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Cations and Related Soil Variables as the Basis for Nutrients Management Strategies in Central Ethiopian Agricultural Soils - I

Assefa Menna[1*]

[1]*Debre Zeit Research Center, Ethiopian Institute of Agricultural Research (EIAR), P.O.Box-2003, Addis Ababa, Ethiopia.*

Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

The study was aimed at assessing the fertility status of soils with special emphasis on cation "concepts" and related physico-chemical variables as decision-support tools in making fertilizer recommendations. Thirty six soil samples collected from three representative locations, namely Arsi (Ar), East-Shewa (ES) and West-Shewa (WS) were considered. The results of the study showed that all the studied soils were salt-free or had no sodicity problems. But, the exchangeable aluminum (Al^{3+}) was detected in some 20.8% of the sites as a manifestation of strongly acidic soil reactions. In all studied soils, the exchangeable potassium (K^{+}) was adequate or even excess in some sites based on the suggested critical thresholds. Some 20.8% of the soils contained low levels of calcium (Ca^{2+}) with values falling below the suggested critical levels. Still some, 12.5% were marginal, leaving 66.7% of the sites to be safe from Ca nutritional problems. Hence, Ca was found to be dominating the soil-colloids, particularly, in the ES zone. Similarly, magnesium (Mg^{2+}) appeared to be deficient in strongly acidic soils (29.2% of the sites). The excess levels of Ca^{2+}, K^{+} and even Mg^{2+} were observed in the alkaline soils sampled from ES. In fact, sandy and strongly acidic soils tend to have relative lower levels of the cations, Mg^{2+} and Ca^{2+}. The overall study revealed that, in addition to the previously reported deficient macronutrients: nitrogen (N), phosphorus (P) and sulfur (S); Mg was also found to be limiting element in some areas followed by

**Corresponding author: E-mail: assefams@yahoo.com;*

Ca. From the micronutrients: boron (B), zinc (Zn), molybdenum (Mo) and iron (Fe) were found to be the most limiting in the studied soils, all in the decreasing order of importance. Therefore, it is suggested that the deficient amounts of nutrients need to be applied and/or formulated for the specific sites, if soil- and plant analytical data are available.

Keywords: Cations; physico-chemical variables; nutrient balance; exchangeable acidity; agro-ecological zones.

1. INTRODUCTION

Shrinking landholding due to an alarmingly increasing population pressure is among the major causes for the declining agricultural production and productivity in Ethiopia, and this is negatively affecting its growth domestic product (GDP). Fragmented landholdings thus impede natural resources management, particularly, soil fertility; and related conventional farming practices. The land tilled by small-scale farmers accounts for 95% of total area under agriculture, and these farmers are responsible for more than 90% of total agricultural output [1]. According to the report, close to 10% of the country's land area is under cultivation and the sector employs about 85% of population, generating over 46% of the GDP and 80% of export earnings. Though the sector is playing significant role in improving food security, even today there's not that much difference in those figures, almost after two decades. Due to such factors, the country is reported to have the highest rates of soil nutrients depletion in the sub-Saharan Africa (SSA), with soil erosion estimated to average 42 tons per hectare per year [2]. These trends are still on rise and have degraded the natural resource base, the soil and threatening sustainable agriculture. In Ethiopia, soil degradation is mainly due to intensive cropping, overgrazing and unsustainable land-use and climate change which further aggravate the loss of soil health and/or its quality making it unfavorable for cropping [2].

Among the soil degradation processes, the nutrient depletion and the decrease in cation retention capacity that results in cation imbalances; and the reduction in total and biomass carbon are the major ones. This is a continuous process, and has become an important factor affecting food and nutrition security in the country. A. Menna et al. [3,4] reported that, N, P, and S were among the most limiting elements in central Ethiopian agricultural soils. The soils were also reported to be poor in soil organic carbon (SOC); and the micro-nutrients B, Zn, Mo and Fe. Some Vertisols in central locations of the country have high nutrients fixing characteristics. For example, despite its low levels, lack of response to applied P is observed in some areas. This might be due to the deficiency of nutrients other than the aforementioned ones. This necessitates the generation of information on the fertility status of soils for predicting the productivity of crops grown. In view of the above background, the objective(s) of this study was, therefore, to assess the fertility status of soils with emphasis on cations and their related physico-chemical variables.

2. MATERIALS AND METHODS

The study was carried out in Arsi, East-Shewa and West-Shewa zones, representing different agro-ecological zones (AEZs) and soil types. In each of the three locations, eight representative fields or sites were selected for making soil fertility assessment (chemical and physical) in two annual cropping seasons. The 24 farmers' fields were geo-referenced using Global Positioning System (GPS)-GARMIN model number-60 assisted by Google earth (2011). The sites were classified by elevation, size and soil-types when known and mapped. The locations and salient features of the sites are presented in Table 2a and 2b, and Fig. 1.

2.1 Soil Sample Preparation and Analysis

The 18 surface soil samples (0-20 cm depth) were collected in 2013-14. The other 18 soil samples (0-20, 20-40 and 40-60 cm depths) were collected in 2015-16. Both sets of samples were taken before planting the annual crops like wheat and faba bean (Table 2a and 2b).

