Eurasian J Soil Sci 2018, 7 (4) 292 - 299

Eurasian Journal of Soil Science

Journal homepage : http://ejss.fesss.org

Characterization and classification of soils of Wolkite University research sites, Ethiopia

Teshome Yitbarek *, Abdeta Jembere, Habtamu Kerebeh

Wolkite University, College of Agriculture and Natural Resource, Department of Natural Resource Management, Ethiopia

Abstract

The main purpose of this study was to characterize and classify soils of Wolkite University research sites, Gurage zone, Ethiopia. In each five research sites, Wabe (RS1), Geche (RS2), Yefereze (RS3), Kotergedra (RS4) and Keratemo (RS5), representative pedons were opened and described. Almost all the pedons were deep (>150 cm) with argillic B horizons and had clay textural class. The pH of the surface soils ranged from strongly acidic (4.5) to moderately acidic (5.6). The soils had medium (2.60%) to high (3.84%) organic carbon content and very low (1.46 mg kg^{-1}) to low (10.34 mg kg-1) available phosphorus. The status of cation exchange capacity (CEC) and base saturation were ranged from medium (23.15) to very high (66.32 cmolc kg^{-1}) and low (33%) to high (99%), respectively. According to WRB classification, pedon RS1 was classified as Haplic Vertisols (Hypereutric) with USD equivalent of Typic Haplusterts. Pedons RS2 and RS3 were classified as Vertic Alisols (Hyperdysric), which is correlated with Ultisols (Typic Haplustults) in USDA classification. Pedon RS4 and RS5 classified as Vertic Luvisols (Hypereutric), which is correlated with Alfisols (Vertic Haplustalfs) in USDA classification. Generally, the soils of the research sites were acidic with low status of available phosphorus, which need amelioration of soil acidity and nutrient management.

Article Info

Received : 20.03.2018
Accepted : 22.06.2018

Keywords: Argilic, nutrient management, pedon, soil acidity.

Introduction

Soils have diverse morphological, physical, chemical and biological properties. As a result, they differ in their responses to management practices, their inherent ability to deliver ecosystem services, as well as their resilience to disturbance and vulnerability to degradation (FAO, 2017). Characterization and classification of soils have therefore paramount importance in using those resources based on their capability and to manage them in sustainable manner. Soil information obtained through systematic identification and grouping use for effective planning of different land uses, as they provide information related to potentials and constraints of the land (Lufega and Msanya, 2017).

Soil characterization studies are major building block for understanding the soil, classifying it and getting the best understanding of the environment (Onyekanne et al., 2012). Soil characterization provides the information for our understanding of the physical, chemical, mineralogical and microbiological properties of soil. It also helps to organize our knowledge, facilitates the transferring of experience and technology from one place to another (Chekol and Mnalku, 2012; Adhanom and Toshome, 2016).

In Ethiopia, the studies that have been made so far were mostly at small scale, which could not be applicable for site specific land use and soil management. Therefore, adequate knowledge on soil characteristics at large scale and or local watershed or farm level is essential in tackling specific and local problems of agricultural production (Hailu et al., 2015).

* Corresponding author.
Wolkite University, College of Agriculture and Natural Resource, Department of Natural Resource Management, Ethiopia
Tel.: +251927426316 E-mail address: teshalm7@gmail.com
e-ISSN: 2147-4249 DOI: 10.18393/ejss.436186

Wolkite University, one of the Universities in Ethiopia, has established five research sites in different location of Gurage zone. The main purpose of establishing those sites were to conduct research by the academic staff of the University, based on the identified thematic areas. To undertake soil related problem solving researches, it is mandatory to have information about the soils of the research sites: the morphological, physical, chemical, biological properties and their management requirements. In view of this fact, this research was initiated and conducted to characterize and classify soils of Wolkite University research sites.

Material and Methods

Description of the study area

The study was conducted at research sites of Wolkite University, which is found in south western Ethiopia. The study encompasses five sites which are found in Gurage Administrative Zone of Southern Nations, Nationalities and Peoples Regional State. Generally, the research sites are located in three Districts of Gurage zone: Wabe (Abeshege), Geche, Kotergedra and Keratemo (Eza), Yefereze (Cheha) and geographically lies between 8°00'00"N to 8°20'00"N and 37°40'00"E to 38°10'00"E as indicated in the figure below (Figure 1).

