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CHARACTERIZATION AND CLASSIFICATION OF OBUDU MOUNTAINS STEEP HILLSIDE SOILS.

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ABSTRACT

Soil characterization helps us understand soils better which leads to their classification into categories. The steep hillside soils of three Obudu mountain ranges were selected for profile study for their morphological and physico-chemical properties at Belekete, Bottom Hill and Belinge. The soils were well drained and deeply weathered. The mean percentage of sand, silt and clay were 54 %, 59 % and 48 %; 22 %, 18 % and 19 %; and 24 %, 23 % and 33 % for Belekete, Bottom Hill and Belinge respectively. The soils were generally acidic with mean pH ranging from 4.52 - 5.93, while mean organic carbon results range from 1.09 to 2.21 %. The mean total nitrogen value of the soils was 0.56 % while the mean cation exchange capacity (NH_4OAc) was 11.23 cmol/kg. The mean available phosphorus ranged from 1.97 - 4.96 mg/kg while the base saturation (NH_4OAc) ranged from 30.75 - 51.59 %. The hillside soil in Belekete was classified as an Ultisol (Typic Paleustult) for possessing kandic B horizon and percent base saturation less than 35 % by sum of cations around 200cm below the soil surface. Using the FAO/UNESCO classification it was classified as Haplic Ferralsol. The hillside soils at Bottom Hill and Belinge possessed argillic B horizon, moderate to high percentage base saturation with umbric and mollic epipedon respectively. They were classified as Alfisols. The Bottom Hill profile was classified as Inceptic Haplustalf (Umbric Acrisol) while Belinge profile as Mollic Haplustalf (Mollic Nitisol). Since the soils are deep, cultivation of tree crops or forestry species can best preserve the soils of these steep hillsides.

Key words: Characterization, classification, steep hillside soils, Alfisols.

INTRODUCTION

In many parts of the World today hillsides are increasingly being cultivated (Jou and Thurow, 1998). Improper hillside farming could lead to soil degradation and threaten sustainable food production. Several factors are responsible for soil degradation; "bad cropping patterns, unsuitable cultivation techniques, misuse of tractor power, improper choice of implements and machine, the abuse of natural vegetation, the extension of cultivation to marginal and sub-marginal lands, faulty irrigation and drainage systems." These problems of soil degradation impact on sustainable food production in the tropics. Of the soil degradation factors, erosion is considered the most serious factor that triggers others (Ojo-Atere *et al*, 2012).

Farming on hillsides has persisted in many parts of the world like Indonesia, Vietnam, and Malaysia where they use it for vegetable farming, because it is highly lucrative (Midmore and Poudel, 1996). The increased pressure for agricultural land use calls for increased soil management practices to protect it. Good soil management should increase production and improve the soil. Soil survey is necessary for soil classification because once soils are classified, we become sure of what properties they possess and how to manage them thus avoiding mistakes that in most cases are always very costly. Consequently, soil survey should precede land development (Ojo-Atere et al., 2012). Several soil classification efforts have been undertaken in Nigeria. These include Smyth and Montgomery (1962), Jungerius (1964), Murdoch et al., (1976), etc. These earlier works were said to be at the series level. Since there is no correlation of the various soil series of the different regions of Nigeria, this constitutes a problem in understanding soil data (Ojo-Atere et al, 2012). This calls for the use of a classification system easily understood by all for easy correlation of data. The Federal Department of Agricultural Land Resources (FDALR, 1991) identified five orders using the Soil Taxonomy of the United States Department for Agriculture (USDA). This included Alfisol, Inceptisol, Vertisol, Ultisol and Entisol. Using the FAO/UNESCO Mapping Legend, Federal Department of Agricultural Land Resources (FDALR) identified the following soil types in Nigeria; gleysols, cambisols, acrisols, luvisols, fluvisols, regosols and nitisols. In addition to these, Sonneveld (1998) identified the following Soils in Nigeria using the World Reference Base for Soil Resources (FAO, 1998); alisols, arenosols, ferralsols, leptosols, lixisols, phaeozems, plinthosols, solonertz and vertisols. Limited information is available for the soils of Obudu mountain because of the rugged plateau characterized by steep hills and rock outcrops. The objective of this study therefore was to characterize and classify (using the USDA Soil Survey Staff, 2003, and the World Reference Base of FAO, 2006) the steep hillsides most vulnerable to erosion in order to offer management advice.