In the second season, three fields, namely GS2, Ke2 and NS2 were selected based on the experimental conditions in the first season. Whereas WG/Do2, Bk2 and BT2 were selected randomly without pre-soil testing, but on areas approximately 0.5-1.5 miles away from first season's S responsive sites for wheat: Do1, Bk1 and BT1 respectively. In both seasons, randomized complete block (RCBD) was used as an experimental design, and was replicated three times. All soil samples were taken from 10 spots per block and bulked together to make a composite sample per farmer field and soil depths.

The disturbed samples were then air-dried immediately in dry-rooms to avoid SO_4^{2-} formation from organic matter (OM), ground and sieved to pass through 1 mm. The soil samples, then, were analyzed for pH, electrical conductivity (EC), exchangeable bases, cation exchange capacity (CEC), saturation percent (SP) or percent base saturation (BS), total nitrogen (TN), organic carbon (OC), available P, sulfate sulfur (SO_4-S), exchangeable acidity, soil textural classes. The contents of Cu, Mn, Fe, Zn, B and Mo were also considered. In the selected soils samples, duplicate analysis was made using wet chemistry laboratories at Sokoine University of Agriculture (SUA), Tanzania; and Holeta and Debre Zeit research centers, EIAR, Ethiopia as per the methods outlined in Table 1.

3. RESULTS AND DISCUSSION

Table 2a and 2b present the base cations and some selected physico-chemical properties and/or their saturation percentages of soils sampled from typical agricultural lands. As shown, all the studied soils were varied in the contents of the variables, which could be attributable to the specific AEZs.

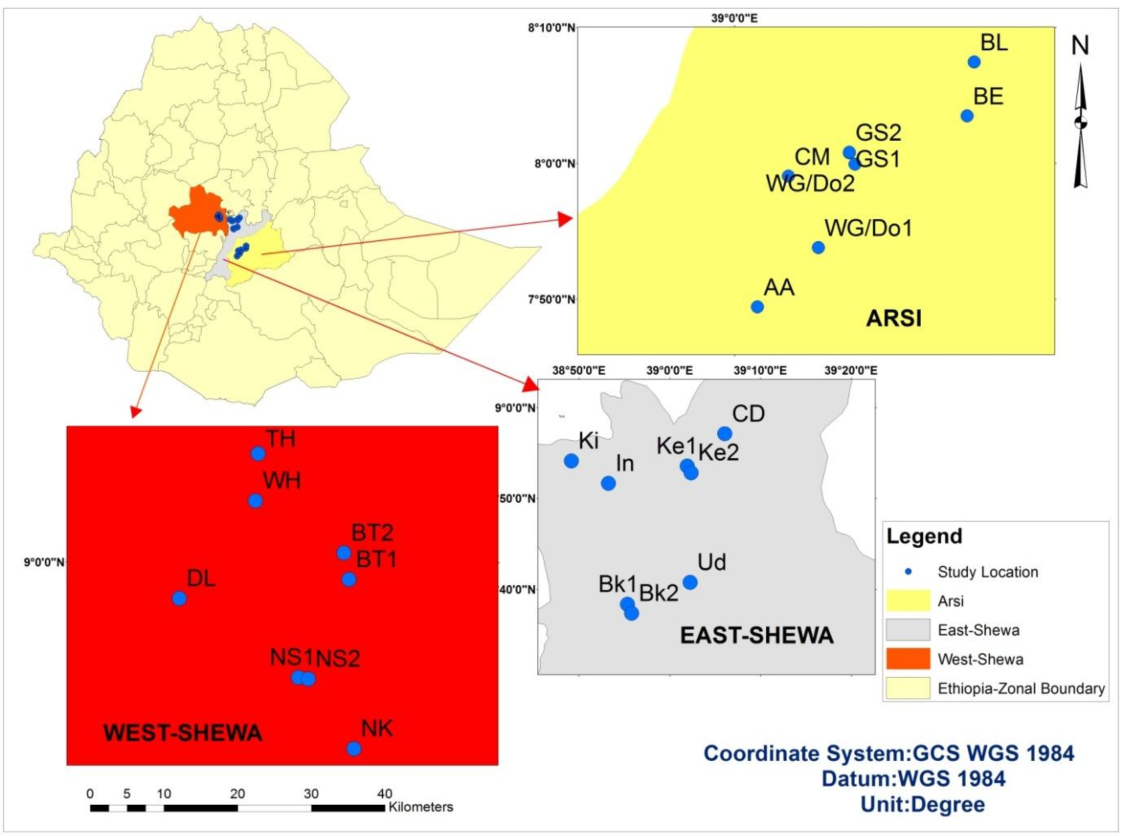

Fig. 1. Locations map showing study site-fields in Arsi, East- and West-Shewa zones

