth and Muniz (1993). The upper limit of optimum Mn concentration range in potato leaf given by Bergmann (1992) was quite low (20-100 µg/g.d.m) and is far away from what most other literatures describe such as a range of 21-200 µg/g.d.m by Walworth and Muniz (1993) and a range of 30-450 µg/g.d.m by Uchida (2000). Thus, the range by Bergmann (1992) was not used as a reference to classify the leaf Mn concentration in the current study to avoid misleading conclusion. Unlike, the present study, in which Mn concentration above the optimum range was detected in potato leaf samples collected from some sites, Nigussie Dechassa (2012), reported most of the sampled potato leaf in the Eastern Ethiopian highland to have had a Mn concentration close to the lower limit and none of the samples showing no Mn concentration above the optimum range.

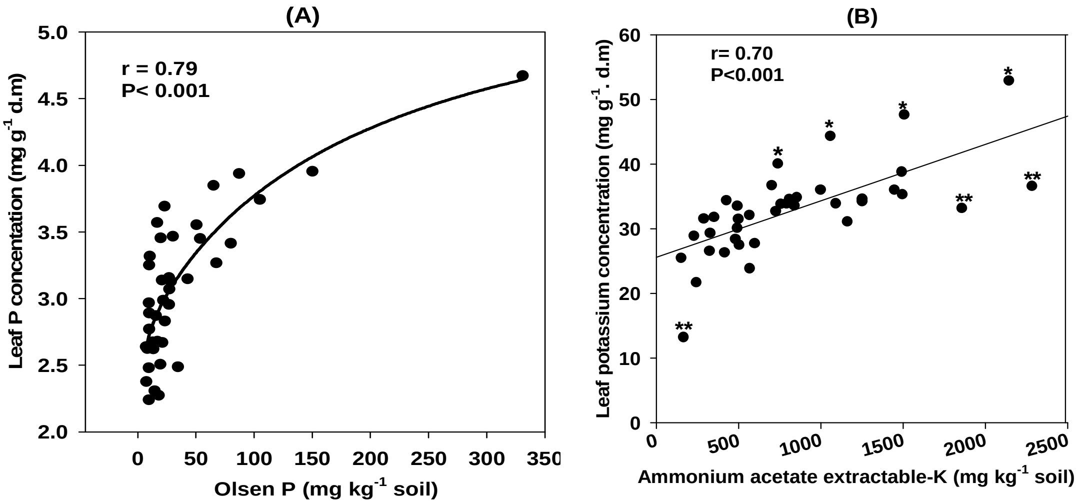

Figure 2. Relationship between leaf P concentration and Olsen P (A) and leaf K concentration and Ammonium acetate extractable K (B). (*, ** shows field sites where the two parameters slightly deviated).