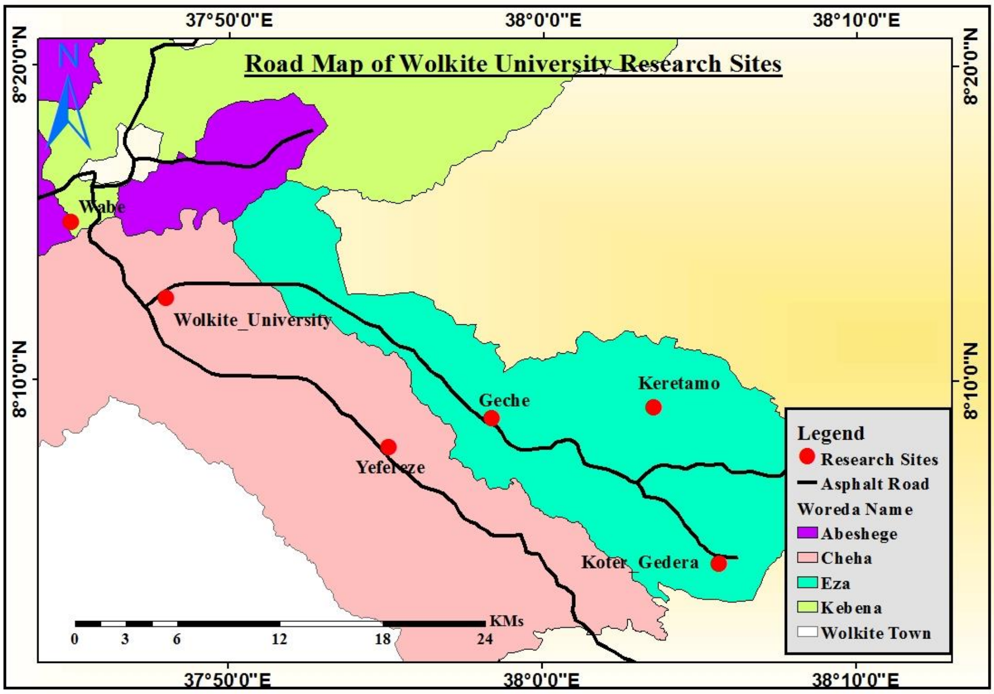

Figure 1. Location map of research sites of Wolkite University

The main rainy season which accounts for around 70-90% of the total annual rainfall occurs from June to September. Two main distinct seasons, dry and wet seasons are recognized in the area. The dry season starts from November to May, while the wet season covers the remaining part of the year, when most of the precipitation takes place. Rain usually starts in March, but the effective rainy season is from June to October with the peak in July, receiving a monthly mean of 222.8 mm of rainfall. Based on the Ethiopian agro ecological classification Wabe, Geche and Yefereze sites are located in the Woyena Dega zone, where as Kotergedera and Keratemo sites are located on the Dega agro-ecological zones. Ten years' data obtained from Meteorology Agency indicated that the mean annual temperature ranges from 14 to 24^{0}C with an average of 20.5^{0}C. The slope steepness of Wabe, Geche and Yefereze sites are characterized by nearly level to sloping, while Kotergedera and Keratemo sites are characterized as nearly level to steep slope as indicated in the table below (Table 1).

Table 1. Location, elevation and slope description of Wolkite University research sites

Site	Latitude	Longitude	Elevation (meter)	Slope (%)	Area (hectare)
Geche	8.15	37.95	2190-2202	0.5-13	1.2
Keratemo	8.14	38.04	2409-2437	0.5-24	6.6
Kotergedra	8.15	38.05	2495-2732	0.6-37	3.5
Wabe	8.25	37.75	1667-1680	1-8	1.3
Yefereze	8.10	37.90	2022-2046	0.6-6	6.1

Soil description and analysis

A representative pedon, 1.5x2 m, was opened in each research site and described in situ following the Guidelines for Field Soil Description (FAO, 2006a). General site information and soil description were recorded and samples were collected from every identified horizon. Based on the morphological properties and the laboratory analysis, the soils of the study area were classified according to WRB (FAO, 2014) and Soil Taxonomy (Soil Survey Staff, 2014).