Key: 1 = Abosara Alko(AA); 2 = Dosha(Do1); 3 = Gora Silingo(GS1); 4 = Chefe Misoma(CM); 5 = Boneya Edo(BE); 6 = Boro Lencha(BL); 7 = Chefe Donsa(CD); 8 = Keteba(Ke1); 9 = Ude(Ud); 10 = Bekejo(Bk1); 11 = Insilale(In); 12 = Kilinto(Ki); 13 = Nano Kersa(NK); 14 = Nano Suba(NS1); 15 = Berfeta Tokofa(BT1); 16 = Dawa Lafta(DL); 17 = Wajitu Harbu(WH); 18 = Tulu Harbu(TH) (1st season). 19 = Wonji Gora(WG/Do2); 20 = GS2; 21 = Ke2; 22 = Bk2; 23 = NS2; and 24 = BT2 (2nd season). The numbers (1) and (2) indicate the information which was generated in 1st and 2nd seasons respectively

Table 1. The analytical method of some parameters of the studied soils

Parameters considered	Unit(s) of measurement	Extraction/Analytical method by:	References
pH	NA	Potentiometrically,1:2.5 soil:water solution	[5]
Total Exch. Acidity (H^+, Al^{3+})	$cmol_c$/kg	1.0M KCl & titration by 0.01M NaOH (@ pH:7.0)	[6]
Electrical Conductivity(EC)	$cmol_c$/kg	1:5 soil:water suspension	[7]
Exchangeable Bases (Na^+, K^+)	$cmol_c$/kg	1*M* NH4OAc solution, pH =7.00	[8]
Exchangeable Bases (Ca^{2+}, Mg^{2+})	$cmol_c$/kg	1*M* NH4OAc solution, pH =7.00	[9]
CEC	$cmol_c$/kg	1*M* NH4OAc solution, pH =7.00	[9]
Total Exchangeable Bases (TEB)	$cmol_c$/kg	Calculate from the exch. Bases	[10]
Saturation Percent (SP/BS)	%	Calculation from exch. Bases	[9]
Exchangeable Al^{3+}	$cmol_c$/kg	The difference between Exch. Al^{3+} and H^+	[11]
TN	%	Kjeldahl as described in	[12]
OC	%	Walkley-Black as described in	[13]
Available P	mg/kg	Bray-I, (pH<7.00)	[14]
Available P	mg/kg	Olsen, (pH>7.00)	[15]
SO_4-S	mg/kg	Calcium Ortho-Phosphate, Turbidimetric	[8]
Soil texture	NA	Hydrometer method	[16]

NA=not applicable

3.1 Soil pH

The pH showed important variations depending on soils and AEZs. It ranged from strongly to slightly acidic (4.85 to 6.71) in WS zone; to strongly acidic to almost neutral (5.30 to 6.98) in Arsi zone; though it was above 7.00 in ES. All the soils in ES zone were calcareous, with nodules of $CaCO_3$. The strongly acidic soils with pH less than 5.50 in some sites like in Arsi, and WS are considered to be not favorable for plant growth. But, still in a tolerable range for crops like wheat (its optimum range being 5.5 to 6.5). Such soils with pH less than 5.5 have great potentials to cause Al-toxicity; deficiencies of some nutrients to plant growth; retardation of bacterial activity and decomposition of OM [17]. However, individual plants and soil organisms reported to vary in their tolerance to both extremities of pH conditions [18). The pH of the soils in the present study falls within a range 4.5 to 8.5 reported by [17 and 18] for agricultural soils, even though most plants thrive well in soils with pH ranging from 6.5 to 7.5 [19]. Generally, both extremities of the soil pH conditions reported to present limitations to growing crops, particularly the availability of plant nutrients like P [20]. Therefore, maintenance of optimum soil pH is imperative for reducing the problems of soil nutrients unavailability.

3.2 Exchangeable Acidity (EA)

In first year(s), the exchangeable Al was detected in 16.7% of soils. In the subsequent year(s), it was detected similarly in only 11.1% of the soils. The overall values ranged from 0.75 to 2.17 $cmol_c$/kg; whereas the exchangeable acidity was ranged from 1.01 to 2.84 $cmol_c$/kg (Table 2a and 2b). The suggested critical thresholds (CTHs) for Al-toxicity were 1.0 $cmol_c$/kg [21]; and 2.0 $cmol_c$/kg [17]. Based on the former, only one soil sample was above this limit. Similarly, based on the latter, also only one soil sample was falling above the threshold value. The content of exchangeable acidity in this range can pose Al or Mn-toxicity in crops. The conditions can also be associated with Mo, Ca, Mg, P and K deficiencies and retardation of microbial activity [17]. Similar to pH, therefore, maintenance of optimum soil conditions is imperative for reducing soil nutrients unavailability problems.

Both exchangeable acidity and Al^{3+} decrease as one goes from surface to sub-surface soils. This may be due to the prolonged intensive leaching of the base cations (Na^+, K^+, Ca^{2+} and Mg^{2+}/adsorbed) from surface to sub-surface soils due to the observed high precipitation in the studied locations.

