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Identification of Growth Limiting Nutrient(s) in Alfisols: Soil Physico-chemical Properties, Nutrient Concentrations and Biomass Yield of Maize

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ABSTRACT

This study was conducted on soil samples collected from Delbo Atwaro watershed, southern Ethiopia, during 2007/08 to study the nutrient(s) status for maize production. Soil fertility diagnostic techniques developed by Agro Services International (ASI), including soil testing, nutrient sorption study and pot experiments were conducted. Greenhouse experiment with 19 fertilizer treatments was conducted in a Completely Randomized Design (CRD) with four replications using maize as a test crop. Chemical analysis of composite soil samples indicated that Ca, Mg, Fe, Mn, Zn, B and Mo were sufficient to support good crop growth, whereas total N, available P, available Cu, S and K were deficient. Sorption studies of P, K, S, Cu and B indicated that the optimum levels of the nutrients for Alfisols of the Delbo Watershed were: 130 mg P, 30 mg K, 20 mg S, 3.0 mg Cu and 1.0 mg B per kg soil. Besides, P and Cu were found to be highly fixed by the soil. The results of soil analysis, dry matter yields, nutrient concentration and uptake by maize indicated that phosphorus and nitrogen to be highly limiting nutrients to support good crop growth and development. Furthermore, Cu, K and S are also potentially limiting nutrients.

Key words: Alfisols, sorption, critical level, agro services international, watershed and pot experiment

INTRODUCTION

Ethiopia is one of the most food insecure countries in Sub-Saharan Africa (Getahun, 2003). Despite the fact that the country has potentially rich land resources, agricultural productivity is low and the nation suffers from recurrent food shortage and hunger. Drought along with low soil fertility due to excessive degradation and nutrient depletion are serious limitations to crop production in Ethiopia (FAO, 1999). The major plant nutrients, N and P, are added to the soil in the form of Di-Ammonium Phosphate (DAP) and urea fertilizers, whereas very little attention has been given to other macro-and micro-nutrients leading to imbalanced and poor nutrient management and crop quality (Mesfin, 1980). Cultivation of improved varieties without balanced nutrient management further aggravated the problem of nutrients to be yield limiting factors (Mesfin, 1998).

Maize (*Zea mays* L.) is one of the most important food crops world-wide. It has the highest average yield per hectare and is third after wheat and rice in area and total production in the world, in Ethiopia, maize grows from moisture stress areas to high rainfall areas and from lowland to the highlands (Mosisa *et al.*, 2001). It is one of the important cereal crops to satisfy the food self-sufficiency program of the country. It plays a key role in the human diet and animal feed and provide adequate amount of energy and protein. Although the soil and climatic condition of the study area are favourable for maize production but it's per hectare grain yield is very low. Low yield is due to many constraints but soil fertility reduction is considered one of the major factors.

Due to negative balances of N and P both in low- and highlands of Wolaita area of southern Ethiopia (Elias, 2004) crops respond well to the fertilization of these nutrients (Beyene *et al.*, 2001). Soils of this region were deficient for most of the nutrients viz. P, Fe, Cu, Mn and Zn (Mulugeta, 2006; Alemayehu, 2007). The proper understanding of the nature and properties of the soils and their management according to their potentials are imperative for maximization of crop production to the potential limits (Abayneh and Brehanu, 2006). Hence, assessment of soil fertility is of considerable importance to determine the factors that limit yield and to take remedial measures.

Because of the dynamic characteristic of soils when any element or material is added to the soil, it is subjected to changes due to the physical, chemical and biological reactions taking place in the soil. For this reason, it is logical to expect that the plant availability, of not only an added element but of elements already present in the soil, may change (John and Venugopal, 2005). Sound knowledge about nutrient sorption properties in soil under different soils is necessary in sustained use of soil for crop production (Moazed *et al.*, 2010). Soil test generally over estimates the nutrient content and analysis of associated plant tissue can be considered as quick and reliable technique for assessing the available status of nutrients (Mari *et al.*, 2006).

The systematic approach for determining soil nutrient status can be used to develop a soil nutrient balance that becomes the basis of soil analysis and fertilizer recommendations (Portch, 1988). This approach provides preliminary information on soil nutrient status and identifies the magnitude of existing nutrient limitations in a cost effective manner (Lifang *et al.*, 2000). Therefore, in this research soil fertility diagnostic technique developed by Agro Services International (ASI), including soil testing, nutrient sorption study and pot experiments to verify the results of soil testing was used.

