

# ANNALI

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ORGANO UFFICIALE  
DELLA SOCIETÀ SASSARESE DI SCIENZE MEDICHE E NATURALI



**MORPHOLOGICAL, CHEMICAL AND MINERALOGICAL  
CHARACTERIZATION OF SOME SOILS DEVELOPED ON  
HARD CARBONATE ROCKS IN SARDINIA <sup>(1)</sup>**

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**SUMMARY**

This preliminary note considers 19 profiles of Sardinian soils developed on hard limestone, dolomitic limestone and dolomite of different age and territorial condition, reporting on the description of the profiles and their physical, chemical and mineralogical characteristics. The results indicate that the soils examined belong to xeric subgroups of three orders: Entisols, Inceptisols and Alfisols.

All the profiles show a clay texture and the clayey constituents are related to the degree of soil evolution.

Keywords: Sardinian soils, Iron minerals.

**RIASSUNTO**

**Caratterizzazione morfologica, chimica e mineralogica  
di alcuni suoli evolutisi su rocce calcaree in Sardegna**

Questa nota riporta le caratteristiche fisiche, chimiche e mineralogiche di 19 profili di suoli della Sardegna evolutisi su calcari compatti, calcari dolomitici e dolomiti di diversa età e condizione territoriale. I risultati indicano che i suoli esaminati appartengono a sottogruppi xerici dei tre ordini: Entisuoli, Inceptisuoli e Alfisuoli. Tutti i profili presentano tessitura argillosa e la composizione della frazione argillosa è in relazione al grado di evoluzione del suolo.

Parole chiave: Suoli della Sardegna, Minerali di ferro.

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## INTRODUCTION

Sardinian soils which have developed on crystalline calcareous or dolomitic substrata often occur in areas of particular natural beauty and are sometimes subjected to agricultural use. There are no studies relative to the genesis, properties and classification of these soils, except for pedological regional cartographies and particular problems (1), (3), (4), (5), (6), (19), (20). So we started a research with the aim of contributing to better knowledge, use and preservation of these soils. This preliminary note reports the description of some profiles typical of different territorial conditions and their physical, chemical and mineralogical characteristics and constitutes an essential background to further studies.

## AREA STUDY

### *Parent material*

In order to investigate the influence of the parent rock on the pedogenic process, we drew up soil profiles developed on hard limestone, dolomitic limestone and dolomite of different eras (tab.1). The description of the most frequent lithological substrata, on which the profile sampling was carried out, is shown below:

- PALEOZOIC: Cambrian (profiles 5, 13, 14, 19)  
Carbonate rock, found in south-western Sardinia, is represented by oolitic and archeocyatidic limestone, more or less arenitic dolomite mixed into the limestone formation, striated or grey massive dolomite, waxy Metalliferous limestone and nodular limestone of Cabitza formation.
- MESOZOIC: Triassic (profiles 2 and 3)  
Dolomite and compact limestone, bugholed dolomite and marly and chalky domes, dark limestone weathered to marl and marly limestone.
- MESOZOIC: Jurassic
  - a) western basin (profiles 1, 4, 17): limestone, siliceous, oolitic, dolomitic, marly and detrital limestone;
  - b) Region of “tacchi” and “tonneri” (profiles 15, 16): characteristic buttes composed of dolomitic limestone over an arenaceous and conglomerate facies.
- CENOZOIC: Miocene (profiles 6, 7, 8, 9, 10, 11, 12, 18): biothermal, marly, compact bioclastic limestone and calcarenites.

### *Vegetation and Land Use*

Only in a few cases the sampling was carried out in cultivated areas. The vegetative associations that occur in the wild areas examined are typical of the following climax, drawn up by Arrigoni (2), who reports a detailed phytoclimatic description of Sardinia:

Table 1 - Monthly temperature and rainfall values (1922-1975) and climatic type (Tornthwaite, 1948) of some stations near to the sampling sites.

Tab. 1 - Valori delle temperature e precipitazioni mensili ( 1922-1975) e tipo climatico (Tornthwaite, 1948) di alcune stazioni prossime ai siti di campionamento.