Table 2a. Physico-chemical properties of soils before planting (2013-16)

Ref. code	Zone	District	PA	Soil type	pH(1:2.5) (soil:H2O)	EC (dS/m)	CEC	BS	Ex. acidity	Ex. Al^{3+}	OC (%)	TN (%)	C:N (Ratio)	Exchangeable bases ($cmol_c$/kg)				TEB ($cmol_c$/kg)
							($cmol_c$/kg)	(%)	($cmol_c$/kg)	($cmol_c$/kg)				Ca^{2+}	Mg^{2+}	K^+	Na^+	
2013-14																		
1-a	Ar	Ti	AA	CV	5.95	0.10	23.80	63.20	na	na	1.11	0.13	8.85	10.74	2.70	1.56	0.04	15.04
2-a	Ar	Ti	Do1	RNi	5.30	0.10	24.30	42.48	1.47	1.14	2.04	0.25	8.09	7.55	1.44	1.10	0.23	10.32
3-a	Ar	Ti	GS1	CV	6.12	0.11	25.30	68.24	na	na	1.17	0.14	8.39	12.52	3.25	1.27	0.23	17.26
4-a	Ar	Ti	CM	Ni	6.94	0.18	31.60	71.83	na	na	2.75	0.13	20.70	13.76	5.64	3.02	0.28	22.70
5-a	Ar	Hi	BE	CV	6.19	0.13	27.80	64.03	na	na	2.77	0.20	13.66	11.45	4.03	2.09	0.23	17.80
6-a	Ar	Hi	BL	Ni	6.98	0.17	29.80	69.19	na	na	1.07	0.11	10.24	13.94	4.62	1.78	0.27	20.62
7-a	ES	Gi	CD	PV	7.91	0.19	45.01	96.64	na	na	0.90	0.06	14.23	33.90	7.33	1.89	0.38	43.50
8-a	ES	Ad	Ke1	PV	8.14	0.25	45.80	96.47	na	na	1.06	0.06	18.84	29.65	8.77	5.49	0.28	44.18
9-a	ES	Ad	Ud	PV	7.14	0.16	39.40	90.80	na	na	1.23	0.10	12.59	26.10	6.06	3.32	0.29	35.77
10-a	ES	Ad	Bk1	PV	7.33	0.18	34.40	93.39	na	na	1.31	0.07	18.76	23.97	5.28	2.40	0.47	32.13
11-a	ES	Ak	In	CV	7.15	0.18	31.40	92.65	na	na	1.35	0.10	13.80	21.13	5.58	2.09	0.28	29.09
12-a	ES	Ak	Ki	PV	8.02	0.24	47.80	95.23	na	na	1.39	0.06	24.86	32.48	8.53	4.18	0.32	45.52
13-a	OL	We	NK	CV	6.71	0.17	26.40	66.98	na	na	1.41	0.07	20.17	11.45	3.85	2.09	0.29	17.68
14-a	OL	We	NS1	RNI	5.65	0.07	15.00	53.73	na	na	1.47	0.13	11.68	3.48	1.21	1.99	0.19	6.86
15-a	OL	We	BT1	RNi	5.07	0.06	16.40	41.60	1.56	1.15	1.69	0.12	14.20	3.65	1.33	1.68	0.16	6.82
16-a	OL	We	DL	RNi	5.86	0.05	18.60	55.91	na	na	1.71	0.14	12.21	5.06	1.39	2.19	0.30	8.94
17-a	OL	We	WH	RNi	5.52	0.08	15.00	51.63	1.01	0.75	2.99	0.15	19.42	3.83	1.15	2.30	0.17	7.44
18-a	OL	We	TH	RNi	5.62	0.08	22.20	52.25	na	na	1.31	0.14	9.38	5.05	2.11	2.91	0.18	10.24
2015-16																		
19-a	Ar	Ti	WG/Do2	PV	5.36	0.08	32.60	42.22	1.77	1.35	2.71	0.21	12.92	5.11	2.62	2.19	0.47	10.39
19-b	Ar	Ti	WG/Do2	PV	6.26	0.15	32.91	55.02	1.45	1.24	2.41	0.11	21.91	5.21	2.82	2.29	0.54	10.86
19-c	Ar	Ti	WG/Do2	PV	6.76	0.18	31.94	62.22	1.37	1.14	2.06	0.11	18.73	5.35	4.92	2.45	0.67	13.39
20-a	Ar	Ti	GS2	Ni	6.24	0.11	26.80	55.24	na	na	2.18	0.17	12.96	6.11	3.20	1.14	0.34	10.80
20-b	Ar	Ti	GS2	Ni	6.63	0.16	27.28	61.24	na	na	1.97	0.11	17.62	6.35	3.45	2.29	0.42	12.50
20-c	Ar	Ti	GS2	Ni	6.75	0.19	26.94	65.24	na	na	1.67	0.11	14.87	6.75	4.20	4.14	0.34	15.44
21-a	ES	Ad	Ke2	PV	8.00	0.20	45.80	83.31	na	na	1.15	0.05	23.56	30.35	8.29	3.77	0.32	42.73
21-b	ES	Ad	Ke2	PV	8.10	0.26	44.99	90.23	na	na	0.80	0.03	25.08	31.08	8.35	4.44	0.36	44.22
21-c	ES	Ad	Ke2	PV	8.40	0.45	45.73	93.31	na	na	0.81	0.03	26.21	32.35	8.49	4.59	0.42	45.85
22-a	ES	Ad	Bk2	PV	7.15	0.10	33.40	71.26	na	na	1.17	0.08	15.25	19.72	5.22	2.50	0.34	27.78
22-b	ES	Ad	Bk2	PV	7.53	0.29	33.74	74.27	na	na	0.88	0.05	16.30	23.72	5.48	2.59	0.41	32.20
22-c	ES	Ad	Bk2	PV	7.64	0.44	33.46	83.19	na	na	0.79	0.05	14.48	24.77	5.69	2.63	0.45	33.55