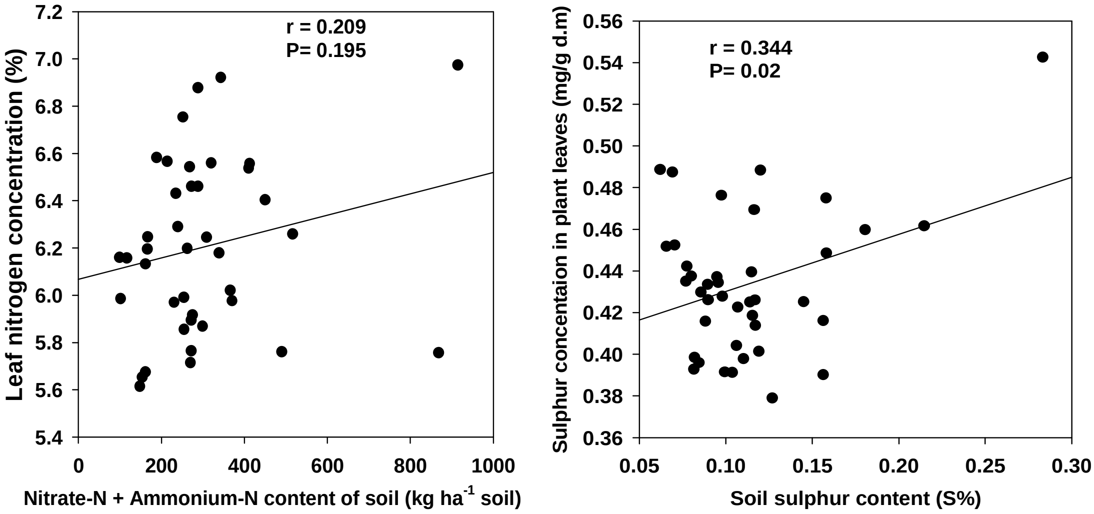

Figure 3. Relationship between leaf N concentration and soil ammonium and nitrate-N content (a) and leaf S concentration and soil S content

The average copper (Cu) concentration in plant leaf in the study area showed narrow range (22-31 µg/g.d.m) (Table 5). The average Mn concentration in plant leaf was slightly higher for Welmera district (31 µg/g.d.m) as compared to that of Tikur-Inchnini/Jibat and Cheliya districts (22 µg/g.d.m, each). At two sites (Ilu Aga-1 and Ilu Aga-2) in Ejere district and another two sites (Dufa-1 and Dufa-2) in Welmera district, a Cu concentration slightly above the optimum range described by Walworth and Muniz (1993) was observed (Annex 1). However, at all the four sites the leaf Cu concentration was still less than the toxic level given by Walworth and Muniz (1993), which is >50 µg/g.d.m.

Table 4. Calcium and magnesium contents (mg g^{-1}.d.m) in potato leaf collected from different districts in West Shoa Zone.

Sl.No	Name of district	No of fields sites sampled	Ca		Mg	
			Range	Average	Range	Average
1	Jeldu	11	12.8-20.3	15.7	4.7-6.9	5.7
2	Tikur-Inchini and Jibat	10	11.3-17.6	13.5	4.3-6.7	5.5
3	Cheliya	10	10.6-22.9	15.2	4.1-8.8	5.9
4	Welmera and Ejere	10	11.4-24.7	16.9	3.7-9.5	7.1
	Optimum range			9.0-9.4[1]		3.6-6.8[1]
				6-20[2]		2.5-8[2]

Optimum range was adopted from (Walworth & Muniz, 1993)[1] and (Bergmann, 1992)[2]

Table 5. Micronutrient contents (µg/g d.m) in potato leaf collected from different districts in West Shoa Zone.

Sl. No	Name of district	No of sites sampled	Mn		Zn		B		Cu		Mo	
			Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.
1	Jeldu	11	64-275	128	29-39	32	18-29	24	21-30	25	2.9-4.6	3.7
2	Tikur-Inchini and Jibat	10	65-143	108	24-35	30	29-108	48	18-26	22	3.2-5.3	4.1
3	Cheliya	10	54-337	137	31-46	37	27-61	40	18-32	22	3.1-4.7	4.0
4	Welmera and Ejere	10	45-192	91	33-65	42	29-75	51	21-42	31	2.4-6.0	4.1
	Optimum range			21-200[1]		21-70[1]		5-40[1]		5-30[1]		-
				40-100[2]		20-80[2]		25-70[2]		7-15[2]		0.2-0.5[2]

Optimum range was adopted from (Walworth & Muniz, 1993)[1] and (Bergmann, 1992)[2]

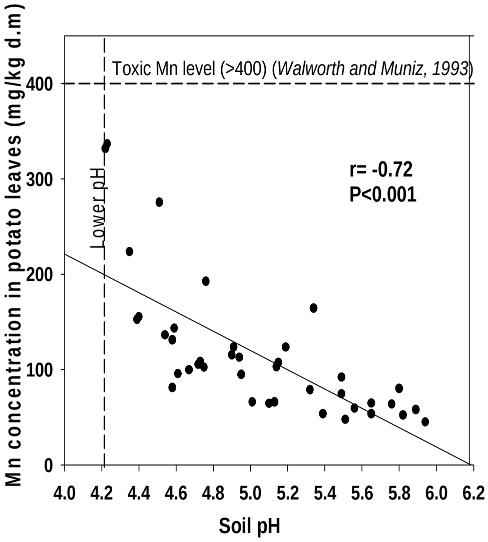

Figure 4. Relationship between soil pH and Manganese concentration in potato leaves.