The physical and chemical properties which were considered for the study were texture, pH, organic matter, total nitrogen, phosphorus, CEC and exchangeable bases. Particle size distribution was analyzed by hydrometer method (Bouyoucos, 1962). Soil pH was measured in the supernatant suspension of a 1:2.5 soil: water mixture using pH meter. Soil organic carbon was determined using the Walkley and Black wet oxidation method (Walkley and Black, 1934). Total nitrogen was determined using the Kjeldahl procedure (Wilke, 2005). Available phosphorus was determined using Olsen method (Olsen and Sommers, 1982), the reading was made using spectrometer at 880 nm. The cation exchange capacity was determined following ammonium acetate method (Sarkar and Haldar, 2005). From the aliquots of the same extract, exchangeable bases were determined. The reading was made with Atomic Absorption Spectrophotometer.

Results and Discussion

Morphological properties

The pedons of the research sites, Wabe (RS1), Geche (RS2), Yefereze (RS3), Kotergedra (RS4) and Keratemo (RS5) were deep (>150 cm) with argillic B horizons (Table 2). Slickensides were noticed in the subsoil horizons of pedon RS1. The moist color of surface horizons varied from brown (10YR 4/3) to dark brown (7.5YR 3/4), whereas the color of the subsurface horizons varied from dark reddish brown (2.5YR 2.5/4) to very dark gray (10YR 3/1) (Table 2). The surface horizons were darker as compared to the subsurface horizons that mainly could be due to accumulation and decomposition of organic materials, as it was also discussed by previous studies (Mulugeta and Sheleme, 2010).

The surface horizons had granular structure with varied grade and size, whereas the subsurface horizons had moderate to very strong, and fine to extremely coarse angular blocky structure (Table 2). The dry consistence of the surface soil was slightly hard (Table 2), whereas the moist and wet consistencies were friable, and sticky/plastic, respectively. Likewise, the subsurface horizons had slightly hard to extremely hard (dry), friable to extremely firm (moist), and slightly sticky/plastic to very sticky/very plastic (wet) consistence.

Selected physical and chemical properties

The clay proportion was highest in all horizons of the pedons and as a result the textural classes of the soils of the research sites were clay (Table 3). Its content varied from 58 to 86%, and generally increased with depth.

The textural differentiation might be caused by an illuvial accumulation of clay, predominant pedogenetic formation of clay in the subsoil, selective surface erosion of clay, upward movement of coarser particles due to swelling and shrinking, biological activity and a combination of two or more of these different processes (FAO, 2014). In the surface horizons of the pedons, silt and sand contents varied from 12 to 26 % and 8 to 30 %, respectively, whereas their respective values varied from 9 to 32 % and 2 to 11 % in the subsurface horizons.

The pH (H2O) of the surface soil of the research sites ranged from 4.5 to 5.6, whereas the subsurface values were between 4.8 and 6.9 (Table 3) indicating that the soils are strongly acidic to neutral (Horneck et al., 2011). In most of the pedons, the pH values increased with increasing depth. Considering the optimum pH for many plant species to be 5.5 to 6.8, the pH of the soils in study area less than 5.5 could be considered as unsuitable for most crop production.

The organic carbon (OC) content ranged from 2.60 to 3.84 % in the surface layers of the pedons and categorized under medium to high (Tekalign et al., 1991). The values decreased with increasing depth in all pedons (Table 3), as observed in previous studies (Dengiz, 2010; Mulugeta and Sheleme, 2010; Paramasivan and Jawahar, 2014). The total N content of the surface soils ranged 0.26 to 0.39%, and rated as high (Tekalign et al., 1991). Similar to OC, total N content decreased with depth in all pedons (Table 3). According to Hartz (2007), soils with less than 0.07% total N have limited N mineralization potential, while those having greater than 0.15% total N would be expected to mineralize a significant amount of N during the succeeding crop cycle, showing that most of the soils have good potential of N mineralization.