MATERIALS AND METHODS

This study was located at the Obudu mountains, which is about 60 km from Obudu town, with the peak at the ranch plateau (about 1576m above mean sea level). The specific locations chosen for this study were the back slopes (mid slopes) of Belegete, Bottom Hill (Ranch Resort) and Belinge. Ekwueme (2003) stated that the Obudu mountains are found on precambrian basement complex rocks and at Obudu Mountains, the xenolith are pyroxene-bearing gneisses. The steep-sided hills which in most cases are multiple in nature are dissected by deep valleys, have slopes of 8-30 percent and above (Sonneveld, 2005). Obudu ranch plateau experiences between 1500-2000 mm of rain per annum (CRADP, 1992).

According to Bulktrade (1989), Cross River State experiences high solar radiation throughout the year. Though the mean annual temperature of the State is between 21-29 ^{0}C, the mean annual temperature at the Obudu plateau does not exceed 24 ^{0}C.

From field observations and interviews of the natives, the agriculture of the study area is made of crops and cattle rearing in mountains. The crops include cassava and cocoyams *(Colocosia antiquorum)* which are widely cultivated as annual crops. Cocoa, oil palm, banana/plantain and swamp rice are also cultivated in the lower slopes and valley bottom. There is bee (*Apis mellifera*) keeping where bush regrowth is thick or forested in the valleys. The grass lands of the upper slopes and mountain tops (plateau) are mainly used for cattle rearing.

Field Studies

Three mid-slopes (back slopes) on three different mountain ranges, were selected for study. A profile pit was dug at each of the three mountain ranges at Belekete, Bottom Hill (Ranch Resort) and Belinge (Fig. 1). Each profile was dug to a maximum of 2 m except where there was an obstruction. These profiles were studied in the field based