Ref. code	Zone	District	PA	Soil type	pH(1:2.5) (soil:H2O)	EC (dS/m)	CEC	BS	Ex. acidity	Ex. Al^{3+}	OC (%)	TN (%)	C:N (Ratio)	Exchangeable bases ($cmol_c$/kg)				TEB ($cmol_c$/kg)
							($cmol_c$/kg)	(%)	($cmol_c$/kg)	($cmol_c$/kg)				Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	
23-a	OL	We	NS2	RNi	5.85	0.07	13.80	53.16	na	na	0.96	0.14	6.83	4.01	1.27	2.09	0.24	7.61
23-b	OL	We	NS2	RNi	5.93	0.21	13.87	55.23	na	na	0.64	0.07	9.16	4.24	1.37	2.19	0.28	8.08
23-c	OL	We	NS2	RNi	5.89	0.25	14.56	58.17	na	na	0.61	0.06	10.18	4.02	1.65	2.21	0.30	8.18
24-a	OL	We	BT2	PV	4.85	0.11	36.20	37.45	2.84	2.17	2.03	0.15	13.16	4.01	1.72	2.26	0.34	8.32
24-b	OL	We	BT2	PV	4.94	0.24	35.42	38.54	2.51	2.03	1.70	0.88	1.95	4.24	1.82	2.34	0.45	8.86
24-c	OL	We	BT2	PV	4.91	0.26	36.43	39.27	2.40	1.75	1.63	0.58	2.82	4.61	2.89	2.50	0.48	10.49

Key: Soil depth (a = 0–20 cm; b = 20–40 cm; and c = 40–60 cm). na = not applicable. Soil types (CV = Chromic Vertisol, RNi = Red Nitisol, PV = Pellic Vertisol); and Soil Texture (SCL = Sandy clay loam, C = Clay, SC = Sandy Clay, and CL = Clay loam); and Av.P for soils with pH >7.0 (analyzed by Olsen); and for soil with pH < 7.0 (Bray-1 method). Study areas [(Ar = Arsi, ES = East-Shewa = E/Shewa, OL = West-Shewa = Oromia Liyuu = O/Liyuu)]; Districts [(Ti =Tiyo, Hi = Hitossa, Ad = Ada'a, and We = Welmera)]

Table 2b. Macronutrients, micronutrients and related properties of the soils before planting (2013-16)

Ref. code	Zone	District	PA	Alt. (m)	Soil Type	Nodules ($CaCO_3$)	Treatments applied (NPS, kg/ha)	Av. P (By)	Av. P (mg/kg)	(SO_4-S) (mg/kg)	Micronutrients (mg/kg)						Soil texture
											Cu	Mn	Fe	Zn	B	Mo	
2013-14																	
1-a	Ar	Ti	AA	2297.02	CV	no	na	Bray-I	5.12	6.94	2.38	41.67	4.80	0.91	0.31	0.05	SCL
2-a	Ar	Ti	Do1	2418.32	RNi	no	na	Bray-I	1.84	10.44	1.38	59.67	6.40	1.01	0.44	0.04	C
3-a	Ar	Ti	GS1	2151.10	CV	no	na	Bray-I	3.73	7.77	1.65	43.33	3.50	0.63	0.43	0.03	SC
4-a	Ar	Ti	CM	1768.98	Ni	no	na	Bray-I	1.11	22.13	0.75	38.33	3.40	0.82	1.22	0.06	C
5-a	Ar	Hi	BE	2359.95	CV	no	na	Bray-I	1.95	21.50	2.38	43.33	5.00	0.76	0.99	0.06	C
6-a	Ar	Hi	BL	2186.37	Ni	no	na	Bray-I	3.29	4.32	1.47	36.67	3.10	0.52	0.38	0.04	SC
7-a	ES	Gi	CD	2426.53	PV	yes	na	Olsen	7.67	15.37	1.29	5.00	1.60	0.34	0.24	0.59	C
8-a	ES	Ad	Ke1	2224.37	PV	yes	na	Olsen	7.55	5.78	1.47	6.70	1.80	0.33	0.23	1.08	C
9-a	ES	Ad	Ud	1873.86	PV	yes	na	Olsen	9.53	12.37	2.38	5.67	2.00	0.32	0.42	0.11	C
10-a	ES	Ad	Bk1	1874.16	PV	yes	na	Olsen	10.82	1.30	2.11	5.00	1.90	0.26	0.35	0.04	SC
11-a	ES	Ak	In	2211.30	CV	yes	na	Olsen	10.99	6.62	1.47	10.00	1.70	0.26	0.24	0.10	C
12-a	ES	Ak	Ki	2204.00	PV	yes	na	Olsen	8.17	8.27	1.56	6.70	1.90	0.19	0.41	1.12	C
13-a	OL	We	NK	2123.74	CV	no	na	Bray-I	0.22	11.89	1.93	46.67	5.10	0.58	0.48	0.05	C
14-a	OL	We	NS1	2229.54	RNI	no	na	Bray-I	0.39	5.64	2.29	50.00	7.10	0.91	0.41	0.07	C
15-a	OL	We	BT1	2252.64	RNi	no	na	Bray-I	1.89	3.82	1.75	60.00	8.20	1.25	0.25	0.06	CL
16-a	OL	We	DL	2173.6	RNi	no	na	Bray-I	0.28	10.83	3.11	63.33	7.60	0.88	0.44	0.05	CL
17-a	OL	We	WH	2335.63	RNi	no	na	Bray-I	1.34	23.02	3.47	50.00	9.10	1.12	1.57	0.06	C
18-a	OL	We	TH	2349.62	RNi	no	na	Bray-I	1.45	24.18	4.11	53.33	5.10	1.17	0.43	0.07	C