Table 2. Selected morphological properties of the pedons

Pedon[1]	Horizon	Depth (cm)	Boundary[2]	Color		Texture (Feel method)	Structure[3]	Consistency[4]	Special features
				Dry	Moist				
RS1	Ap	0-38	CS	10YR 5/2	10YR 4/1	Clay	ST,ME,GR	SHA,FR,ST,PL	Crack
	Bi1	38-120	GS	10YR 4/2	10YR 3/1	Clay	VST,CO,AB	HA,FI,VST,VPL	Slickenside
	Bi2	120-200+	-	10YR 5/4	10YR 4/4	Clay	VST,VC,AB	VHA,EFI,VST,VPL	Slickenside
RS2	Ap	0-26	CS	10YR 5/4	10YR 4/3	Clay	MO,FI,GR	SHR,FR,SST,SPL	-
	Bt1	26-42	CS	7.5YR 4/3	7.5YR 3/3	Clay	ST,ME,AB	SHA,FR,ST,PL	-
	Bt2	42-92	GS	7.5YR 4/4	7.5YR 3/4	Clay	ST,CO,AB	SHA,FR,ST,PL	-
	Bt3	92-200+	-	10R 4/4	10R 4/5	Clay	ST,ME,AB	SHA,FR,ST,PL	-
RS3	Ap	0-28	CS	7.5YR 4/6	7.5YR 3/4	Clay	ST,FI,GR	SHA,FR,ST,PL	-
	Bt1	28-139	GS	2.5YR 4/6	2.5YR 5/4	Clay	ST,ME,AB	SHA,FR,ST,PL	-
	Bt2	139-200+	-	7.5YR 4/6	2.5YR 2.5/4	Clay	ST,FM,AB	SHA,FF,ST,PL	-
RS4	Ap	0-17	CS	7.YR 5/4	7.5YR 4/4	Clay	MO,FM,GR	SHA,FR,ST,PL	-
	Bt1	17-53	GS	7.5YR 5/3	7.5YR 5/2	Clay	ST,CO,AB	SHA,FR,ST,PL	-
	Bt2	53-92	GS	7.5Y 4/3	7.5YR 4/2	Clay	ST,CO,AB	SHA,FR,ST,PL	-
	Bt3	92-200+	-	7.5YR 4/4	10YR 4/3	Clay	ST,CO,AB	SHA,FR,ST,PL	-
RS5	Ap	0-20	CS	7.5YR4/4	7.5YR3/4	Clay	MO,FM,GR	SHA,FR,ST,PL	-
	Bt1	20-60	GS	7.5YR4/3	7.5YR3/3	Clay	ST,CO,AB	SHA,FR,ST,PL	-
	Bt2	60-90	GS	7.5YR4/2	7.5YR3/2	Clay	ST,CO,AB	SHA,FR,ST,PL	-
	Bt3	90-150+	-	7.5YR4/4	7.5YR3/3	Clay	ST,CO,AB	SHA,FR,ST,PL	-

[1] RS1 = Wabe research site; RS2 = Geche research site; RS3 = Yefereze research site; RS4 = Kotergedra research site; RS5 = Keratemo research site

[2] CS = Clear and smooth; GS = Gradual and smooth;

[3] ST= Strong; MO= Moderate; VST= Very strong; FI= Fine; FM= Fine and medium; ME= Medium; CO = Coarse; VC= Very coarse; GR= Granular; AB= Angular blocky

[4] SHA= Slightly hard; HA= Hard; VHA= Very hard; FR=Friable; FI=Firm; EFI=Extremely firm; ST= Sticky; SST= Slightly sticky; VST = Very sticky; PL= Plastic; SPL= Slightly plastic; VPL= Very plastic;

Table 3. Selected physical and chemical proprieties of soils of Wolkite University research sites