	CAGLIARI		FLUMINI MAGGIORE		VILLANOVATULO		SASSARI	
January	10.5	49.0	9.9	101.0	8.2	89.2	8.9	63.0
February	10.9	45.0	10.4	88.0	8.7	89.2	9.3	59.0
March	12.6	40.0	11.3	67.0	10.1	76.4	11.2	53.0
April	15.0	32.0	13.3	54.0	12.9	59.7	14.1	44.0
May	18.5	31.0	17.0	40.0	16.2	48.4	17.3	36.0
June	22.6	9.0	19.9	14.0	20.5	20.6	21.4	14.0
July	25.3	2.0	22.5	1.0	23.7	10.4	24.2	4.0
August	25.5	7.0	23.0	8.0	23.9	11.6	24.5	10.0
September	23.2	34.0	20.9	33.0	21.2	40.6	22.0	49.0
October	19.2	61.0	17.7	82.0	16.2	67.5	17.6	72.0
November	15.2	60.0	13.9	110.0	12.3	88.7	13.4	89.0
Dicember	11.7	65.0	10.9	126.0	9.2	114.3	10.1	90.0
Climatic Type	D d B'3 d'		C1 w2 B'2 d'		C1 w2 B'2 d'		C1 w B'2 d'	

- 1) thermoxerophylic climax of the forests with mixed sclerophyllae and coastal scrub, characterized by:
  - horizon of brushwood and coastal scrub (profiles 1, 2, 4, 12, 17, 18, 19);
  - horizon of forest of mixed evergreen sclerophyllae (profiles 3, 5, 6, 7, 8, 9, 10, 11);
- 2) climax of *Quercus ilex* forest, characterized by:
  - mesophylic horizon of *Quercus ilex* forest (profiles 13,14);
  - cold humid horizon of mountain forests of *Quercus ilex* and *Quercus pubescens* (profiles 15,16).

### *Climate*

Due to its geographical position Sardinia has climatic conditions typical of the mediterranean area, characterized by autumn-winter rainfall and serious summer water deficit. The insularity of the region produces mild climatic conditions in the coastal areas whereas some areas of the hinterland have microclimatic conditions characterized by higher rainfall and lower average temperatures (sites 13 and 14). The data of the mean monthly and annual rainfall and temperature of some representative stations situated in areas near the sampling sites (table 1) were elaborated according to Thornthwaite (30) (fig. 1). This method allowed us to identify the climate type and the soil water regime of each station and to classify the soils according to the Soil Taxonomy (28) (table 2).

Table 2 - Description fo some representative profiles.  
 Tab. 2 - Descrizione di alcuni profili rappresentativi.

Profile number	Location Comune s.s.l. (Province)	Elevation s.s.l. (a)	Parent material (type)	Landfor	Vegetation and land use	Horizon	Depth (cm)	Colour mount	Tenure	Structure	Consistence	Drainage	Bounding clay	Calcians	Skeleton vol%	Moistening	Moisture	Soil Taxonomy (USDA, 1975)
1	Arca de Canai S. Antioco (Cagliari)	110	limestone and dolomite (Jurassic)	hillside	degraded xerophillic scrub (garigue)	A1	0-20/22	5YR 3/3	C	f/m 3 sbb/ct	f/m 3	mfr 4	4	s	-	25-30	- 2	Lithic Xerothent
2*	Capo Caccia Alghero (Sassari)	116	compact limestone (Cretaceous)	hillside	degraded xerophillic scrub	Bt	0-40	2.5 YR 4/6	C	f/m 3 sbb	dhb 4	4	s	sa	10/15	-	4	Lithic Rhodoterrif
4	Arca de Canai S. Antioco (Cagliari)	65	limestone and dolomite (Jurassic)	hillside	degraded xerophillic scrub	A1	0-27/30	2.5YR 4/4,5	C	f/m 2 sbb	mfr 4	4	c	-	5/10	-	2	Integrate between Lithic Rhodoterrif and Typic Rhodoterrif
5	Puna Quadrosu Sennadi (Cagliari)	129	dolomite limestone (medium Cambric)	hillside	pastured xerophillic scrub	A1	0-12/18	2.5YR 3/4	C	0 sbb	dhb 4	4	c	-	5	-	4	Typic Rhodoterrif
						Bt1	12/18-45/55	2.5YR 3/6	C	m3 sbb	dh 3	8	8	5	5	-	4	
						Bt2	45/55-63/75	2.5YR 3/6	C	m/c 3 sbb	dh 2	8	8	sa1	2,5	-	4	
						Bt3	65/75-90/100	2.5YR 3/6	C	c/vc 3 sbb	dh 2	8	8	sa1	5/10	fld	4	
6**	Monte Frescu (Sassari)	120	organogenic limestone, compact calcarenite (Miocene)	plateau	pastured grassland	Ap	0-25	5YR 4/4	SC	m 3 sbb/sbb	mfi 4	4	s	-	5	-	2	Typic Rhodoterrif
						Bt	25-65/70	2.5YR 3/6	SC	m 3 sbb	mfi 4	4	s	sa1	5	-	2	
12	Monte Urpinu (Cagliari)	95	compact organogenic limestone (Miocene)	hillside	xerophillic scrub	A1	0-15	5YR 3/3	SC	f/m 3 sbb/sbb	mfr 4	4	s	-	10	-	2	Lithic Rhodoterrif
						Bt	15-35	5YR 3/3	SC	f/m 3 sbb	mfr 4	4	s	sa1	10-15	-	4	