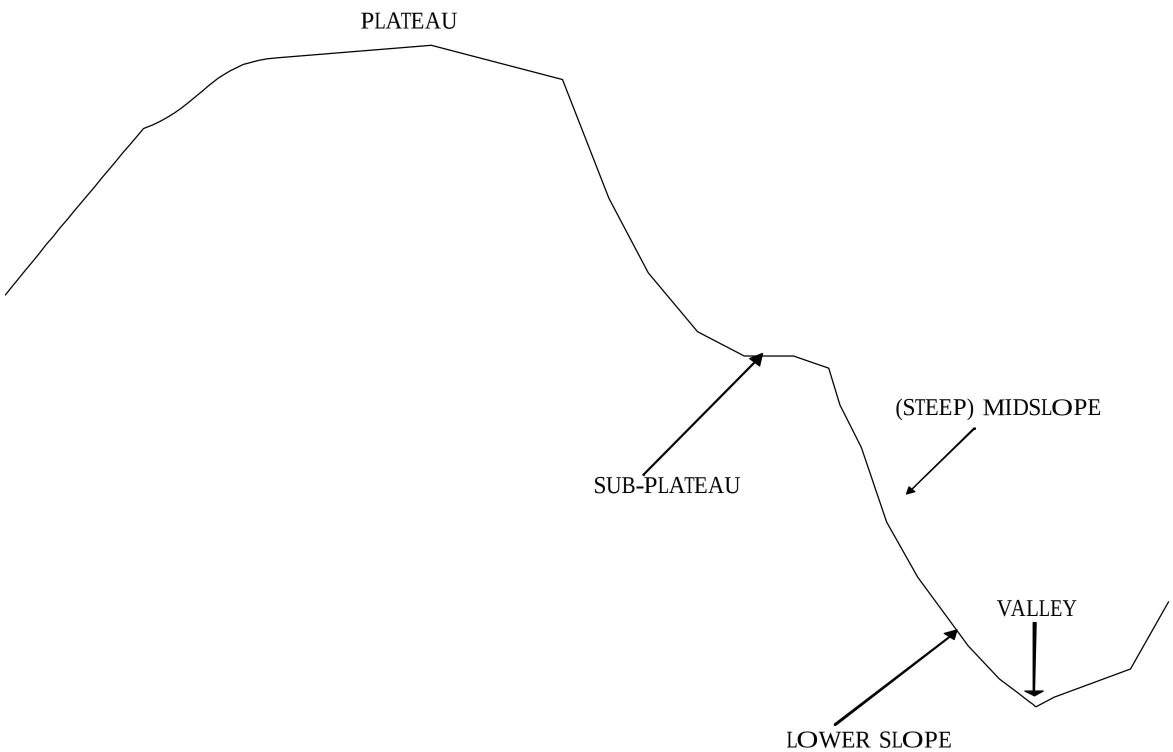

Fig. 1: Mountain toposequence showing steep midslope (back slope).

on horizons to determine their morphological characteristics. Soil samples were collected in cores from different horizons for determining the bulk density while others in polythene bags for other laboratory studies.

Laboratory studies

The samples brought from the field were air-dried, ground and sieved through a 2 mm-sized sieve. The fine earth fraction was used for particle size analysis using the Day (1965) method, which employed the Bouyoucos hydrometer, and sodium hexametaphosphate as the dispersant. From information on percent sand, silt and clay, the soil textures were determined using the USDA textural triangle (NSSC, 1995). Bulk density was determined using the Blake (1965) method while total porosity using the bulk density results (Vomocil, 1965) and particle density assumed to be 2.65 g/cm^3, for most mineral soils (Hillel, 1982).

Soil pH was determined potentiometrically with a glass electrode pH meter (IITA, 1979) in water. This was at 1: 2.5 soil-water ratio. The Walkley and Black wet oxidation method (Allison, 1965) was used to determine the contents of organic carbon while the micro-Kjeldhal method (Bremner and Mulvaney, 1982) was employed to digest and distil for total nitrogen.

The procedure of Bray and Kurtz (1945) No. 1 was used to determine available phosphorus. KCl was used for extraction and the exchangeable hydrogen and aluminium determined separately (McLean, 1965).
The contents of exchangeable cations (Ca, Mg, K and Na) were determined using the method of Chapman (1965) after leaching with IN

NH_4OAc. From the leachate the contents of Ca and Mg were read from an atomic absorption spectrophotometer (AAS) while K and Na were determined by use of flame photometer.

The CEC by NH_4OAc (pH 7.0) was determined using NH_4OAc saturation and the adsorbed NH_4^+ displaced using the acid-NaCl method (Chapman, 1965). The effective cation exchange capacity (ECEC) was determined by summing up the total exchangeable bases and exchangeable acidity (IITA, 1979). Both the effective and neutral base saturation were calculated by dividing total exchangeable bases (Ca, Mg, K and Na) by the ECEC and CEC respectively and finding their percentages (NSSC, 1995).

The two systems of soil classification used were (i) Soil Taxonomy of the United States Department of Agriculture (USDA) (Soil Survey Staff, 2003), and (ii) the FAO (2006).