Pedon[1]	Horizon	Depth (cm)	Particle size distribution (%)			Textural class	pH	Organic C (%)	Total N (%)	Available P (mg kg^{-1})
			Sand	Silt	Clay					
RS1	Ap	0-38	20	22	58	Clay	5.6	3.78	0.38	1.46
	Bi1	38-120	7	12	81	Clay	6.9	1.22	0.12	1.51
	Bi2	120-200^{+}	5	9	86	Clay	6.8	0.29	0.03	0.50
RS2	Ap	0-26	19	24	57	Clay	5.3	2.77	0.28	6.05
	Bt1	26-42	4	32	64	Clay	5.9	0.49	0.05	0.74
	Bt2	42-92	3	21	76	Clay	5.8	1.36	0.14	0.75
	Bt3	92-200^{+}	2	14	84	Clay	5.8	0.63	0.06	0.49
RS3	Ap	0-28	8	26	66	Clay	4.9	2.60	0.26	1.27
	Bt1	28-139	2	16	82	Clay	4.9	0.93	0.09	0.50
	Bt2	139-200^{+}	4	12	84	Clay	5.1	0.42	0.04	0.77
RS4	Ap	0-17	30	12	58	Clay	4.5	3.84	0.39	10.34
	Bt1	17-53	4	26	70	Clay	4.9	3.05	0.31	6.52
	Bt2	53-92	7	22	71	Clay	4.9	1.14	0.12	8.09
	Bt3	92-200^{+}	11	23	66	Clay	5.1	0.57	0.06	8.79
RS5	Ap	0-20	9	25	66	Clay	5.9	3.63	0.37	9.40
	Bt1	20-60	9	28	63	Clay	5.3	2.14	0.22	3.14
	Bt2	60-90	3	20	77	Clay	4.8	2.06	0.21	2.50
	Bt3	90-150^{+}	2	26	72	Clay	5.2	1.56	0.16	3.82

[1]RS1 = Wabe research site; RS2 = Geche research site; RS3 = Yefereze research site; RS4 = Kotergedra research site; RS5 = Keratemo research site;

The available phosphorus content of the pedons ranged from 0.49 in subsoil to 10.34 mg kg-1 in surface horizon (Table 3), which could be categorized from very low to low (Jones, 2003). Relatively the maximum available P was recorded in pedon RS4, where the OC was highest (3.84). According to Carrow et al. (2004), P-Olsen between 12 to 18 mg kg^{-1} is considered as sufficient and hence the available P in surface horizons of all pedons was insufficient range. Available P values declined with increasing depth which could be attributed to decrease in soil OM. The increase in clay content with depth could have also contributed to decrease available P (Mulugeta and Sheleme, 2010).

Cation exchange capacity, exchangeable bases and base saturation

The overall cation exchange capacity of the soils ranged between 23.15 and 66.32 cmolc kg^{-1} (Table 4), which is medium to very high in accordance with the rating of Hazelton and Murphy (2007). The highest CEC was recorded in pedon RSS1, where the highest pH (6.9) was observed and as the pH values of the pedons decrease the CEC also decreased. This showed that soil pH and CEC have direct relation.

Table 4. Exchangeable bases, cation exchange capacity, and percent base saturation

Pedon	Depth (cm)	Exchangeable bases cmol$_c$ kg^{-1}					CEC[2], cmol$_c$ kg^{-1}		ESP[3] (%)	PBS[4] (%)
		Ca	Mg	K	Na	TEB[1]	Soil	Clay		
RS1	0-38	19.37	18.33	0.75	0.35	38.8	46.73	81	0.7	83
	38-120	33.05	17.88	1.30	1.00	53.23	66.32	82	1.5	80
	120-200^{+}	35.74	20.35	1.44	1.15	58.68	59.14	69	1.9	99
RS2	0-26	4.63	3.60	0.48	0.06	8.77	28.85	51	0.2	30
	26-42	7.99	1.60	0.24	0.13	9.96	23.15	36	0.6	43
	42-92	9.16	3.77	0.41	0.18	13.52	29.12	38	0.7	46
	92-200^{+}	4.86	3.78	0.49	0.16	9.29	26.56	32	0.6	35
RS3	0-28	8.65	6.79	0.84	0.11	16.39	33.59	51	0.4	49
	28-139	5.96	5.96	0.50	0.14	12.56	28.50	35	0.5	44
	139-200^{+}	6.0	4.98	0.64	0.19	11.89	31.00	37	0.6	38
RS4	0-17	5.70	5.06	1.25	0.02	21.23	25.73	44	0.1	83
	17-53	3.22	3.87	0.27	0.05	26.32	30.44	43	0.2	86
	53-92	3.22	2.66	0.24	0.05	22.84	24.48	34	0.2	93
	92-200^{+}	5.99	7.98	0.28	0.15	18.18	28.92	44	0.5	63
RS5	0-20	4.81	9.23	1.38	1.02	23.22	36.56	55	1.9	64
	20-60	4.45	2.54	0.49	0.02	22.13	32.46	52	0.1	68
	60-90	3.20	5.13	0.28	0.05	25.48	33.31	43	0.2	76
	90-150^{+}	3.20	5.11	0.31	0.02	26.86	31.42	44	0.1	85

