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Soil-plant Nutrient Status and Relations in Common Cereal Crop Growing Fields of Kambata Tembaro Zone, Southern Ethiopia

Alemu Lelago[1], Wassie Haile[2], Mesfin Bibiso[1], Sheleme Beyene[2], Tegbaru Bellete[3]

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ABSTRACT

Background: Plant analysis and soil testing are necessary to assess the fertility status of soils and their capacity to feed plants and when necessary, to recommend balanced fertilizers. This study aimed to evaluate the soil and plant nutrient status and their relationships in different cropping systems of the Kambata Tembaro (KT) zone, in southern Ethiopia.

Methods: Maize, tef, sorghum and wheat leaves from 28, 55, 29 and 75 smallholder farmers' fields, respectively with their respective soil samples were collected and analyzed.

Result: The soil pH ranged from strongly acidic to neutral. The mean separation method confirmed that the means of all soil properties investigated in this study showed significant differences ($P<0.001$) among different crop-growing fields. Soil available P and S, total N, extractable B and Cu were deficient in most of the soils and plant tissues. The amount of exchangeable K, Ca, Mg and Zn were found to be sufficient in soils of the study area but their deficiency was recorded in most of the tissues. Soil available P, exchangeable K, Ca and Zn significantly ($P<0.01$) and positively correlated (r= 0.33, 0.37, 0.20 and 0.15), respectively with tissue content of the respective elements.

Key words: Macro and micronutrients, Plant tissue analysis, Soil.

INTRODUCTION

The depletion of soil fertility caused by erosion, organic matter and plant nutrient removal, intensive crop cultivation, low and unbalanced fertilizer use, removal of vegetative cover (such as straw or stubble) and nutrient imbalances are among the major challenges affecting agricultural productivity and food security in Ethiopia (Haileselassie *et al.,* 2005; Tadele *et al.,* 2013). In Ethiopia, the depletion rate of N, P and K was reported to be 122, 13 and 82 kg ha^{-1} $year^{-1}$, respectively; this was estimated to be the highest in sub-Saharan Africa (Haileselassie *et al.,* 2005). Until recently, the major sources of fertilizers being used in Ethiopia have been diammonium phosphate (DAP) and urea, which supply only N and P. However, it was only in 2014 that the fertilizer recommendation package started to change dramatically. This indicates that very little attention has been given to other macro and micronutrients (Wondwosen and Sheleme, 2011).

Maize, tef, wheat and sorghum are the main cereal crops being cultivated in Kambata Temabaro zone. The average yield in the zone with blanket N and P application rate is 2.46, 1.06, 1.67 and 1.98 t/ha for maize, tef, wheat and sorghum, respectively. This level is lower than the national average yield level for the mentioned crops. In order to boost the yield of crops, knowledge about soil-crop interaction is very vital. However, there is very limited or no research study on soil-plant nutrient relation in the study area. Therefore, the objective of this study was to evaluate the soil and plant nutrient status and their relationships in different cropping systems of KT Zone, southern Ethiopia.

[1]Department of Chemistry, Wolaita Sodo University, Ethiopia.
[2]Hwassa University, Ethiopia.
[3]Agricultural Transformation Agency, Ethiopia.

Corresponding Author: Mesfin Bibiso, Wolaita Sodo University, Wolaita Sodo, Ethiopia. Email: mefbab2009@gmail.com

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MATERIALS AND METHODS

Soil sampling and analysis

A total of 309 soil samples were taken from 0-20 cm depth using auger from 80 maize, 95 tef, 80 wheat, 36 sorghum and 18 enset growing fields of Kedida Gamela, Kecha Bira and Damboya woredas, KT zone, Southern Ethiopia in 2021. Soil pH (1:2 soil: water suspension) was measured with a pH meter and glass electrode. Available P, available S, exchangeable basic cations and extractable micronutrients were determined using Mehlich-III multi-nutrient extraction method (Mehlich, 1984). Mid-infrared diffused reflectance spectral analysis was also used to determine the amount of soil OC, TN and CEC. Particle size distribution, pH, OC, TN and CEC were analyzed at the National Soil Testing Center, Addis Ababa. The concentration elements were analyzed at Yara International Soil Laboratory in London following standard laboratory procedures.