In order to set priorities for future soil fertility, it is important to identify the most limiting nutrients. Thus, this study was initiated to identify the most growth limiting nutrient (s) in Alfisols of Delbo Atwaro watershed, compute plant response to added nutrients and generate data for optimal fertilizer recommendation under filed conditions.

MATERIALS AND METHODS

Description of the study sites: Greenhouse experiment was conducted in 2007 and 2008 at the National Soil Testing Center on soil samples collected from Delbo Atwaro watershed, located at 12 km east of Sodo town in Wolaita Zone of the Southern Nations, Nationalities and Peoples' Regional State. The latitude, longitude and altitude ranged between 6° 54.349 and 6° 54.628 N, 37° 50.388 and 37°50.589 E and 2098 to 2116 masl for the watershed. According to Sodo meteorology center the long term mean annual precipitation and temperature were 1340 mm and 19.9°C, respectively.

Soil sampling and sample preparation: The dominant soil type from the watershed, Alfisols (Alemayehu, 2007) was selected for this study. About 30 sub samples at 0-30 cm depth was collected randomly from dominant homogenous arable lands and one composite sample was made. A total of 500 kg of soil sample was taken for greenhouse experiment and laboratory analyses. Soil samples were air-dried in a dust free area, the portions to be used for pot experiment was desegregated and crushed to pass a 5 mm sieve and the remaining to be used for physicochemical analyses was ground to pass a 2 mm sieve. The soil samples were ground to pass a 0.5 mm size sieve for the determinations of organic carbon and total nitrogen.

Soil analysis: Composite samples were analyzed for particle size by the modified sedimentation hydrometer procedure (Bouyoucos, 1951); soil pH and EC in 1:2.5 soil: water mixture (Schofield and Taylor, 1955); organic carbon (Walkley and Black, 1934); total N (Bremmer and Mulvaney, 1982); available phosphorus (Olsen and Sommers, 1982); CEC and exchangeable bases (Ca, Mg, K and Na) 1 M ammonium acetate (pH 7) method (Van Reeuwijk, 1993); SO_4-S by KH_2PO_4 extractant (Johnson and Fixen, 1990); DTPA-extractable Fe, Mn, Zn and Cu by Lindsay and Norwell (1978) and water-soluble boron by hot water extraction (Sippola and Ervio, 1977).

Sorption studies of nutrient elements: Soil analysis revealed that the concentrations of P, Cu, B, K and S were less than three folds of their respective critical levels. Thus, the sorption studies of P, K, S, Cu and B were carried out in duplicate bottles with 5 treatments and 2 controls. Five gram soil saturated with 5 mL of the sorption treatments solution in bottles and 5 mL distilled water in control left for few hours to create anaerobic conditions, gently shaken for complete mixing and the soil was air dried. This system of wetting and drying allows the element to react with the soil under moisture regimes ranging from complete saturation to air dry and simulates the kind of reactions which may be expected to take place under field condition in a short period (Hunter, 1980). Air dried samples were extracted and analyzed for P, K, S, Cu and B using standard procedures, as outlined under the soil analysis section.

Sorption curve was prepared for each element by plotting the amount of element extracted against the amount added and was used to determine the amount of element to be added as a treatment in the greenhouse experiment.

Greenhouse experiment: Except for N and Mo, the optimum treatment for each element was based on the soil analysis. The necessary amounts of each element to build up to three folds of the respective critical levels were added. The critical levels considered in the study were 12, 121, 10, 1, 0.5, 0.4 and 0.5 mg kg^{-1} soil for P, K, S, Mn, Zn, Cu and B, respectively (Havlin *et al*., 1999).

Accordingly, the amounts of nutrient elements added to the optimum treatment were: 130 mg P, 30 mg K, 20 mg S, 3.0 mg Cu and 1.0 mg B per kg soil. N was added at the rate of 500 mg kg^{-1} soil. Although molybdenum was not added to the optimum treatment, its status was checked by a special treatment similar to the other elements. To determine the status of each essential element and the fertility status of the original soil 19 treatments were selected (Table 1). The treatments received similar additions of elements as that of the optimum treatment except the element to be tested, either by leaving the element or by adding the amount indicated in Table 1. The rates of adding elements to the optimum treatment plus the element being tested were according to Hunter (1980).

Greenhouse experiment was conducted with 19 treatments quadruplicated in completely randomized design. Five kg soil was incubated at optimal temperature and moisture with required amounts of stock nutrient solutions, mixed thoroughly and transferred to plastic pots (19×19×21 cm). Four seeds of maize (*Zea mays*, BH-540) were sown in each pot and thinned to 2 plants at two leaves stage. The soil was moistened with distilled water approximately to 60% field capacity at planting, whereas it was maintained at field capacity during the experimental period by watering whenever needed.