[1]TEB= Total exchangeable bases; [2] CEC = Cation exchange capacity; [3] ESP = Exchangeable sodium percentage; [4] PBS = Percent base saturation

The results revealed that the contents of exchangeable Ca and Mg varied from 3.20 to 35.74 and 1.60 to 20.35 cmolc kg-1, respectively, whereas exchangeable K varied from 0.24 to 1.44 cmolc kg-1. In accordance with the ratings of FAO (2006b), the soils are categorized under low to very high for Ca, medium to very high for Mg and low to very high for K content. Calcium and magnesium were the predominant basic cations in the soils. Similar observations had been made in the previous studies (Sharu et al., 2013, Paramasivan and Jawahar, 2014; Kebede et al., 2017). The exchangeable Na accounted only 0.1 to 1.9% of the exchangeable cations (Table 4). The Na content throughout the profiles of all pedons was low indicating the absence of sodicity problem. The percent base saturation of the pedons ranged from 33 to 99% (Table 4), which could be categorized under low to very high contents (Hazelton and Murphy, 2007).

Classification of soils of Wolkite University research sites

Soil classification based on WRB legend

Pedon RS1 possessed thick (≥ 25 cm) subsurface horizons that had greater than 30% clay, with cracks that open and close periodically and had slickensides in the subsurface horizones, which qualify it for vertic diagnostic horizons and also had base saturation (by 1M NH4OAc) of 50 percent or more throughout between 20 and 100 cm from the soil surface and 80 percent or more in some layer between 20 and 100 cm of the soil surface (Table 4), that qualify hypereutric with haplic principal qualifier. Thus, the pedon is classified as Haplic Vertisols (Hypereutric).

The remaining four pedons: RS2, RS3, RS4 and RS5 had subsurface horizons with distinct higher clay content than the overlying horizons, qualifying for argic subsurface diagnostic horizon. Pedon RS2 and RS3 had low base status, vertic principal qualifier and hyperdystric (base saturation <50% by 1M NH_4OAc) supplementary qualifier, as a result the pedons classified as Vertic Alisols (Hyperdysric). Alisols correlates with Ultisols in USDA classification. However, pedons RS4 and RS5 had base saturation (by 1M NH4OAc) of 50 percent or more throughout between 20 and 100 cm from the soil surface and 80 percent or more in some layer between 20 and 100 cm of the soil surface (Table 4), as a result the pedons classified as Vertic Luvisols (Hypereutric). Luvisols correlates with Alfisols in USDA classification.

Table 5. Diagnostic horizons, properties, quantifiers and soil types of Wolkite University research sites according to WRB (FAO, 2014)

Pedon	Diagnostic horizon	Diagnostic properties	Soil type	Area (hectare)
RS1	Vertic	Vertic	Haplic Vertisols (Hypereutric)	1.2
RS2	Argic	Vertic	Vertic Alisols (Hyperdysric)	6.6
RS3	Argic	Vertic	Vertic Alisols (Hyperdysric)	3.5
RS4	Argic	Vertic	Vertic Luvisols (Hypereutric)	1.3
RS5	Argic	Vertic	Vertic Luvisols (Hypereutric)	6.1

Soil classification based on Soil Taxonomy

Pedon RS1 had 30 percent and more clay, exhibit slickensides and cracks that open and close periodically. Thus, the pedons were classified under Vertisols. If not irrigated during the year, the cracks remained opened for 90 or more cumulative days per year, qualifying it for Usterts suborder; and Haplusterts and Typic Haplusterts at great group and subgroup, respectively.