Plant sampling and analysis

About 25 leaves per field were collected from different plants and homogenized to make one representative sample for a field. From the composite samples, sub-samples were taken for analyzing macronutrients and micronutrients. The tissue analysis was carried out at Horticoop Soil and Water Analysis Laboratory, at DebreZeit, in Ethiopia. Nitrogen was determined using Kjeldahl distillation procedure. Plant digests using concentrated hydrochloric acid were prepared to extract and analyze P, K, S, Ca, Mg, Cu, Fe, Mn and Zn using inductively coupled plasma spectrometry.

Statistical analysis

Descriptive statistics was applied for calculation of means, median standard errors and CV. Correlation analysis was performed to assess relationships among soil and plant nutrient contents. Differences at the P<0.05 level of significance were reported as significant.

RESULTS AND DISCUSSION

The fertility status of soils collected from different crop growing fields

The mean pH value under enset crop was found to be the highest followed by maize in all woredas whereas the lowest pH was recorded under wheat growing field (Table 1). This may be due to farmers' application of house refuse and wood ash for improving the fertility of the soils (Chakoro *et al.* 2015). The existence of the lowest mean pH value in wheat growing field could be due to application by farmers more N fertilizers for wheat than other crops without proper management of acidic soils.

The mean separation showed that the means of both available P and S significantly (P<0.001) varied among crops. Relatively highest mean value of P and S was obtained in enset field followed by maize field. This is due to the fact that enset is commonly cultivated on plots or fields close to the homesteads where ash and house refuse are commonly added to the soil by farmers (Tittonell *et al*., 2005).

Table 1: Soil pH, EC, available P and S, OC and TN in soils of different cropgrowing fields of KT zone, southern Ethiopia.

Crop grown	Descriptive statistics	pH H_2O	P mg kg^{-1}	S	OC %	TN
Maize (N=80)	Mean	6.31	27.61	8.87	1.14	0.09
	Median	6.33	16.00	8.00	0.74	0.001
	Minimum	5.1	1.00	3.12	0.01	0.002
	Maximum	7.9	129.00	20.00	2.98	0.55
	SD	0.60	28.50	3.12	1.04	0.06
	CV (%)	9.46	117.55	35.15	91.23	66.67
Tef (N=95)	Mean	6.14	6.00	6.84	1.33	0.12
	Median	6.0	5.00	6.00	1.35	0.10
	Minimum	4.5	0.00	3.00	0.0012	0.001
	Maximum	8.5	24.00	20.00	4.27	0.53
	SD	0.78	4.79	3.04	1.03	0.1
	CV (%)	12.38	79.83	44.44	77.30	83.33
Sorghum (N=36)	Mean	6.21	6.79	6.66	1.09	0.08
	Median	6.1	4.00	6.00	0.99	0.04
	Minimum	4.6	1.00	5.00	0.02	0.001
	Maximum	7.7	24.0	15.00	4.27	0.38
	SD	0.6	5.66	1.99	0.70	0.06
	CV (%)	9.67	83.32	29.88	64.07	75.00
Wheat (N=80)	Mean	5.96	5.71	6.18	2.16	0.21
	Median	5.90	4.00	6.00	2.36	0.24
	Minimum	5.12	1.00	3.00	0.002	0.001
	Maximum	7.10	25.00	11.00	4.06	0.53
	SD	0.44	4.67	1.50	0.80	0.80
	CV (%)	7.50	81.75	24.27	39.00	38.01
Enset (N=18)	Mean	6.58	63.06	13.06	1.85	0.19
	Median	6.40	35.00	12.00	1.73	0.19
	Minimum	5.4	3.00	8.00	0.002	0.001
	Maximum	8.5	267.00	28.00	4.26	0.464
	SD	0.81	71.07	3.41	0.90	0.08
	CV (%)	12.35	112.71	26.35	48.52	42.11

Total nitrogen and OC in enset and wheat fields were relatively high. This might be due to the materials added to the soil from the plant parts and organic inputs (application of manure and domestic waste). Also, enset has highly degradable vegetative parts which are used to maintain soil fertility (Chakoro *et.al*, 2015).

The highest mean values of all exchangeable bases were observed in enset growing field (Fig 1). This may be due to reduction in leaching and possible reduction in loss of nutrients by enset, (Eyob 2014; Hilette *et al.* 2015).

Soil micronutrient status

The Mehlich-3 extractable micronutrients showed statistically significant ($P<0.001$) differences among different types of crop growing fields. The highest mean of Cu, Mn, B and Fe were obtained from enset growing fields whereas the highest mean value for Zn was obtained in wheat growing fields (Table 2).