Table 1: Treatment descriptions and amount of element added to each treatment on alfisol

Treatment No.	Treatment description	Amount of element added to the treatments (mg kg^{-1} soil)
1	Check	None
2	Opt.	N (500), P (130), K (30), S (20), Cu (3) and B (1).
3	Opt.-N	
4	Opt.-P	
5	Opt.+P	P (100)
6	Opt.-K	
7	Opt.+K	K (80)
8	Opt.+Ca	Ca (400)
9	Opt.+Mg	Mg (240)
10	Opt.-S	
11	Opt.+S	S (60)
12	Opt.+Fe	Fe (20)
13	Opt.+Mn	Mn (30)
14	Opt.+Zn	Zn (10)
15	Opt.-Cu	
16	Opt.+Cu	Cu (4)
17	Opt.-B	
18	Opt.+B	B (2)
19	Opt.+Mo	Mo (2)

Opt.: Optimum treatment, Opt. +: Optimum treatment plus the indicated element, Opt. -: Optimum treatment without the indicated element

Height of 6 weeks-old plants was recorded and the plants were harvested and separated into shoots and roots. The shoots and roots were dried at 70°C to constant weights after washing them with 0.001 M HCl, tap water and finally with distilled water. Dry shoot and root weights were measured. The dry shoot plant material was finely ground using stainless steel grinder and passed through 1 mm mesh sieve for chemical analysis.

Plant analysis: Plant samples were analyzed for N by wet-oxidation method of the modified Kjeldahal procedure (Nelson and Sommers, 1973) and K, Ca, Mg, Mn, Fe, Cu and Zn following dry ashing method (Wolf, 1982). The determination of K was carried out using flame photometer, whereas the other cations were measured by AAS. Phosphorus in the digest aliquot obtained through calcinations was determined colorimetrically by molybdate and metavanadate method and sulfur by magnesium nitrate dry ashing (Wolf, 1982). Boron in the plant samples was measured colorimetrically using Azomethine-H by dry ashing with CaO (Sippola and Ervio, 1977).

Statistical analysis: The collected data were analyzed statistically by using Fisher's analysis of variance technique and Least Significant Difference test (LSD) (Steel and Torrie, 1984). Least significant difference test at 1 and 5% probability level were used to compare the significance of treatments means on plant height, fresh weight, dry weight and nutrient uptakes.

RESULTS AND DISCUSSION

Physico-chemical characteristics: The textural class of the surface soil was loam with high silt to clay ratio (1.5) indicating that the soil is not highly weathered. According to Atengo (2005), low silt to clay ratio is used as an index of advanced stage of soil development. Buol *et al*. (2003) also

Table 2: Physico-chemical characteristics of the surface soils of the study areas

Soil characteristics	Alfisols	Soil characteristics	Alfisols
Sand (%)	34	CEC (cmol (+)/kg soil)	22.50
Silt (%)	39	Base Saturation (%)	67.00
Clay (%)	26	K Mg^{-1}	0.40
Textural class	Loam	Ca Mg^{-1}	6.10
pH in water (1:2.5)	6.0	Av. P (mg kg^{-1} soil)	3.64
EC (1:2.5) ds m^{-1}	0.05	Av. K (mg kg^{-1} soil)	329.00
Organic carbon (%)	2.08	Av. S (mg kg^{-1} soil)	21.93
Total N (%)	0.18	Fe (mg kg^{-1} soil)	10.81
C: N ratio	12	Mn (mg kg^{-1} soil)	41.06
Na (cmol(+)/kg soil)	0.12	Zn (mg kg^{-1} soil)	16.56
K (cmol(+)/kg soil)	0.84	Cu (mg kg^{-1} soil)	0.39
Ca (cmol(+)/kg soil)	12.06	B (mg kg^{-1} soil)	0.64
Mg (cmol(+)/kg soil)	1.96		

pointed out that high clay content is an indication of complete alteration of weatherable minerals into secondary clays and oxides.

The soil was slightly acidic (pH: 6) with low organic carbon and total nitrogen contents (Table 2) in accordance with the ratings of Landon (1991). These low contents of Total Nitrogen (TN) and Organic Carbon (OC) could be attributed to the effect of intensive and continuous cultivation that aggravated OC oxidation. Research findings revealed that cultivation of the land results in reduction of organic carbon and total nitrogen (Saik *et al.*, 1998; Negassa and Gebrekidan, 2003). Kebede and Laktionov (1996) also reported that intensive cultivation of Nitosols at Holetta decreased its organic carbon content as compared to the uncultivated counter part of the same soil.