segue tab. 2

13***	Punta Piedra Piccola Iglesias (Cagliari)	725	vezaat debris on dolomitic limestone (Cambrian)	mountain- side	Quercus flex forest	Or A1	1.5-0.5 0.5-0.0 0-10/12	scarce/decomposed organic residues partially decomposed organic residues	SL f 3 cr/abk	f 3 mfr 4 c	10-20	2	Typic Xerochrept
						Bw1	10/13.10/40	SL f 3	mfr 4 B	4 B	3.5	2	
						Bw2	30/40-70/80	SL 3 f	mfr 4 B	4 B	3	2	
						Bw3	70/80-90/100	SCL 3 B	mfr 4 B	4 B	3.8	2	
15	Su Stampu Scui (Nuoro)	1160	limestone, dolomitic limestone, dolomitic (Jurassic)	mountain- side	pastured scrophilic grassland	A1	0-40	C	m 3 abk	mfr 4 B	30	2	Lithic Xerochrept
16	Tacca S. Maria Sudali (Nuoro)	610	limestone, dolomitic limestone, dolomitic	mountain- side	Quercus flex forest	A11 A12/Bw1	0-10/35 30/35-50/75	SCL SCL	f/m 2 abk/abk m/2 abk	mfr 4 B	60-80 60-80	2	Cumalic Xerochrept
18	Matta Canna Cabasa (Oristano)	30	organogetic limestone (Miocene)	flat	arable	Ap	0.15/20	CL	m 3 abk	dbh 4 B	3.5	4	Lithic Rhodoveralf
						Bt	17/20-10/40	CL c 3	dbh 4 B	4 B	2.5	4	
19	Is Tre Canabbi Boggero (Cagliari)	110	limestone, dolomitic limestone (Cambrian)	plateau	degraded scrophilic scrub	A1 Bt	0.25/50 25/30-40/70	SCL SC	f 3 abk m(c) 3 abk	dbh 4 B	20 45-50	4	Lithic Rhodoveralf

\* Similar to profiles 3, 11, 17. \*\* Similar to profiles 7, 8, 9, 10. \*\*\* Similar to profile 14. 0 USDA, 1952: pages 139, 140, 141, 170, 171. 00 a = clay; s = sesquioxides. 0 = 0 - 1 = < 10%  
 . 2 = 10-50% . 3 = > 50%.