The Mehlich-3 extractable Fe ranged from 67.30 to 209.72, 46.84 to 217.8, 70.15 to 233.32, 107.74 to 211.03 and 103.87 to 221.12 mg kg^{-1} in maize, tef, sorghum, wheat and enset growing fields, respectively. Also, the Melich-3 extractable Zn ranged from 1.50 to 2 5.70, 1.3 to 29.00, 1.50 to 20.4, 1.6 to 38.70 and 7.20 to 39.02 mg kg^{-1} in maize, tef, sorghum, wheat and enset growing fields, respectively. In this study, considering 20 and 1.5 mg kg^{-1} Melich-3 extractable Fe and Zn, respectively, as critical levels, samples from all crop growing fields were found to have sufficient level of available Fe and Zn.

Plant tissue nutrient content and relationship with soil nutrients

Soil and plant tissue macronutrient status

According to Schwab *et al.* (2007); Fageria *et al.* (2011); Jones *et al.* (1991) and Engel and Zubriski (1982), in all plant tissues regardless of type of crops TN is insufficient. This result confirms that N is the major yield limiting element in the study areas. Inadequate level of N in plant tissue may be due to low soil organic matter, poor agronomic practices, application of low N fertilizer than the recommended rate and continuous cultivation.

Table 2: Soil micronutrient of maize, tef, sorghum wheat a growing.

Crop	Descriptive statistics	Fe	Zn	B	Mn	Cu
		mg kg^{-1}				
Maize (N=80)	Mean	123.97	8.73	0.55	164.43.	1.28
	Std Dev	32.26	5.65	0.34	55.07	0.35
	Median	12.40	7.35	0.44	153.50	1.30
	Minimum	67.30	1.5	0.15	66.0	0.6
	Maximum	209.72	25.7	1.71	300.0	2.9
	CV (%)	20.02	64.69	61.38	33.15	27.17
Tef (N=95)	Mean	134.02	5.99	0.28	138.04	1.11
	Std Dev	38.54	3.90	0.18	53.54	0.26
	Median	130.56	4.00	0.24	133	1.10
	Minimum	46.84	1.30	0.04	26.00	0.60
	Maximum	217.8	29.00	0.71	304.00	1.90
	CV (%)	28.54	65.04	64.29	38.78	23.20
Sorghum (N=35)	Mean	137.27	5.83	0.33	146.91	1.15
	Std Dev	36.69	3.07	0.19	49.04	0.24
	Median	136.25	4.80	0.28	137.00	1.20
	Minimum	70.15	1.50	0.06	62.00	0.70
	Maximum	233.32	20.4	0.78	264.00	1.60
	CV (%)	26.73	52.65	57.58	33.38	20.80
Wheat (N=66)	Mean	163.42	14.29	0.36	132.38	1.70
	Std Dev	27.06	7.76	0.17	41.40	0.30
	Median	164.69	14.45	0.35	136.50	1.20
	Minimum	107.74	1.60	0.02	49.00	0.60
	Maximum	211.03	38.70	0.72	252	1.80
	CV (%)	16.56	54.30	46.50	29.93	25.75
Enset (N=18)	Mean	156.27	21.19	1.01	180.44	1.75
	Std Dev	34.70	9.89	0.49	47.91	1.65
	Median	15.23	21.45	0.89	171.00	0.66
	Minimum	103.87	7.20	0.34	121.00	1.00
	Maximum	221.12	39.2	2.03	285.00	3.40
	CV (%)	22.20	46.67	49.06	26.55	37.76

According to Schwab *et al.* (2007) and Fageria *et al.* (2011) P was found to be deficient in 96.43, 85, 89.66 and 69.44% of maize, tef, sorghum and wheat leaf tissues, respectively. This indicates that, more or less, the soil test and plant tissue tests are equally important to manifest P deficiency (Fig 2). Also, about 89, 87, 87 and 61% of maize, tef, sorghum and wheat tissue were deficient in K. The result reflects unexpectedly the deficiency of K in plant tissue even though the soil test showed almost all soil samples have adequate amount of K (Fig 2).

Wide variability existed in both Ca^{2+} and Mg^{2+} contents within plant tissues. Both Ca and Mg were sufficient in maize plant tissue while Ca were deficient in 50, 10.35 and 59.72% of tef, sorghum and wheat plant tissues, respectively. Similarly, 94.50, 75.86 and 85.00% often, sorghum and wheat plant tissues analyzed were found to be deficient in Mg. This result also showed that deficiency of Ca and Mg in some plant tissues occurred regardless of their excess amounts in the soil (Fig 2).