The Cation Exchange Capacity (CEC) of the soil was medium (Landon, 1991) and the exchange complex was saturated with Ca (54%) and Mg (9%) as the main adsorbed cations. Concentrations of exchangeable cations (Table 2) followed the order of Ca>Mg>K>Na. This might have resulted from the strong energy of adsorption of Ca making it typically more abundant as an exchangeable cation than are Mg, K or Na. Ca and Mg concentrations in the soil were adequate for crop production and response for Ca and Mg fertilizers may not be expected. In addition, the Percent Base Saturation (PBS) value was 67% indicating good fertility status of the soil. However, exchangeable K content of the soil was less than three times its critical value (121 mg kg^{-1} soil) showing the probability of crop response to K additions.

Available phosphorus content (3.65 mg kg^{-1} soil) was very low. Although the Bray-1 and Olsen and Sommers (1982) soil P tests were developed for acidic and calcareous soils, respectively, Olsen and Sommers (1982) method was used to quantify plant available P, as it was recommended for all types of Ethiopian soils (Mamo and Haque, 1991). The low availability of P may be due to the inherent P deficiency of the soil and P fixation. Application of P fertilizer is, therefore, required for optimum crop production. The result is in agreement with the study of Tigist (2007). Kena *et al.* (1996) have confirmed that available P content of most soils in the region is less than 5 mg kg^{-1} which is in the range of low P content. The available sulfur content (21.93 mg kg^{-1} soil) was below the critical value (30 mg S kg^{-1} soil) could be considered as one of the limiting factors for crop production.

The status of micronutrients, except that of boron, was in the order of Mn>Zn>Fe>Cu (Table 2). The availability of Mn, Zn and Fe was sufficient to meet crop needs. However, the concentration of Cu was below the critical value, indicating that copper is likely one of the yield limiting nutrients in the soil. This is in agreement with the finding of Beyene (1983), Atengo (2005), Mulugeta (2006) and Alemayehu (2007) who reported Cu to be deficient in the soils of the region.

The available boron content (0.64 mg kg^{-1}) was sufficient for crops growing on the soil, as it was higher than its critical value. However, owing to the coarse soil texture and thereby high leaching of B in such humid region (Gupta, 1985) the B content the soil is relatively lower than that of the nearby Ultisols (Wondwosen, 2008).

Sorption characteristics of the experimental soils: The amounts of P, Cu and B retention, as percent of the applied nutrients were 75-83, 63-69 and 3-46, respectively. The sorption results indicated that P and Cu were highly fixed by the soil. Similar results were recorded by Naseri *et al.* (2010), Mehdi *et al.* (2007) and Ayub *et al.* (2002). The clay mineralogy and presence of oxides and hydroxides of Fe and Al could have been the dominant factors affecting P and Cu sorption. High sorption of phosphate by amorphous materials and oxides and hydroxides of iron and aluminium have been reported by Fitter (1974) and Sertsu and Ali (1983). Owing to low pH (Table 1) and dominance of kaolinite mineral, B was not fixed by the soil. Increasing pH, clay content, organic matter and presence of Al compounds favor H_4BO_4- adsorption.

The sorption curves of S and K indicated their low fixation which is attributed to weak strength for sulphate retention (Mengel and Kirkby, 1987) and kaolinite to be the dominant clay mineral in the soil. Potassium fixation predominantly occurs in soils high in 2:1 clays and with large amounts of illite as a result of reentrapment of K^+ ions between the layers of the 2:1 clays indicating that 1:1 minerals such as kaolinite do not fix K.

Plant height and biomass yield: Results of plant height and shoot and root weights showed that missing of some nutrients had significantly ($p = 0.001$) affected the growth dry matter yield of maize (Table 3). Comparison of the mean values of plant height and shoot and root dry weights showed that the lowest values were obtained from the control and treatments without N and P. The yield of shoot dry weight in the control and treatments without N and P were reduced by 87, 80 and 76%, respectively, as compared to the optimum treatment.

The biological yields indicated that N and P, in that order, were limiting nutrients to support good crop growth implying that the soil was inherently poor in N and P status and external supply of N and P fertilizers are required to support plant growth and yield. This is in line with the low OC, TN and available P contents of the experimental soil (Table 2). Similar results were reported in Nitisols of Agaro, Metu and Tepi and Acrisols of Haru (Zebene and Wondwosen, 2007). According to Beyene *et al.* (2001) most soils in the central part of southern Rift Valley including the Wolaita area are highly responsive to commercial fertilizers, especially N and P fertilizers. Haile and Belayneh, 1986 also reported high response of different crops to applied N and P.