Ref. code	Zone	District	PA	Alt. (m)	Soil Type	Nodules ($CaCO_3$)	Treatments applied (NPS, kg/ha)	Av. P (By)	Av. P (mg/kg)	(SO_4-S) (mg/kg)	Micronutrients (mg/kg)						Soil texture
											Cu	Mn	Fe	Zn	B	Mo	
								2015-16									
19-a	Ar	Ti	WG/Do2	2418.32	PV	no	na	Bray-I	2.01	31.98	2.56	61.67	4.10	0.87	1.60	0.06	C
19-b	Ar	Ti	WG/Do2	2418.32	PV	no	na	Bray-I	1.51	24.98	2.32	61.60	4.00	0.87	1.99	0.07	C
19-c	Ar	Ti	WG/Do2	2418.32	PV	no	na	Bray-I	1.15	23.13	2.45	61.52	4.12	0.80	2.11	0.06	C
20-a	Ar	Ti	GS2	2151.10	Ni	no	na	Bray-I	3.01	12.11	2.47	41.67	4.60	0.93	0.38	0.05	CL
20-b	Ar	Ti	GS2	2151.10	Ni	no	na	Bray-I	2.04	7.10	2.37	41.55	4.60	0.91	0.60	0.49	CL
20-c	Ar	Ti	GS2	2151.10	Ni	no	na	Bray-I	1.51	6.01	2.40	41.39	4.60	0.92	1.11	0.50	CL
21-a	ES	Ad	Ke2	2224.37	PV	yes	na	Olsen	9.02	6.77	1.47	6.70	2.10	0.36	0.34	1.06	C
21-b	ES	Ad	Ke2	2224.37	PV	yes	na	Olsen	7.07	4.14	1.42	6.13	2.12	0.33	0.66	1.00	C
21-c	ES	Ad	Ke2	2224.37	PV	yes	na	Olsen	4.06	3.10	1.41	6.44	2.22	0.31	1.21	1.11	C
22-a	ES	Ad	Bk2	1874.16	PV	yes	na	Olsen	12.01	4.03	3.20	5.50	2.20	0.49	0.21	0.05	SC
22-b	ES	Ad	Bk2	1874.16	PV	yes	na	Olsen	8.06	2.03	3.11	5.31	2.23	0.42	0.33	0.07	SC
22-c	ES	Ad	Bk2	1874.16	PV	yes	na	Olsen	5.07	2.01	3.26	5.42	2.24	0.45	0.76	0.08	SC
23-a	OL	We	NS2	2229.54	RNi	no	na	Bray-I	0.89	4.58	2.38	55.00	6.90	0.98	0.44	0.05	C
23-b	OL	We	NS2	2229.54	RNi	no	na	Bray-I	0.51	2.13	2.33	55.00	6.87	0.89	0.63	0.05	C
23-c	OL	We	NS2	2229.54	RNi	no	na	Bray-I	0.53	1.53	2.29	55.00	6.99	0.99	0.71	0.06	C
24-a	OL	We	BT2	2252.64	PV	no	na	Bray-I	0.50	35.83	3.11	65.00	8.20	1.21	0.41	0.04	C
24-b	OL	We	BT2	2252.64	PV	no	na	Bray-I	0.30	25.13	3.10	65.10	8.00	1.20	0.52	0.06	C
24-c	OL	We	BT2	2252.64	PV	no	na	Bray-I	0.20	20.12	3.19	65.01	8.12	1.23	0.74	0.05	C

Key: Soil depth (a = 0–20 cm; b = 20–40 cm; and c = 40–60 cm). na = not applicable. Soil types (CV = Chromic Vertisol, RNi = Red Nitisol, PV = Pellic Vertisol); and Soil Texture (SCL = Sandy clay loam, C = Clay, SC = Sandy Clay, and CL = Clay loam); and Av.P for soils with pH >7.0 (analyzed by Olsen); and for soil with pH < 7.0 (Bray-1 method). Study areas [(Ar = Arsi, ES = East-Shewa = E/Shewa, OL = West-Shewa = Oromia Liyuu = O/Liyuu)]; Districts [(Ti =Tiyo, Hi = Hitossa, Ad = Ada'a, and We = Welmera)]

In general, the CTHs for pH and acidity have been reported to vary among soil-types, plant species, and even between different cultivars within the same crop species [22,23]. Therefore, for advising growers on the need for appropriate liming materials, identification of critical soil pH, H^+ and Al^{3+} contents for a particular crop species is essential. The development of crop varieties with an Al tolerance for a particular locality is also crucial.