RESULTS AND DISCUSSION

The depths of the (mid slope) soil profiles at Obudu mountains were 160, 140, and 130 cm for Belegete, Bottom Hill (Ranch Resort) and Belinge respectively. Using these results, it could be concluded that soils at the middle slopes were deep, falling between 100 and 150 cm or more. The soil colours were dark reddish brown (5YR 3/4), brownish black (7.5YR 2/2) and orange (2.5YR 6/8) at Belekete, Bottom Hill and Belinge (Table 1). Considering the brown to black colour of the top soils and the well drained conditions of the subsoil horizons depicted by their reddish colours, it can be concluded that the top soil colours signify high organic matter accumulation, thus, conferring high fertility to the soils (Plaster, 1992). The reddish colour of the soils is indicative that these soils are highly weathered (Olson, 1983) and the dominance of iron oxides in the pedogenic environment (Sen *et al.*, 1997).

Mottles were observed in the last horizon of the mid slope of Belinge transect. They were few, fine distinct red (10YR 4/8) mottles. The near absence of mottle confirms the well drained conditions of these soils under aerobic conditions (Sen *et al.*, 1997).

Table 1: Morphological Properties of the Obudu Mountains mid (back) slope soils

Horizon	Depth (cm)	Colour	Mottle	Texture	Structure	Consistence	Boundary
Profile 1 USDA: Typic Paleustults FAO/UNESCO: Haplic Ferralsol 1195msl							
Ah	0-10	5YR ¾	-	S L	2, 3 m & co Cr	Sl s(wet), fr(moist)	ab & s
BAt	10-35	2.5YR4/6	-	S C	2, 3 f& m sbk &abk	s&pl(wet),fr(moist)	gr & w
Btx	35-80	2.5YR3/6	-	SC	1 abk&p,	s&pl(wet),fr(moist)	c & w
Bt	80-160	2.5YR4/8	-	SC	2, m & co sbk, abk & p	pl&vs (wet), fr (moist)	
Profile 2 USDA: Inceptic Haplustalfs FAO/UNESCO: Umbric Acrisol : 1567msl							
Ah	0-50	2.5YR 6/8	-	SL	1 ,2 f & m cr & gr	ns (wet), v fr (moist)	ab & s
ABs	50-75	5YR 5/8	-	SC	1& 2 m sbk &abk	s (wet), v fr (moist)	gr & s
Bx	75-140	10YR 2/3	-	SC	3 m sbk, abk & p	v s (wet), v fr (moist)	
Profile 3 USDA: Mollic Haplustalfs FAO/UNESCO: Mollic Nitisol: 620msl							
Ap	0-22	7.5YR 2/2	-	SL	2,3 m & co cr &gr	ns (wet), v fr (moist)	ab & s
Bt	22-74	2.5YR4/6	-	SC	2,3 m & co sbk, & p	v s (wet), fr (moist)	gr & s
BCt	74-130	5YR 4/8	10YR4/8	SC	2, 3 m & co pr	pl & v s (wet), fr (moist)	

Only one horizon at Belinge had clay texture. The textures for all the topsoil horizons were sandy loam or sandy clay loam. Textures of the subsurface horizons were either gravelly sandy clay loam or sandy clay loam.

Roots were found in almost all horizons of the soils. The distribution in the top soil was many, very fine to coarse roots. At the horizons just below the top soil, the distribution was common, very fine to medium roots.

The nature of transition from one horizon to another from the surface horizons for all the profiles was abrupt and smooth. The nature of the subsoil horizon boundaries was gradual and smooth.

The silt contents of the soils generally increased with depth in the first two profiles and decreased with depth at Belinge and the range was between 16 and 28 %. Distribution of clay in the horizons decreased with depth at Belegete, fluctuated at Bottom Hill and could be said to generally increase at Belinge ranging from 18 to 40 %.

The contents of organic carbon decreased with depth except for the profile at the Bottom Hill (Ranch Resort) that was in the reverse order. The values were from 0.21 to 5.13 %. The top soil horizon values for the study sites are high and are comparable to those obtained in temperate climates (Thurow and Smith, 1998).