Although the amounts of Cu, B, K and S were less than three folds of their respective critical values (Table 2) neither their omission in the pot experiment nor application above the optimum treatment resulted no significant yield variation on plant height and shoot and root dry weights as compared to the optimum treatment (Table 3). In addition, application of Ca, Mg, Mn, Zn, Mo and Fe did not also bring significant increases in these parameters as compared to the optimum treatment (Table 3) owing to the high contents of these nutrients in the experimental soil

Table 3: Plant height, shoot and root dry weights of maize as influenced by treatments on alfisols

Treatment types	Shoot dry weight	Root dry weight	Plant height (cm)
	---(g pot^{-1})---		
Check	6.4^b	5.9^b	6.2^b
Optimum	48.2^a	20.1^a	34.1^a
Opt. -N	9.9^b	8.7^b	9.3^b
Opt. -P	11.6^b	8.7^b	10.1^b
Opt. +P	44.1^a	20.0^a	32.0^a
Opt. -K	46.7^a	20.7^a	33.7^a
Opt. +K	46.3^a	21.2^a	33.7^a
Opt. +Ca	44.0^a	22.0^a	33.0^a
Opt. +Mg	44.4^a	21.7^a	31.5^a
Opt. -S	44.8^a	21.4^a	33.1^a
Opt. +S	49.2^a	20.5^a	34.8^a
Opt. +Fe	49.1^a	19.9^a	34.5^a
Opt. +Mn	47.5^a	20.2^a	33.9^a
Opt. +Zn	45.2^a	20.1^a	32.6^a
Opt. -Cu	44.8^a	20.4^a	32.6^a
Opt. +Cu	47.6^a	20.6^a	34.1^a
Opt. -B	46.9^a	21.0^a	33.9^a
Opt. +B	47.3^a	20.4^a	33.8^a
Opt. +Mo	47.1^a	21.1^a	34.1^a
LSD (0.01)	7.931	4.289	4.591
CV (%)	10.37	12.20	8.24
Significance	***	***	***

Means within a column followed by similar letter are not significantly different at p = 0.01, *** Significant at the 0.001 probability level

(Table 2) and revealing that Ca, Mg, Mn, Zn, Mo and Fe were sufficient for crop production. Addition of S and Cu gave higher responses compared to those S-and Cu-omitted treatments, respectively (Table 3) although the dry matter yields were not statistically significant from the optimum treatment.

Nutrients uptakes and concentrations

Macronutrients: Uptake and concentrations of N and P in maize plants were significantly ($p \le 0.001$) enhanced due to their application (Table 4). The N and P uptakes and concentrations in plant materials of N-and P-omitted treatments, respectively, were very low as compared to the other treatments, reflecting of poor dry matter production (Table 3) and signifying these nutrients to be limiting in the soil in line with the low OC, TN and available P contents of the soil (Table 2). Omission of N and P increased the concentration of P and N in the respective treatments due to reduced dry matter under nutrient stress as a result of Steenberg effect (Jones, 1998). Due to the low dry matter yields, however, the uptakes of these elements in the respective treatments were also very low.

Differences in nutrient uptake were better explained by dry matter production rather than nutrient concentration in the shoot due to the dramatic dry matter yield responses to applied N and P fertilizers (Table 3). The correlations between these two elements and others considered in the study were also very high indicating that their supply should be balanced by adequate availability of other nutrients for optimum growth and development (Mengel and Kirkby, 1987)

Table 4: Macronutrients uptake and concentrations in maize shoot as influenced by treatments