Similar to that of Mn, the optimum leaf Cu concentration range for potato given by Bergmann (1992) seems quite low (7-15 µg/g.d.m) and hence was not referred for classifying the Cu concentration in potato leaf in the current study. In agreement with the present finding, Nigussie Dechassa (2012) also found a leaf Cu concentration in potato cultivated in the Eastern Ethiopian Highlands in the optimum range described by Walworth and Muniz (1993).

The average boron (B) concentration in plant leaf in the study area ranged between 24-51 µg/g.d.m (Table 5). The average B concentration in plant leaf was slightly lower at Jeldu district (24 µg/g.d.m) as compared to the other districts where it ranged between 40-51.4 µg/g.d.m. The average leaf B concentration at Welmera and Ejere as well as Tikur-Inchini and Jibat districts is above the sufficiency range given by Walworth and Muniz (1993) but within the sufficiency range given by Bergmann (1992) (Table 4). When the optimum leaf B concentration described by Bergmann (1992) was used as a reference, no field site showed deficiency of this essential micronutrient, whilst at three field sites (Mungo Abayi, in Jibat; Illu barga, and Dufa in Welmera), the leaf B concentration was even higher than the optimum range. However, when the optimum range given by Walworth and Muniz (1993) is used as a reference, about 30% of the surveyed field sites showed a leaf B concentration above the sufficiency range. According to the same reference, a leaf B concentration >55 µg/g.d.m was delineated as toxic level. However, in the current study even if a leaf B concentration as high as 108.4, 75, 73.5, 70.7 µg/g.d.m was recorded, plants at all sites did not exhibit any visible symptom of B toxicity; thus, questioning the accuracy of lower B toxic level given by Walworth and Muniz (1993) as opposed to the fair toxic level of B given by Bergmann (1992), which goes beyond 70 µg/g.d.m. On the other hand, when the lower limit of sufficiency range given by Walworth and Muniz (1993) was considered, no field site showed deficiency of this micronutrient while plants at few field sites in Jeldu district had a leaf B concentration in the deficiency range (Annex 1) although a clear deficiency symptom could not be observed in the field.

The average Molybdenum (Mo) concentration in plant leaf in the study area showed narrow range (3.7-4.1 µg/g.d.m) (Table 5). At Wemera and Ejere districts, a wider range of Mo concentration (2.4-6 µg/g.d.m) was observed compared to the other districts. At the entire surveyed field site, the leaf Mo concentration was above the sufficient range given by Bergmann (1992). In agreement with the observation of Nigussie Dechassa

(2013), the leaf Mo concentration in the current study was in the range of 10 fold higher than the sufficient range given by Bergmann (1992). Thus, Mo deficiency did not account for the lower potato tuber yield on farmers' field (Gebremedhin *et al*., 2013) in the study area.

Conclusion

The nutrient concentrations in potato leaf tissue were in the optimum range (compared to the range described in literature) for most of the micronutrients, nitrogen, sulphur, calcium and magnesium. However, in almost all the field sites plants showed lower phosphorus concentration in their leaf than the optimum amount described in literature. In some field sites the potassium concentration in plant leaf was also slightly lower than the optimum range although this was not related to lower soil available potassium content. The concentrations of micronutrients in potato leaf were all in the sufficient range or even above as in the case of molybdenum, boron and manganese. A very high manganese concentration closer to toxic level was observed at two districts, where lower soil pH was detected. There was a considerable variation in Mn concentration among the field sites of the study area compared to the other micronutrient which did not show much variation between the field sites. In Chelia district, the highest Mn content (337 mg g^{-1} d.m) was observed indicating that there could be manganese toxicity in potato crop grown on the farmland unless the soil pH is managed through lime application. Since the phosphorus concentration in the potato leaf in most cases was much below the optimum concentration for the crop, phosphorus fertilizer trials should be conducted on the sites having low leaf P concentration to assess crop response both in terms of P concentration and yield to applied mineral P fertilizer.