Table 2. Physical Properties of the Obudu Mountains mid slope soils

Profile	Horizon	Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Texture	% Gravel	Bulk Density (g/cm^3)	Porosity (%)	Hydraulic cond. (cm/hr)
	Ah	0-10	26	18	56	SCL	12.79	0.87	67.17	77.1
1	BAt	10-35	26	20	54	GrSCL	31.62	1.98	25.28	40.03
	Btx	35-80	24	22	54	GrSCL	37.33	2.06	22.26	7.58
	Bt	80-160	22	28	50	SCL	8.76	2.07	21.89	2.22
	Ah	0-50	18	18	64	GrSL	54.64	1.53	42.26	13.4
2	ABs	50-75	34	16	50	GrSCL	26.06	1.79	32.45	14.75
	Bx	75-140	18	20	62	GrSL	19.7	1.18	55.47	22.25
	Ap	0-22	18	24	58	GrSL	18.11	1.75	33.96	0.67
3	Bt	22-74	42	16	42	GrC	41.55	1.98	25.25	2.11
	BCt	74-130	40	16	44	GrCL	23.33	2	24.53	0.31

Table 3: Some Chemical Properties of Obudu mountains mid slope soils

Profile	Horizon	Depth (cm)	pH (water)	O.C (%	Total N (%	Avail. (mg/k	Ca (cmol/k	Mg (cmol/k	K (cmol/k	Na (cmol/k	EA (cmol/k	Exc.Al (cmol/kg)	Exch. H (cmol/kg)	CEC (NH$_4$OAc) (cmol/kg)	B.S (NH$_4$OA (%)	ECEC (cmol/k	B.S (cmol/k (%)
	Ah	0-10	4.1	3.00	1.06	2.63	3.14	1.40	0.32	0.21	3.20	2.6	0.6	10.50	48.29	8.27	61.31
	BAt	10-35	4.4	0.74	0.60	1.75	2.71	0.41	0.09	0.21	5.40	4.8	0.6	11.80	28.98	8.82	38.78
1	Btx	35-80	4.6	0.44	0.07	1.75	1.86	0.27	0.09	0.26	5.60	3.6	2.0	10.10	24.55	8.08	30.69
	Bt	80-16	5.0	0.21	0.04	1.75	2.00	0.33	0.09	0.23	5.80	2.2	3.6	12.50	21.20	8.45	31.30
	Ah	0-50	5.0	0.34	0.09	7.00	1.43	0.30	0.05	0.32	1.00	0.8	0.2	4.40	47.73	3.10	67.74
2	ABs	50-75	4.7	1.18	0.32	3.50	3.00	0.50	0.07	0.32	1.20	0.6	0.6	5.60	69.46	5.09	76.42
	Bx	75-14	4.1	5.13	0.81	4.38	2.00	0.43	0.18	0.26	3.20	1.6	1.6	8.20	35.00	6.07	47.28
	Ap	0-22	6.2	2.40	0.35	1.75	6.14	3.85	0.50	0.28	1.00	0.8	0.2	15.10	71.32	11.77	91.50
3	Bt	22-74	5.9	0.80	0.07	3.50	1.86	0.79	0.39	0.30	1.20	1.0	0.2	8.20	40.73	4.54	73.57
	BCt	74-13	5.7	0.32	0.07	2.63	2.00	0.59	0.27	0.26	1.40	1.2	0.2	7.30	42.74	4.52	69.03

The total nitrogen values of the surface horizons fell between 0.09 and 1.06 %. The subsurface horizon values were between 0.04 and 0.81%. Such values had been rated as high (Enwezor *et al.,* 1989; Holland *et al.,* 1989; FMANR, 1990) while Defoer *et al.,* (2000) considered them very good since nitrogen value greater than 0.1% is rated good.

The soils were deficient in available phosphorus because the values were generally less than 6.0 mg/kg (FMANR, 1990; Landon, 1991; Defoer *et al.*, 2000).