	Concentration (%)						Uptake (g pot^{-1})					
Treatment types	N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S
Check	1.26^{c}	0.21^{b}	3.63^{b}	0.36^{c}	0.11^{de}	0.13^{bc}	0.08^{d}	0.01^{b}	0.23^{f}	0.02^{c}	0.01^{d}	0.008^{c}
Optimum	2.69^{b}	0.28^{a}	2.77^{cde}	0.46^{bc}	0.25^{bc}	0.17^{ab}	1.30^{ab}	0.13^{a}	1.34^{abc}	0.22^{b}	0.12^{bc}	0.084^{a}
Opt. -N	0.85^{d}	0.28^{a}	3.90^{b}	0.35^{c}	0.11^{e}	0.10c	0.08^{d}	0.03^{b}	0.39^{ef}	0.04^{c}	0.01^{d}	0.010^{c}
Opt. -P	3.47^{a}	0.14^{c}	4.72^{a}	0.54^{ab}	0.21^{bcde}	0.19^{a}	0.40^{c}	0.02^{b}	0.55^{e}	0.06^{c}	0.02^{d}	0.022^{c}
Opt. +P	2.70^{b}	0.30^{a}	2.92^{cde}	0.44^{bc}	0.21^{bcd}	0.17^{ab}	1.19^{b}	0.13^{a}	1.29^{abc}	0.19^{b}	0.09^{bc}	0.076^{a}
Opt. -K	2.84^{b}	0.30^{a}	2.18^{f}	0.47^{bc}	0.27^{bc}	0.18^{ab}	1.33^{ab}	0.14^{a}	1.02^{d}	0.22^{b}	0.13^{bc}	0.082^{a}
Opt. +K	2.79^{b}	0.29^{a}	3.02^{c}	0.48^{bc}	0.27^{bc}	0.18^{ab}	1.29^{ab}	0.13^{a}	1.40^{ab}	0.22^{ab}	0.13^{bc}	0.085^{a}
Opt. +Ca	2.84^{b}	0.30^{a}	2.60^{cdef}	0.65^{a}	0.30^{b}	0.18^{ab}	1.25^{ab}	0.13^{a}	1.14^{cd}	0.29^{a}	0.13^{bc}	0.079^{a}
Opt. +Mg	2.77^{b}	0.28^{a}	2.53^{cdef}	0.44^{bc}	0.44^{a}	0.17^{ab}	1.23^{ab}	0.12^{a}	1.12^{cd}	0.20^{b}	0.20^{a}	0.077^{a}
Opt. -S	2.58^{b}	0.28^{a}	2.72^{cdef}	0.41^{bc}	0.23^{bc}	0.10^{c}	1.15^{b}	0.12^{a}	1.22^{bcd}	0.18^{b}	0.10^{bc}	0.046^{b}
Opt. +S	2.72^{b}	0.26^{ab}	2.43^{def}	0.45^{bc}	0.23^{bc}	0.20^{a}	1.34^{ab}	0.13^{a}	1.19^{bcd}	0.22^{b}	0.11^{bc}	0.091^{a}
Opt. +Fe	2.90^{b}	0.27^{a}	2.96^{cd}	0.36^{c}	0.18^{cde}	0.16^{abc}	1.42^{a}	0.13^{a}	1.46^{a}	0.18^{b}	0.09^{c}	0.077^{a}
Opt. +Mn	2.81^{b}	0.29^{a}	2.70^{cdef}	0.42^{bc}	0.23^{bc}	0.20^{a}	1.34^{ab}	0.14^{a}	1.28^{abc}	0.20^{b}	0.11^{bc}	0.093^{a}
Opt. +Zn	2.73^{b}	0.30^{a}	2.78^{cde}	0.44^{bc}	0.25^{bc}	0.18^{ab}	1.23^{ab}	0.13^{a}	1.25^{abcd}	0.20^{b}	0.11^{bc}	0.082^{a}
Opt. -Cu	2.65^{b}	0.28^{a}	2.62^{cdef}	0.45^{bc}	0.22^{bc}	0.17^{ab}	1.18^{b}	0.12^{a}	1.17^{bcd}	0.20^{b}	0.10^{bc}	0.076^{a}
Opt. +Cu	2.71^{b}	0.28^{a}	2.75^{cde}	0.41^{bc}	0.23^{bc}	0.19^{a}	1.29^{ab}	0.13^{a}	1.31^{abc}	0.20^{b}	0.11^{bc}	0.093^{a}
Opt. -B	2.77^{b}	0.29^{a}	2.51^{cdef}	0.42^{bc}	0.26^{bc}	0.17^{ab}	1.30^{ab}	0.14^{a}	1.18^{cd}	0.20^{b}	0.12^{bc}	0.081^{a}
Opt. +B	2.74^{b}	0.28^{a}	2.48^{cdef}	0.47^{bc}	0.31^{b}	0.18^{ab}	1.30^{ab}	0.13^{a}	1.17^{cd}	0.22^{ab}	0.15^{ab}	0.083^{a}
Opt. +Mo	2.79^{b}	0.28^{a}	2.42^{def}	0.42^{bc}	0.24^{bc}	0.17^{ab}	1.32^{ab}	0.13^{a}	1.14^{cd}	0.20^{b}	0.11^{bc}	0.080^{a}
LSD (0.01)	0.372	0.06	0.55	0.133	0.103	0.06	0.234	0.028	0.23	0.061	0.055	0.02
CV (%)	7.60	12.07	10.22	16.15	23.49	15.40	11.22	12.88	11.19	17.78	28.53	15.12
Significance	***	***	***	***	***	***	***	***	***	***	***	***