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Annex 1. Nutrient concentration in potato leaf samples collected from different districts in West Shoa Zone.

Field site	District	Varieties sampled	Total N (mg g^{-1} d.m)	P (mg g^{-1}d.m)	K (mg g^{-1} g.m)	S (mg g^{-1} d.m)	Ca (mg g^{-1} d.m)	Mg (mg g^{-1} .m)	Zn (µg/g d.m)	Mn (µg/g d.m)	Cu (µg/g d.m)	B (µg/g d.m)	Mo (µg/g d.m)
Galesa Qota Gesher	Jeldu district	Menagesha	58	2.31	32.8	5.4	16.5	4.8	31	102	21	28	3.9
Galesa Qoftu		Gudene	60	2.51	34.0	4.6	12.8	5.5	39	103	23	24	3.4
Chilanko-1		Jalene	63	2.87	31.1	4.6	13.2	5.2	36	107	24	22	4.2
Chilanko-2		Jalene	66	3.47	31.8	4.5	16.8	4.7	34	223	30	21	3.4
Edensa Gelan-1		Gudene	69	3.94	34.3	4.2	17.7	6.3	31	74	21	27	4.6
Edensa Gelan-2		Gudene	59	2.99	33.9	4.3	14.7	6.1	32	64	29	25	3.1
Edensa Gelan -3		Gudene	65	3.45	27.5	3.8	20.3	6.9	30	81	23	21	3.7
Kolu Gelan-1		Gudene	64	3.46	23.9	4.0	14.4	5.9	29	95	24	18	4.0
Kolu Gelan-2		Gudene	61	2.89	26.4	4.3	15.0	6.0	33	275	28	24	2.9
Chilanko-3		Gudene	57	2.62	33.6	4.2	15.3	5.6	30	155	24	29	4.0
Mean			62	3.05	30.9	4.4	15.7	5.7	32	128	25	24	3.7
Birbira fi Doguma	Tikur Inchini and Jibat districts	Wechecha	62	3.25	34.4	4.0	12.8	5.3	28.6	113	21.0	29.0	3.7
Ula Lankiso		Jalene	57	2.63	36.8	3.9	12.5	5.0	32.1	143	26.3	29.7	3.5
Maganur		Gudene	66	2.97	34.9	4.3	11.4	4.7	31.7	131	22.5	40.0	3.6
Walda Hidhe-1		Local var.	66	2.48	33.6	4.0	11.5	4.3	24.5	136	20.2	34.0	3.4
Buyema Qochore		Local var.	62	3.16	34.7	4.1	13.1	6.7	33.0	66	21.4	58.2	4.9
Bilo Abaye		Gudene	62	2.67	34.6	4.3	11.3	5.5	33.5	66	21.9	42.0	3.2
Togo Wixate		Gudene	56	3.55	36.1	3.9	17.6	5.3	31.8	65	24.4	62.6	4.5
Mugno Abayi (Jibat)		Gudene	64	2.24	44.4	4.3	16.0	6.4	24.3	124	17.9	108.4	3.7
Tutu Jibat		Gudene	65	2.38	30.2	4.2	16.5	6.3	28.1	108	19.7	38.2	4.6
Walda Hindhe-2		Gudene	59	2.96	33.2	4.0	12.6	5.7	35.5	123	20.7	38.6	5.3
Mean			61	2.83	35.3	4.1	13.5	5.5	30.3	108	21.6	48.1	4.1
Rafiso Alenga-1	Cheliya	Gudene	62	3.15	38.9	4.0	14.4	6.1	34.4	92	23.6	32.6	4.3
Rafiso Alenga-2		Gudene	57	3.13	32.2	4.4	15.5	5.4	36.3	95	31.6	40.1	4.5
Alle Ula Dhabi		Gudene	66	4.67	47.7	4.3	22.9	6.1	46.0	58	17.8	46.8	4.6

Annex 1. Continued.