The exchangeable Ca ranged from 1.43 to 6.14 cmol/kg. The values in the topsoil ranged between 1.43 and 6.14 cmol/kg while the subsurface values were from 1.86 to 3.00 cmol/kg. The exchangeable Mg values varied from 0.19 to 3.85 cmol/kg. The topsoil values ranged from 0.30 to 3.85 cmol/kg while the subsurface values varied from 0.27 to 0.79 cmol/kg. K values varied from 0.05 to 0.5 cmol/kg. The variation of the values at the surface soils was from 0.05 to 0.5 cmol/kg while for the subsurface it ranged from 0.07 to 0.39 cmol/kg. On the other hand, exchangeable Na varied from 0.21 to 0.32 cmol/kg while the subsurface values variation was from 0.23 to 0.30 cmol/kg. Exchangeable K was rated medium in the surface horizons but high in the subsoil of these Obudu mountain mid slopes. Chude (1998) reported that exchangeable K values range from 0.07 to 0.86 cmol/kg and tend to be highest in basement complex and lowest in sandstone soils in Nigeria. The CEC values for the surface horizons were between 4.4 and 15.1 cmol/kg while in the subsoil horizons, it ranged from 5.6 to 12.5 cmol/kg. The values indicate that the soils have medium or high CEC being generally around 10 cmol/kg and above (Defoer *et al.,* 2000). The mean ECEC values of the soils are low (Udo and Ogunwale, 1986).

The base saturation values of these soils were from 30.69 to 91.50 %. Values for surface soils ranged from 61.31 to 91.50 % while for subsoil horizons, the values ranged from 30.69 to 76.41 %. These values for both surface and subsurface soils of the study sites were rated medium (Udo and Ogunwale, 1986; Landon, 1991). Chude (1998) stated that the base saturation of the forest zone in Nigeria is low, below 50%.

USDA Soil Taxonomy: Taxonomic classification of these mountain soils was undertaken at the Order, Suborder, Great Group and Subgroup levels.

Table 4: Summary of the Chemical Properties of Obudu mountains mid slope soils

Profile		pH (water)	O.C (%)	TotalN (%)	Avail. P (Mg/kg)	Ca (cmol/kg)	Mg (cmol/kg)	K (cmol/kg)	Na (cmol/kg)	EA (cmol/kg)	Exch.Al (cmol/kg)	Exch.H (cmol/kg)	CEC (NH.OAc) (cmol/kg)	B.S (NH.OAc) (%)	ECEC (cmol/kg)	B.S (ECEC) (%)
	Range	4.10-5.00	0.21-3.0	0.04-1.06	1.75-1.63	1.86-3.14	0.27-1.40	0.09-0.32	0.21-0.26	3.20-5.80	2.20-4.80	0.60-3.60	10.10-12.50	21.20-48.29	8.08-8.82	30.69-61.31
1	Mean	4.52	1.09	0.44	1.97	2.42	0.60	0.14	0.22	5.00	3.30	1.70	11.22	30.75	8.40	40.52
	S.E	0.18	0.64	0.24	0.22	0.30	0.26	0.05	0.01	0.60	0.58	0.71	0.55	6.05	0.15	7.10
	S.D	0.37	1.28	0.48	0.44	0.60	0.53	0.11	0.02	1.21	1.16	1.42	1.11	12.01	0.31	14.33
	Range	4.10-5.30	0.34-5.13	0.09-0.81	3.50-7.00	1.43-3.00	0.30-0.50	0.05-0.18	0.26-0.32	1.00-3.20	0.60-1.60	0.20-1.60	4.40-8.20	35.00-69.46	3.10-6.07	47.28-76.40
2	Mean	4.60	2.21	0.40	4.96	2.14	0.41	0.10	0.30	1.80	1.00	0.80	6.06	50.73	4.75	63.81
	S.E	0.26	1.47	0.21	1.05	0.45	0.05	0.04	0.02	0.70	0.30	0.41	1.12	10.06	0.87	8.63
	S.D	0.45	2.55	0.36	1.82	0.79	0.10	0.07	0.03	1.21	0.52	0.72	1.94	17.24	1.51	14.96
	Range	5.70 -6.20	0.32-2.40	0.07-0.35	1.75-3.40	1.86-6.14	0.59-3.85	0.27-0.50	0.26-0.20	1.00-1.40	0.80-1.20	0.20-0.20	7.30-15.1	40.73-71.32	4.52-11.77	69.03-91.50
3	Mean	5.93	1.17	0.16	2.62	3.33	1.74	0.38	0.28	1.20	1.10	0.20	10.20	51.59	6.94	78.03
	S.E	0.14	0.62	0.09	0.50	1.40	1.05	0.06	0.01	0.11	0.11	1.96	2.46	9.87	2.41	6.85
	S.D	0.25	1.08	0.16	0.87	2.43	1.82	0.11	0.02	0.20	0.20	3.40	4.26	17.11	4.18	11.88