Means within a column followed by similar letter are not significantly different at p = 0.01, *** Significant at the 0.001 probability level

Potassium uptake and concentration in the plants were significantly ($p \leq 0.001$) increased due to K fertilizer application (Table 4). Potassium concentrations in the control as well as N-and P-omitted treatments were higher than the K-added treatments which might be due to dry matter reduction and accumulation of K in the plants. The finding is in agreement with the relatively low available K content of the soil (Table 2) indicating the possibility of having response to K application, particularly for sensitive crops in Delbo Atwaro. Tafesse (1990) has reported that at Wollega State farms, K-deficiency was observed in Alfisols subjected to intensive cultivation. Mesfin (1980) and Zebene and Wondwosen (2007) have also indicated that some Ethiopian soils contain low levels of K and K is a limiting element next to P and N in such soils.

The uptakes and concentrations of Ca, Mg and S were significantly ($p \leq 0.001$) increased due to the applications of the respective elements (Table 4). However, the concentrations of the elements within the plant material were within the critical range for maize (Jones *et al.*, 1991) except that of N-and S-omitted treatments, showing that the soil had adequate Ca and Mg for crop production. The results are also in agreement with the high dry matter yields obtained in Ca- and Mg-omitted treatments (Table 3) and with the high level of exchangeable Ca and Mg contents of the soil (Table 2). Low concentration of S in control and S-omitted treatments (Table 4) could be due to inadequate soil available S (Table 2) indicating that the possibility of having response to S application particularly on sensitive crops.

Table 5: Micronutrients uptake and concentrations in maize shoot as influenced by treatments on alfisols

	Concentration					Uptake				
	Fe	Mn	Zn	Cu	B	Fe	Mn	Zn	Cu	B
Treatment types	(mg kg^{-1} dry weight)					(mg pot^{-1})				
Check	91^{de}	124^{gh}	52^{c}	3.1^{f}	12.4^{c}	0.58^{d}	0.79^{g}	0.33^{c}	0.02^{d}	0.08^{e}
Optimum	122^{bcd}	149^{fgh}	56^{c}	10.0^{abcd}	23.4^{b}	5.87^{bc}	7.16^{cdef}	2.72^{b}	0.48^{a}	1.13^{ab}
Opt.-N	74^{e}	106^{h}	47^{c}	7.2^{e}	22.6^{b}	0.73^{d}	1.05^{g}	0.47^{c}	0.07^{cd}	0.22^{de}
Opt.-P	158^{b}	137^{fgh}	73^{ab}	10.9^{a}	25.3^{ab}	1.83^{d}	1.59^{g}	0.85^{c}	0.13^{bc}	0.29^{de}
Opt.+P	108^{cde}	133^{fgh}	53^{c}	9.4^{abcd}	25.9^{ab}	4.74^{c}	5.85^{f}	2.34^{b}	0.41^{a}	1.14^{ab}
Opt.-K	114^{cd}	120^{gh}	62^{bc}	7.7^{de}	22.5^{b}	5.32^{bc}	5.62^{f}	2.92^{ab}	0.36^{ab}	1.05^{bc}
Opt.+K	124^{bcd}	170^{def}	54^{c}	9.6^{abcd}	23.3^{b}	5.75^{bc}	7.87^{cdef}	2.51^{b}	0.45^{a}	1.08^{b}
Opt.+Ca	121^{bcd}	215^{bc}	52^{c}	8.0^{cde}	27.1^{ab}	5.30^{bc}	9.47^{bc}	2.27^{b}	0.35^{a}	1.19^{ab}
Opt.+Mg	98^{cde}	200^{bcd}	55^{c}	8.8^{abcd}	25.6^{ab}	4.37^{c}	8.88^{bcd}	2.43^{b}	0.39^{a}	1.14^{ab}
Opt.-S	132^{bc}	152^{efg}	54^{c}	8.3^{bcde}	22.0^{b}	5.90^{bc}	6.81^{def}	2.44^{b}	0.37^{a}	0.98^{bc}
Opt.+S	124^{bcd}	174^{cdef}	56^{c}	9.4^{abcde}	22.7^{b}	6.11^{bc}	8.56^{bcde}	2.75^{b}	0.46^{a}	1.12^{b}
Opt.+Fe	220^{a}	218^{b}	62^{bc}	9.9^{abcd}	23.2^{b}	10.80^{a}	10.73^{ab}	3.03^{ab}	0.49^{a}	1.14^{ab}
Opt.+Mn	159^{b}	263^{a}	57^{c}	9.4^{abcde}	25.4^{ab}	7.55^{b}	12.51^{a}	2.71^{b}	0.44^{a}	1.21^{ab}
Opt.+Zn	133^{bc}	193^{bcde}	83^{a}	10.5^{abc}	25.8^{ab}	6.02^{bc}	8.70^{bcde}	3.72^{a}	0.47^{a}	1.16^{ab}
Opt.-Cu	122^{bcd}	134^{fgh}	57^{bc}	4.4^{f}	21.6^{b}	5.45^{bc}	6.01^{f}	2.56^{b}	0.20^{c}	0.97^{bc}
Opt.+Cu	116^{cd}	138^{fgh}	57^{bc}	10.7^{ab}	23.2^{b}	5.53^{bc}	6.57^{def}	2.74^{b}	0.51^{a}	1.11^{b}
Opt.-B	111^{cde}	139^{fgh}	56^{c}	7.7^{de}	13.5^{c}	5.22^{bc}	6.52^{ef}	2.62^{b}	0.36^{a}	0.63^{cd}
Opt.+B	116^{cd}	152^{efg}	60^{bc}	8.3^{bcde}	32.2^{a}	5.46^{bc}	7.16^{cdef}	2.84^{ab}	0.39^{a}	1.52^{a}
Opt.+Mo	115^{cd}	143^{fgh}	50^{c}	10.2^{abcd}	22.5^{b}	5.43^{bc}	6.72^{def}	2.36^{b}	0.48^{a}	1.06^{b}
LSD (0.01)	39.79	43.53	16.45	2.57	7.45	2.37	2.45	0.95	0.065	0.42
CV (%)	17.02	14.34	20.13	15.88	17.07	24.29	19.18	21.6	21.02	23.14
Significance	***	***	*	***	***	***	***	***	***	***