Field site		Varieties sampled	Total N (mg g-1 d.m)	P (mg g-1d.m)	K (mg g-1 g.m)	S (mg g-1 d.m)	Ca (mg g-1 d.m)	Mg (mg g-1.m)	Zn (µg/g d.m)	Mn (µg/g d.m)	Cu (µg/g d.m)	B (µg/g d.m)	Mo (µg/g d.m)
Jasro Dire Geda-1	Cheliya	Aba Minmino (local)	66	3.27	35.4	4.8	13.5	6.0	40.0	54	17.6	35.5	4.5
Jarso Dire Geda-2		Aba Minmino (local)	62	3.42	33.9	4.2	14.9	4.1	43.2	79	19.0	31.6	4.7
Bilo fi Kaku		Aba Minmino (local)	62	3.07	33.9	4.9	10.6	5.3	33.7	100	23.3	61.3	3.6
Tulu Kosoru-1		Aba Minmino (local)	56	2.83	31.6	4.3	17.7	6.7	32.4	115	23.1	39.4	3.6
Tulu Kosoru-2		Aba Minmino (local)	64	3.57	21.7	4.8	14.8	5.9	36.2	337	21.1	26.9	3.4
Tulu Kosoru-3		Guasa	65	3.32	13.3	4.3	15.8	8.8	30.6	332	20.2	43.4	3.1
Jarso		Aba Minmino (local)	59	2.49	40.1	3.9	12.3	4.7	41.8	105	24.4	42.7	3.5
Mean			62	3.29	32.9	4.4	15.2	5.9	37.5	137	22.2	40.0	4.0
Robgebya (wolmera)	Welmera/Ejere Districts	Gudene	58	2.28	26.6	4.4	24.7	9.5	48.1	164	32.4	29.3	4.8
Ilu Barga (wolmera_		Gudene	69	3.96	53.0	3.9	18.3	6.6	41.5	80	20.9	73.5	3.7
Ilu Aga (Ejere)		Gudene	62	2.64	25.5	4.5	19.7	9.2	45.9	153	34.5	70.7	6.0
Ilu Aga (Ejere)		Gudene	66	3.14	28.9	4.5	18.1	6.5	43.4	192	42.1	35.0	4.4
Dufa-1 (walmera)		Gudene	60	2.77	31.6	4.9	17.7	8.1	34.5	64	36.5	75.5	4.2
Dufa-2 (Walmera)		Gudene	62	2.68	29.4	4.7	13.5	6.0	33.0	59	37.6	33.2	2.4
Dufa-3 (Walmera)		Gudene	68	3.85	36.1	4.4	16.6	6.8	35.7	52	26.2	60.3	3.6
Talacho (Walmera)		Gudene	70	3.74	36.7	4.4	14.8	6.9	38.0	53	21.9	51.0	3.2
Birbirsa Siba (Walmera)		Local	59	2.68	28.5	4.4	13.8	7.5	37.1	45	31.1	32.3	4.3
Barfata Tokofa Roge (Walmera)		Local	62	3.69	27.8	4.9	11.4	3.7	64.6	48	29.4	53.4	4.6
Mean			63	3.14	32.4	4.5	16.9	7.1	42.2	91	31.2	51.4	4.1
Optimum range			60-64[1] 50-65[2]	4.8-5.7[1] 4-6[2]	36.2-37.2[1] 50-60.6[2]	2-5[1]	9-9.4[1] 6-20[2]	3.6-6.8[1] 2.5-8[2]	21-70[1] 20-80[2]	21-200[1] 40-100[2]	5-30[1] 7-15[2]	5-40[1] 25-70[2]	2-5[2]

Optimum range was adopted from (Walworth and Muniz, 1993)[1] and (Bergmann, 1992)[2].