Classification at the family level could not be undertaken because the mineralogy was not determined by instrumentation. However, the mineralogy was estimated by calculation (NSSC, 1995) which may give direction for further studies.

Profile 2 (Bottom Hill) and 3 (Belinge) were classified as Alfisols for possessing umbric A and mollic A epipedons respectively; argillic B horizon and moderate to high percentage base saturation. Profile 1(Belegete) was classified as an Ultisol for possessing kandic B horizon and percentage base saturation less than 35% by sum of cations around 200cm below the soil surface.

Further classification at the Suborder level put profiles Bottom Hill, and Belinge soils as Ustalfs for having ustic moisture regime. At the Great Group level, these profiles were classified as Haplustalfs. At the Subgroup level, profile 3 (Belinge) had mollic epipedon and classified as Mollic Haplustalf while profile 2 (Bottom Hill) was classified Inceptic Haplustalf for possessing an argillic horizon and no densic, lithic or paralithic contact within 100 cm of the soil surface.

Profile 1 being an Ultisol was classified as Ustult at the Suborder level because of its ustic moisture regime. For having no densic, lithic or paralithic material within 150 cm from the soil surface, and no clay decrease of 20 % from the maximum within 150 cm from the surface, it was classified as Paleustult at the Great Group level, and as Typic Paleustult at the Subgroup level.

Profiles 2 and 3 were classified as Acrisol and Nitisol respectively for having argillic B horizon with CEC (by NH_4OAc) of less than 16 cmo1/kg soil and base saturation less than 50% (by NH_4OAc) in at least some part of the horizon within 125 cm of the surface. Profile 2 was further classified as Umbric Acrisols for having Umbric A horizon, lacking plinthite within 125 cm of the surface and lacking hydromorphic properties within 100 cm of the surface. Profile 3 had a mollic A horizon and base saturation of less than 50% (by NH_4OAc) in at least some parts of the B horizon within 125 cm of the soil surface to be classified as mollic Nitisol. Profile 1 was classified as Ferralsols for possessing oxic B horizon within 100 cm of the soil surface and lacking argillic B horizon above the oxic B horizon. Profile 1 possessed an oxic B horizon that is neither red to dusky red nor yellow to pale yellow; lacking an umbric A horizon, and plinthite within 125 cm of the surface. At the lower category, it was classified Haplic Ferralsols.

Contrary to the expectation of encountering shallow soils on these steep hillsides, the profiles were generally deep (measuring more than 100 cm). Alfisols were the major soils on these hillsides though some others (e.g. Ultisols), could be found. Deliberate action must be undertaken to preserve the productivity of these hillsides because they are very much prone to erosion. Since the communities around these hillsides are farming on them, soil conservation measures like use of vetiver to check soil drift down hill must be incorporated in their farming technologies. Presently, there is nothing of this sort. Alternatively, crops suitable for zero tillage should be adopted. From observation, swamp rice cultivation is common in the valleys. Farmers should be encouraged to adopt upland rice on these hillsides. This will leave a lot of biomass after harvest. Also, tree species cultivation is another way of farming these steep lands and preserving their productivity.

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