Soil and plant tissue micronutrient status

Wide variability existed in the micronutrient contents in the plant tissue samples (Table 3). According to Schwab *et al.* (2007), Fageria *et al.* (2011); Jones *et al.* (1991) and Engel and Zubriski (1982),considering 6 ppm for maize and sorghum and 4.5 ppm for tef and wheat as critical levels of Cu, 97, 89.1, 34 and 88.89% of maize, tef, sorghum and wheat plant tissues analyzed were found to be deficient in Cu. This indicates that the Cu deficiency is manifested more in tissue test than in soil test (Fig 2). This may be due to the factors that retard copper uptake by plants. But in all plant tissue samples, both Fe and Mn were sufficient.

According to Schwab *et al.* (2007), Fageria *et al.* (2011); Jones *et al.* (1991) and Engel and Zubriski (1982), it was found that 68, 60, 62 and 41.67% of maize, tef, sorghum and wheat plant tissues analyzed were found to be deficient in Zn. This revealed that Zn is one of the limiting nutrients in some parts of the study areas despite the fact that its amount is sufficient in the soil (Fig 2).

Soil and plant nutrient relationships

The result of correlation analysis revealed that the plant tissue content of P, K, Ca and Zn showed positive and significant ($P<0.01$) correlation (Table 4). But the plant tissue Mg, Cu, Fe and Mn concentrations showed a non-significant ($P>0.05$) relationship with their respective amounts in the soil. This non-significant correlation indicates the existence of other factors than the nutrient content in the soil which are responsible for this poor correlation.

From the correlation analysis, it was found that correlated positively and significantly ($P<0.05$) with tissue Ca and K concentrations. Soil pH affects the solubility,

Table 3: Nutrient concentration in plant tissue samples.

Crop		N	P	K	Ca	Mg	S	Cu	Fe	Mn	Zn
	%							mg kg^{-1}			
Maize (N=28)	Mean	1.16	0.12	0.92	0.52	0.12	0.05	2.98	213.18	61.49	17.17
	SD	0.2	0.07	0.88	0.23	0.04	0.02	1.15	83.07	30.62	11.68
	Median	1.14	0.90	0.46	0.52	0.11	0.05	3.12	190.44	53.33	10.07
	Minimum	0.72	0.02	0.17	0.20	0.05	0.02	1.46	102.55	12.73	9.80
	Maximum	1.65	0.31	2.08	1.00	0.28	0.12	6.61	422.98	131.49	44.06
	CV (%)	23.32	58.14	49.87	44.23	33.33	40.00	38.77	38.97	49.83	64.50
Tef (N=55)	Mean	1.25	0.14	1.16	0.28	0.07	0.06	2.87	302.14	62.70	16.73
	SD	0.39	0.06	0.71	0.12	0.02	0.02	1.07	207.50	26.45	5.71
	Median	1.21	0.13	1.01	0.21	0.06	0.05	2.84	184.19	62.26	12.70
	Minimum	0.57	0.05	0.36	0.10	0.03	0.02	0.96	43.90	20.83	5.43
	Maximum	2.56	0.27	1.86	0.60	0.15	0.11	5.87	1223.29	127.67	33
	CV (%)	31.52	45.05	70.79	42.86	28.70	33.33	37.33	68.66	42.19	34.13
Sorghum (N=29)	Mean	1.33	0.12	0.84	0.47	0.12	0.04	2.29	150.08	21.41	10.98
	SD	0.40	0.05	0.33	0.21	0.05	0.01	0.75	130.9	13.67	4.41
	Median	1.26	0.13	0.81	0.49	0.11	0.04	2.18	69.19	17.70	10.73
	Minimum	0.83	0.01	0.08	0.03	0.01	0.01	1.10	57.04	4.84	3.89
	Maximum	2.31	0.26	1.49	1.01	0.23	0.08	4.15	349.41	75.93	18.72
	CV (%)	30	41.67	39.29	44.68	41.67	25.00	33.00	46.07	63.83	40.02
Wheat (N=75)	Mean	1.27	0.16	1.49	0.17	0.07	0.06	2.63	265.54	58.54	21.48
	SD	0.37	0.06	0.92	0.1	0.03	0.02	1.23	179.17	38.34	11.44
	Median	1.26	0.15	1.27	0.12	0.06	0.06	1.33	119.04	36.04	19.24
	Minimum	0.62	0.06	0.35	0.03	0.03	0.02	0.82	38.60	15.78	6.34
	Maximum	2.48	0.36	4.86	0.61	0.27	0.15	7.38	1245.13	378.14	92.00
	CV (%)	29.13	37.50	61.75	58.82	42.85	33.33	46.77	67.47	65.49	51.38