3.3 Electrical Conductivity (EC)

The overall EC values of the studied soils range from 0.05 to 0.25 (dS/cm). As per the suggested criterion for salt affected soils [17,18] all the soils were salt-free or had no sodicity problems to the extent that can pose effects on yield reduction. This means that there was no problem of salinity, even at sub-surface levels, though the EC values showed a slight increase with soil depths. In contrast, soils that might contain a high accumulation of soluble salts will adversely affect plant growth.

3.4 Cation Exchange Capacity (CEC)

The CEC determines the ability of soils to bind or hold nutrients against leaching, and it is usually influenced by soil texture, clay mineralogy and OM [18]. It is the measure of the quantity of negatively charged sites on soil surfaces that can retain cations by electrostatic forces. The overall CEC of surface soils ranged from 13.80 to 47.80 $cmol_c$/kg. The CEC values < 6.0 $cmol_c$/kg are considered to be very poor, and that between 6.0 to 12.0 $cmol_c$/kg as poor [24]. Such a low CEC soils are typically weathered and have limited capacity to supply plant nutrients like Ca^{2+}, Mg^{2+} and K^+ [24]. Except some 16.7% of the soils or sites, all soils including the sub-surface ones fall within a range 15 to 25 $cmol_c$/kg, which is suggested to be medium; and 25 to 40 $cmol_c$/kg, which is considered to be high based on the criterion developed for tropical soils [17]. There was no clear trend of increase or decrease with depth. But, all the studied Vertisols had high levels of CEC and this is in accordance with that report by Hailu et al. [25].

3.5 Saturation Percent (SP)

The SP of surface soils ranged from 37.45 to 96.64%. According to Landon [17] and FAO [26] the SP values less than 20% is suggested to be low; 21 to 60% medium; and above 60% high. From the report, the values between 20 to 60% are suggested to be less fertile, whereas that above 60% were suggested to indicate better fertility of soils. Based on both criteria, about 41.7% of the soils are considered to be less fertile for supporting good crop growth. The soils with such categorization have come from Arsi and WS zones. In fact, those soils were acidic in reaction. If the SP could be used solely as a criterion, those areas would need better soil fertility management practices. In general, SP of the studied soils varied from site to site; and observed to increase with soil depths owing to the differences in agro-ecological zones and the leaching of bases cations down to soil profiles. The relative low levels of BS in surface soils might be an indication of intensive leaching of the bases down to the soil profiles. On the other hand, the high levels of BS nearly equals to 100% recorded in ES might possibly be due to the dissolution (dissolving or decomposing) of $CaCO_3$ from calcareous sandy clay soils.

3.6 Carbon to Nitrogen Ratios (C:N Ratio)

According to Uriyo et al. [27], the C:N ratio above 30 in most cases is considered N limited and could not support good plant and microbial growth. The ideal microbial diet is at C:N ratio 24:1, the soil microbial average being 8:1 [18]. In the present study, the C:N ratio for surface soils ranged from 6.83 to 24.86, which are fairly below 30. But, none could match the frequently quoted average for mineral soils, 10:1, which was suggested to indicate good quality OM. As indicated in the Tables, only 16.7% of the sites (13.9% of soils) had the soil OC content well above the critical levels (CL); while some 11.0% were in equilibrium with the CL.

The contents of OC and TN of surface soils were critically low and also tend to decrease with depth; though the C:N ratios did not show a consistent pattern. The relative higher levels of OC and TN at the surface could be due to the correspondingly higher accumulation of OM at soil surfaces. Therefore, the practices that enrich SOC should be encouraged, as it would negatively affect the quality of soils. However, Landon [17] questioned the C:N ratio concepts as an indicator of good fertility of soils. For maintaining good soil health, therefore, the author encouraged using the individual C and N of soils under investigations instead of using the C:N ratios.

4. EXCHANGEABLE CATIONS

The widely accepted general trends of base cations in typical agricultural soils are that Ca should be higher than Mg; Mg higher than K and K higher than Na. The contents of base cations (Ca, Mg, K and Na) of the studied soils are presented in Table 2a. The sub-sections discuss the sufficiency level concept as soil-testing with emphasis on the base cations as decision-support tools in fertilizer formulations.