Pedon RS2 and RS3 had argillic diagnostic horizons with a base saturation (by sum of cations) of less than 35 percent, and hence categorized under the order Ultisols (Soil Survey Staff, 2014). The pedons were further grouped under Ustults at suborder level due to their ustic soil moisture regime and Haplustults and Typic Haplustults, at great group and subgroup levels, respectively. Pedon RS4 and RS5 also had argillic diagnostic horizons with a base saturation (by sum of cations) of greater than 35 percent, and hence categorized under the order Alfisols. The pedons were further grouped under Ustalfs at suborder level due to their ustic soil moisture regime and Haplustalfs and Typic Haplustalfs, at great group and subgroup levels, respectively (Table 6).

Table 6. Diagnostic horizons and soil types of Wolkite University research sites according to Soil Taxonomy (Soil Survey Staff, 2014)

Pedon	Diagnostic horizon	Subgroup	Area (hectare)
RS1	Vertic	Typic Haplusterts	1.2
RS2	Argillic	Typic Haplustults	6.6
RS3	Argillic	Typic Haplustults	3.5
RS4	Argillic	Vertic Haplustalfs	1.3
RS5	Argillic	Vertic Haplustalfs	6.1

Conclusion

Field study was carried out to characterize and classify soils of Wolkite University research sites. Five representative pedons (RS1, RS2, RS3, RS4 and RS5) were opened and described. Three soil types: Haplic Vertisols (Hypereutric), Vertic Alisols (Hyperdysric) and Vertic Luvisols (Hypereutric) were identified according to WRB and with their Soil Taxonomy equivalent as Typic Haplusterts, Typic Haplustults and Vertic Haplustalfs, respectively. The soils of the research sites were acidic with low status of available phosphorus, which need amelioration of soil acidity and nutrient management, especially available phosphorus as it is more influenced by soil acidity.

Acknowledgement

The authors would like to thank the Wolkite University for the financial support and the staff of the Research and Community Service of the University for their facilitation.

References

Adhanom, D., Toshome, T., 2016. Characterization and classification of soils of Aba-Midan sub watershed in Bambasi Wereda, West Ethiopia. *International Journal of Scientific and Research Publications* 6(6): 390-399.

Bouyoucos, G.J., 1962. Hydrometer method improvement for making particle size analysis of soils. *Agronomy Journal* 54(5): 179-186.

Carrow, R.N., Stowell, L., Gelernter, W., Davis, S., Duncan, R.R., Skorulski, J., 2004. Clarifying soil testing: III. SLAN sufficiency ranges and recommendations. *Golf Course Management* 72(1): 194-198.

Chekol, W., Mnalku, A., 2012. Selected Physical and Chemical Characteristics of Soils of the Middle Awash Irrigated Farm Lands, Ethiopia. *Ethiopian Journal of Agricultural Sciences* 22(1): 127-142.

Dengiz, O., 2010. Morphology, physico-chemical properties and classification of soils on Terraces of the Tigris River in the South-east Anatolia Region of Turkey. *Journal of Agricultural Sciences* 16(3): 205-212.

FAO, 2006a. Guidelines for soil description. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. 97p. Available at: [Access date: 06.01.2018]: http://www.fao.org/docrep/019/a0541e/a0541e.pdf

FAO, 2006b. Plant nutrition for food security. A Guide for Integrated Nutrient Management; FAO Fertilizer and Plant Nutrition Bulletin 16, Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. 347p. Available at [Access date : 06.01.2018]: http://www.fao.org/docrep/010/a0443e/a0443e00.htm

FAO, 2014. World Reference Base for Soil Resources 2014. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. 192p. Available at [Access date : 06.01.2018]: http://www.fao.org/3/a-i3794e.pdf

FAO, 2017. Voluntary Guidelines for Sustainable Soil Management. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. 16p. Available at [Access date : 06.01.2018]: http://www.fao.org/3/a-bl813e.pdf

Hailu, A.H., Kibret, K., Gebrekidan, H., 2015. Characterization and classification of soils of Kabe Subwatershed in South Wollo Zone, Northeastern Ethiopia. *African Journal of Soil Science* 3(7): 134-146.