Means within a column followed by similar letter are not significantly different at $p \leq 0.01$, *, *** Significant at the 0.05, 0.001 probability levels, respectively

Micronutrient uptake and concentrations: The uptakes and concentrations of Fe, Mn, Zn, Cu and B in the plant material were significantly ($p \leq 0.001$) increased due to application of the respective elements (Table 5). The concentrations of Fe, Mn, Zn and B were found to be within the critical range for maize at the stage of harvesting and significant differences in dry matter yields were not obtained by omitting each element as compared to the optimum treatment (Table 3) indicating the existence of adequate amounts of these elements for crop production. These findings are also in agreement with the high available Mn, Zn, B and Fe levels in the soil (Table 2). The report of Dibabe *et al.* (2007) also showed high available Mn in different zones of the country.

Copper concentration in check plants and those of Cu-omitted treatments were found to be below the critical value. This could be attributed to the very low available Cu content of the soil (Table 2) indicating that there might be a response to Cu particularly on sensitive crops. The growth parameters did not however, show response to copper application which might partly be due to the short duration, as the critical period in copper-deficient plants is the early booting stage at the onset of pollen formation (Marschner, 1993). Studies by Dibabe *et al.* (2007) also revealed the deficiency of copper in different soil types of Ethiopia when determined by the chemical analysis, but no response of plant height, dry matter yield and concentration of nutrients in pot experiment.

Addition of Mo to the optimum treatment did not result in significant differences in biological yields, nutrients uptakes and concentrations within the plant material as compared to the optimum treatment, without Mo. Therefore, it could be concluded that the Mo contents of the experimental soils are adequate for crop production.

CONCLUSIONS

Low soil fertility as a result of excessive degradation and nutrient depletion are reported to be serious limitations to agricultural productivity. The results of the soil chemical analysis indicated that the amounts of total N, available P and available Cu were deficient, whereas B, S and K were less than three times their critical values. The sorption results also indicated that P and Cu are highly fixed.

The results revealed that the experimental soil was inherently poor in N and P status and external supply of N and P fertilizers are required to boost plant growth and production. Besides, Cu, K and S are also potentially limiting nutrients, whereas Ca, Mg, Mn, Zn, B, Mo and Fe were sufficient to support good crop growth. However, more detailed research and field experimentation are needed on N, P, Cu, K and S, as they were found deficient in plants and soil. In order to predict fertilizer requirements, the soil test for available P must be calibrated against crop response in field trials for the major crops grown in the area.

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