4.1 Calcium

Exchangeable Ca content in the studied soils varied with soils and/or AEZs. It ranged from 3.48 to 33.90 $cmol_c/kg$. As per the ratings by Marx et al. [28], for majority of crops, therefore, 20.8% of the soils were Ca deficient. In that regard, some 12.5% were almost in equilibrium (or marginal) leaving 66.7% of the soils safe from Ca deficiency. The Ca content seems to be high in some sites due to alkaline soil reactions, but not to the extent that it can significantly affect the availability of nutrients like P for arable crops. The results suggest that, Ca was dominating the soil colloids, particularly, in ES zone, due to the calcareous nature of the soils. The results of the study affirmed that, some 20.8% of the sites need Ca fertilization. Other forms like foliar formulations could also be used to correct Ca nutrition problems, particularly, in strongly acidic soils of WS zone. Generally, Ca levels tend to increase irregularly with depth, which could be due to the increased levels of $CaCO_3$ or the leaching of Ca to sub-surface soils, and profiles.

4.2 Magnesium

Magnesium contents in the surface soils ranged from 1.15 to 8.77 $cmol_c/kg$. As per the ratings suggested by Schwartz and Corrales [21] for most crops, about 29.2% of the soils were found to be deficient in Mg. The problem was observed only in more acidic, and sandy soils sampled from Arsi and WS zones. This would limit crop growth, particularly, through the imbalance that would be created between Mg and related nutrients like K. Hence, for attaining maximum crop yields, supplemental Mg may be needed in the deficient areas. But, for the Vertisols from ES, the result is in accordance with that reported by Hailu et al. [25]. In the specific site-soils the exchangeable Mg was also found to increase irregularly with depth. The relatively increasing levels of Mg in sub-soils may suggest that, the underlying horizons might have higher levels Mg, possibly due to the leaching of cations or high contents of Mg in the soil's parent materials.

4.3 Potassium

Potassium is one of the most abundant elements in soils and its chemical compounds are very soluble, but its mineral forms micas and orthoclase feldspars are slowly soluble. In the present study, the exchangeable K ranged from 1.10 to 5.49 $cmol_c/kg$. The CLs for surface soils were between 0.2 to 0.5 $cmol_c/kg$ for most crops [29]. As per these suggestions, all the soils had either high or very high levels of exchangeable K. This fairly high level of exchangeable K is consistent with the findings by Hailu et al. [25]. Some soils from ES had very high levels of K and this might create imbalances with other nutrients like Mg.

The main sources of K for plants growing under natural conditions are the weathering of K minerals and organic K sources [18]. But, since the studied soils had low OC contents, the parent materials of the soils must be dominated by micas and orthoclase feldspar minerals. In general, the total K in soils will be dependent on soil parent material, the extent of weathering, leaching of soil minerals, the type of clay minerals, soil texture, the OM contents and K fertilizer history. The relative lower levels of K in sandy and low pH soils, is in accordance with that reported by Brennan and Bell [30]. Therefore, owing to its very high levels of K in the studied soils, K indexing studies involving the different extraction methods or solutions might be needed.

4.4 Sodium

The Na contents in surface soils ranged from 0.04 to 0.47 $cmol_c/kg$. Uwitonze et al. [31] rated the exchangeable Na content between 0.10 to 0.30 $cmol_c/kg$ as low; and below 0.01 $cmol_c/kg$ as very low. In contrary, the Na content of 1.0 $cmol_c/kg$ and above was rated to be the highest and detrimental to plant roots. Therefore, the studied soils had no sodicity problem including the sub-surface layers. This would also mean that the soils had low ESP values below 6.0%. The relative higher levels of Na were observed in the soils sampled from the peripheries of great rift-valley systems. Generally, the values were observed to increase with depth. The low levels of exchangeable Na in the topsoil may be attributed to its solubility and mobility when soils are sufficiently moist, leading its subsequent accumulation in sub-soils [32].

5. CONCLUSIONS

The soil fertility assessment made in 24 sites showed significant variations in soil nutrients status. The base cations distribution was closely related with the research outputs reported in other areas, except that exchangeable K was equal to or slightly greater than Mg in few of the sites. Exchangeable-Al was detected in strongly acidic soils, and this was positively correlated with Ca and Mg deficiency, thus necessitating liming, and/or the application of supplemental Ca and Mg fertilizers. All the soils were salt-free or had no sodicity problem. The exchangeable K was adequate in all sites, or even excess in some sites, based on the suggested CTHs. Generally, strongly acidic- and sandy soils tend to have relative lower levels of base cations. Those results indicate that, the levels of major cations (Ca, Mg, K, Na and H) should be taken into account when formulating fertilization guidelines. The overall study clearly demonstrated that, in addition to the aforementioned deficient macronutrients and micronutrients, Ca and Mg were found to be limiting in some sites. Hence, in addition to the strategies meant for amending acid-soils, all the deficient nutrients need to be applied for specific sites, if soil- and plant analytical data are available. In addition to augmenting with supplemental inorganic fertilizes, nutrient recycling strategies for optimizing SOC pool are strongly advisable. Furthermore, the CTHs for all the major cations including pH and exchangeable acidity for specific soil conditions and/or crops need to be developed. Overall, the results of the study could be used to design similar, but more advanced research interventions in other areas; and could also play significant role in soil-fertility management and land-use planning programs in the country.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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