Hartz, T.K., 2007. Soil Testing for Nutrient Availability. Procedures and Interpretation for California Vegetable Crop Production. University of California, Vegetable Research and Information Center, USA. Available at [Access date : 06.01.2018]: http://vric.ucdavis.edu/pdf/fertilization_Soiltestingfornutrientavailability2007.pdf

Hazelton, P., Murphy, B., 2007. Interpreting Soil Test Results: What do all the numbers mean? Second edition. CSIRO Publishing. Australia. 52p.

Horneck, D.A., Sullivan, D.M., Owen, J.S., Hart, J.M., 2011. Soil Test Interpretation Guide. Oregon State University, Extension Service, USA. Available at [Access date : 06.01.2018]: https://ir.library.oregonstate.edu/downloads/00000020g

Jones, J.B. 2003. Agronomic Handbook: management of crops, soils, and their fertility. CRC Press, Boca Raton, Florida, USA. 482p.

Kebede, M., Skimbir, T., Kasa, G., Abera, D., Girma, T., 2017. Description, characterization and classification of the major soils in Jinka Agricultural Research Center, South Western Ethiopia. *Journal of Soil Science and Environmental Management* 8(3): 61-69.

Lufega, S.M., Msanya, B.M., 2017. Pedological characterization and soil classification of selected soil units of Morogoro District, Tanzania. *International Journal of Plant and Soil Science* 16(1): 1-12.

Mulugeta, D., Sheleme B., 2010. Characterization and classification of soils along the toposequence of Kindo Koye Watershed in Southern Ethiopia. East African Journal of Sciences 4 (2): 65–77.

Olsen, S.R., Sommers, L.E.,1982. Phosphorus. In: Methods of soil analysis. Part 2 Chemical and microbiological properties. 2nd edition. Page, A.L. (Ed.). American Society of Agronomy, No. 9, Madison, WI, USA. pp. 403-430.

Onyekanne, C. F., Akamigbo, F. O., Nnaji, G. U., 2012. Characterization and classification of soils of Ideato North local government area. *Nigerian Journal of Soil Science* 22(1): 11-17.

Paramasivan, M., Jawahar D., 2014. Characterization, classification and crop suitability of L.E. some black cotton soils of southern Tamil Nadu. *Agropedology* 24 (1): 111-118.

Sarkar, D., Haldar, A., 2005. Physical and Chemical Methods in Soil Analysis: Fundamental Concepts of Analytical Chemistry and Instrumental Techniques. New Age International Limited Publishers, 176p.

Sharu, M.B., Yakubu, M., Noma, S.S., Tsafe, A.I., 2013. Characterization and classification of soils on an agricultural landscape in Dingyadi District, Sokoto State, Nigeria. *Nigerian Journal of Basic and Applied Sciences* 21(2): 137-147.

Soil Survey Staff, 2014. Keys to Soil Taxonomy. 12rd Edition. United States Department of Agriculture (USDA), Natural Resources Conservation Service. Washington DC, USA. 360p. Available at [Access date : 06.01.2018]: https://www.nrcs.usda.gov/wps/PA_NRCSConsumption/download?cid=stelprdb1252094&ext=pdf

Tekalign, T., Haque, I., Aduayi, E.A., 1991. Soil, plant, water, fertilizer, animal manure and compost analysis. Plant sciences division working Document No: B13. International Livestock Centre for Africa (ILCA), Addis Ababa, Ethiopia.

Walkley, A., Black, C.A., 1934. An examination of Digestion method for determining soil organic matter and proposed modification of the chromic acid titration method. *Soil Science* 37(1): 29-38.

Wilke, B.M., 2005.Determination of chemical and physical soil properties. In: Manual of soil analysis: monitoring and assessing soil bioremediation, R. Margesin, F. Schinner (Eds.). Vol 5, Springer-Verlag, Berlin Heidelberg, pp.79-82.