SD= Standard deviation, N= The number of each plant samples.

availability and uptake of soil nutrients (Mesfin, 2007). The tissue P concentration was also positively and significantly correlated with soil K and tissue Ca, Mg and Cu. Also, tissue Ca and Mg concentrations correlated positively and significantly ($P<0.01$) with soil P and K but thecorrelation with Zn was found to be negative and significant. According to Westermann *et al*. (2011), the excess of P can cause deficiency of nutrients such as Fe, Cu, Zn and Mn. In addition to this, K uptake correlated positively and significantly with soil P, Ca and Mn.

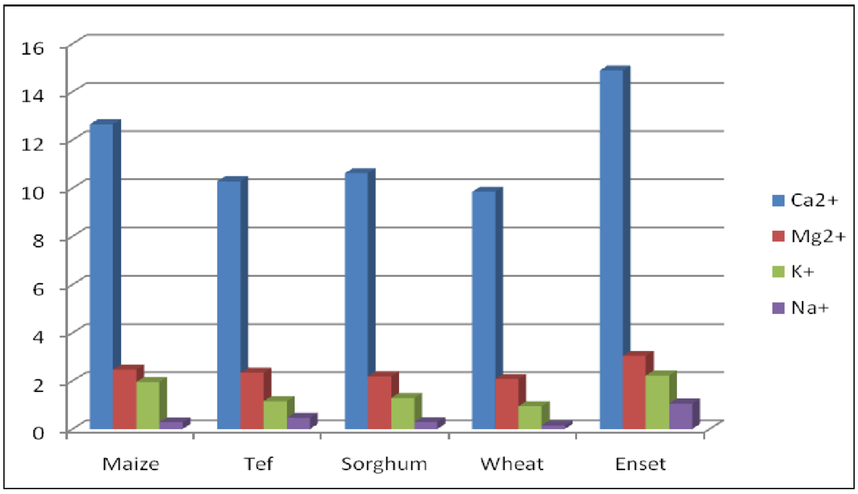

Fig 1: Means of exchangeable basic cations of soil samples collected from different types of crop growing fields.

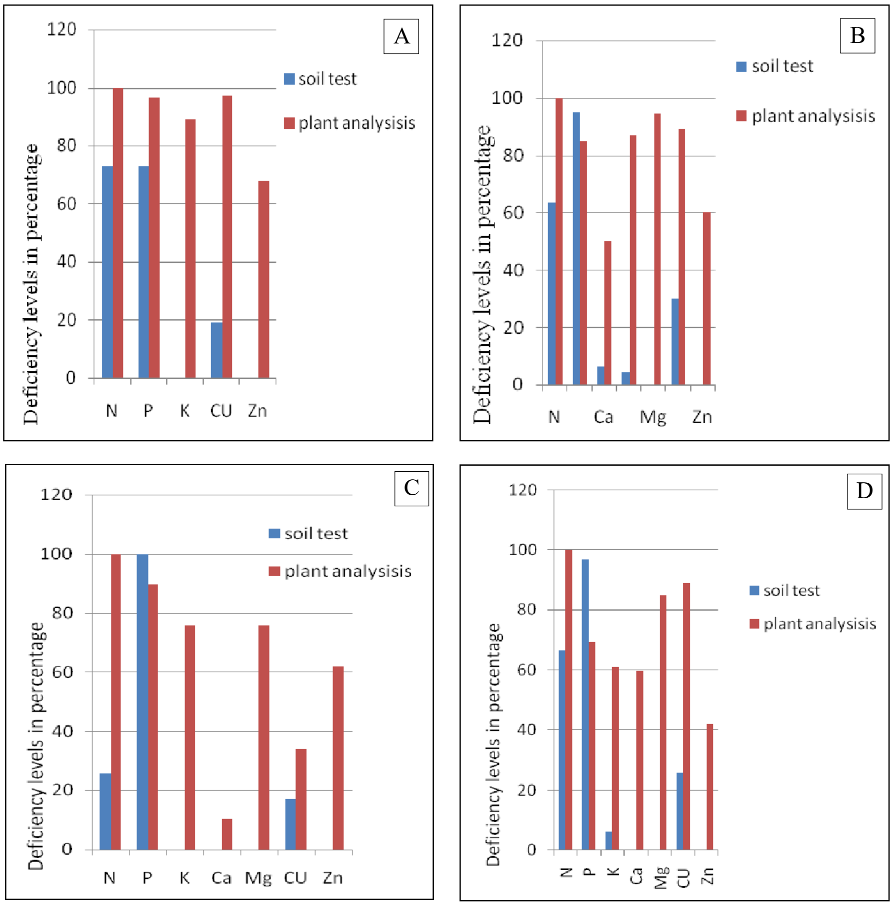

Fig 2: The relation of the deficiency level (%) of nutrient (A) in maize tissue and soil, (B) in tef tissue and soil, (C) in sorghum tissue and soil, (D) in wheat tissue and soil.

Table 4: Pearson correlation matrix for relationship between soil and plant tissue nutrients in KT Zone, Southern Ethiopia.

	Soil test										Plan tissue analysis								
	pH	P	K	Ca	Mg	S	Cu	Fe	Mn	Zn	N	P	K	Ca	Mg	Cu	Fe	Mn	Zn
Soil pH	1.00	0.3**	0.5**	0.61**	0.13	0.02	0.26*	-0.4**	0.24**	0.11	0.09	0.08	0.17*	0.16*	0.09	0.09	0.03	-0.04	0.05
Soil P		1.00	0.6	0.5**	0.2*	0.56**	0.46**	-0.18*	0.35**	0.25**	0.02	0.33**	0.21**	0.20*	0.19**	0.16**	0.02	0.05	0.08
Soil K			1.00	0.58**	0.38**	0.41**	0.32**	-0.46**	0.41**	0.13	0.06	0.17*	0.37*	0.19**	0.17**	0.11	-0.02	-0.02	0.08
Soil Ca				1.00	0.48***	0.12	0.32**	-0.2**	0.41**	0.21**	0.03	0.13	0.20**	0.2**	0.16**	0.19*	-0.09	-0.04	-0.06
Soil Mg					1.00	0.13	0.37**	-0.10	0.21**	-0.01	-0.03	0.05	0.11	0.05	0.09	0.08	-0.10	-0.10	-0.04
Soil S						1.00	0.25**	-0.11	0.14*	0.13	-0.04	0.03	0.04	-0.02	0.03	0.06	-0.05	0.04	0.06
Soil Cu							1.00	0.21**	0.28**	0.45**	-0.13	0.10	0.06	0.01	0.06	0.04	-0.14	-0.12	-0.12
Soil Fe								1.00	-0.24**	0.42**	-0.06	-0.02	-0.05	-0.06	-0.07	-0.05	0.02	0.001	-0.04
Soil Mn									1.00	0.16*	-0.07	0.13	0.15*	-0.001	-004	0.11	-0.10	-0.30	0.04
Soil Zn										1.00	-0.06	-0.2	-0.12	-0.25**	-0.18*	-0.07	0.08	0.03	0.15*
Plant N											1.00	0.25*	0.24*	0.12	0.04	0.42**	0.12	0.03	0.16*
Plant P												1.00	0.72**	0.12	0.21**	0.25**	0.16*	0.18*	0.53**
Plant K													1.00	-0.03	0.09	0.41**	0.32**	0.35**	0.41**
Plant Ca														1.00	0.76**	0.17*	-0.01	-0.05	-0.05
Plant Mg															1.00	0.18	0.07	0.03	0.09
Plant Cu																1.00	-0.05	0.42**	-0.07
Plant Fe																	1.00	0.88**	0.60**
Plant Mn																		1.00	0.67**
Plant Zn																			1.00

*, ** Correlation is significant at $p < 0.05$ and 0.01, respectively.

CONCLUSION

The plant tissue analysis showed the deficiency of K, Cu, Mg and Zn regardless of their high amount in the soil, thus calling for further study to identify the factors that inhibit their availability for plants. In order to increase crop production, the deficient elements mainly N, P, K, S, Cu, Zn and B should be included in the fertilizer program of the study areas. Also this it can be concluded that soil available P, exchangeable K, Ca and Zn significantly and positively correlated.

Conflict of interest: None.

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