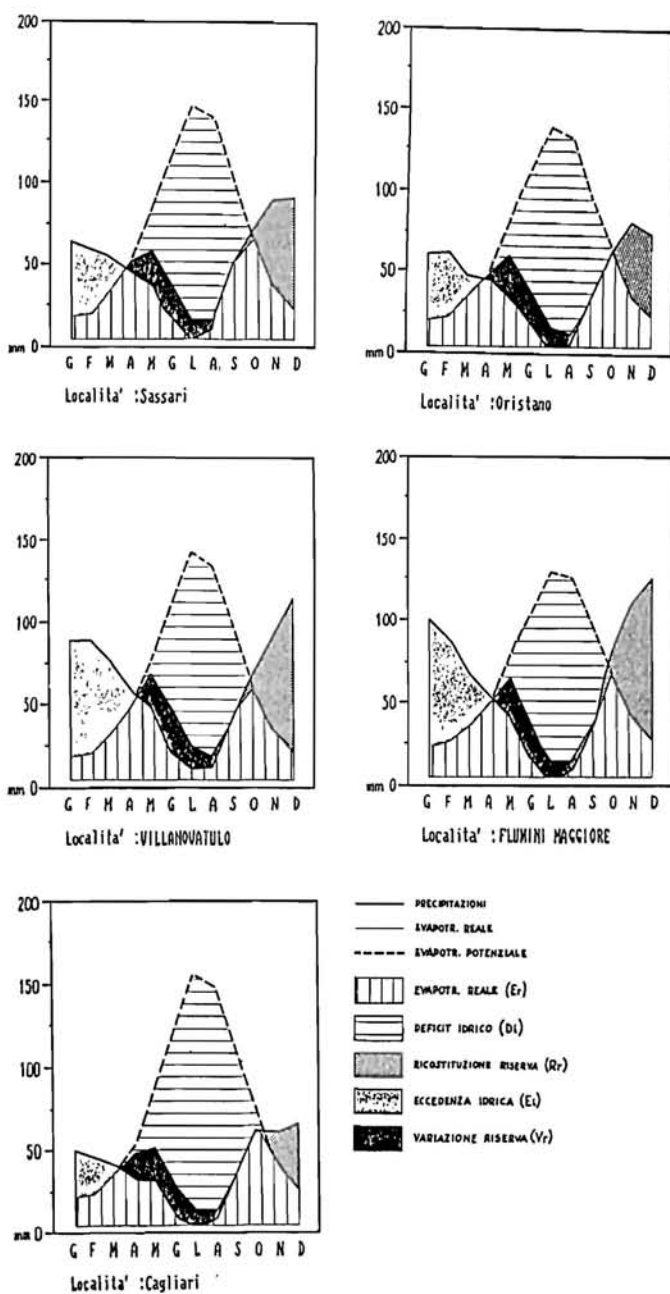


Fig. 1 - Hydrological balance of some stations near the sample profiles.

Fig. 1 - Bilancio idrologico di alcune stazioni prossime ai profili campionati.

## MATERIALS AND METHODS

Soil samples were collected in different localities of Sardinia from 19 profiles developed on hard limestone, dolomitic limestone and dolomite (fig. 2), taking into account the substratum age, geographic location and land use. The description of the profiles was performed in accordance with the criteria reported by Sanesi (24) and FAO (10). The classification of the soils was performed using the criteria reported in the Soil Taxonomy (29) and FAO classification (11).

Particle size analysis of the <2mm soil fractions was carried out by the pipette method (21) both in hexametaphosphate suspension (untreated samples) and after H<sub>2</sub>O<sub>2</sub> and dithionite-citrate-bicarbonate (DCB) treatment and hexamethaphosphate dispersion (treated samples).

pH was measured in a 2.5:1 soil:solution suspension. The exchange bases and the CEC at pH 8.2 were determined according to the SISS methodology (26). The AEC was evaluated by the method suggested by Mehlich (17).

Humic and fulvic acids were extracted using the method reported by Kononova (15). Organic carbon content was found by dichromate oxidation (31) and nitrogen by the Kjeldahl method; carbonate was determined by the volumetric method.

Ammonium oxalate and DCB soluble Fe, Al and Mn were extracted according to the method of Schwertmann (25) and Mehra and Jackson (18), respectively; extracts were spectrometrically analysed to quantify the removed ions with a Beckman Spectraspan IV instrument.

Identification of clay minerals was carried out by X-ray diffractometric analysis on oriented samples of DCB treated clay fractions, using a Philips PW 1730 instrument with Cok<sub>α</sub> radiation operating at a rate of 1.2 2θ/min.

The iron oxides were concentrated by boiling 1g of the <2 μm fractions with 100 ml of a 5M NaOH solution. In order to prevent dissolution and recrystallization of iron compounds a proper amount of Na<sub>4</sub>SiO<sub>4</sub> was added to obtain a final Si concentration of 0.2M (14). The concentrated powdered fractions were subjected to diffractometric analysis.

## RESULTS AND DISCUSSION

Table 3 gives particle size distribution after H<sub>2</sub>O<sub>2</sub> and dithionite treatment and hexamethaphosphate dispersion (treated samples). Percentages in brackets show the distribution obtained for some profiles after hexamethaphosphate dispersion (untreated samples).

Comparison of the values obtained by the two different analytical methods indicates that the removal of organic matter and iron compounds causes an increase in the clay fraction, due to the destruction of microaggregates, and a consequent variation of the silty and sandy fractions.



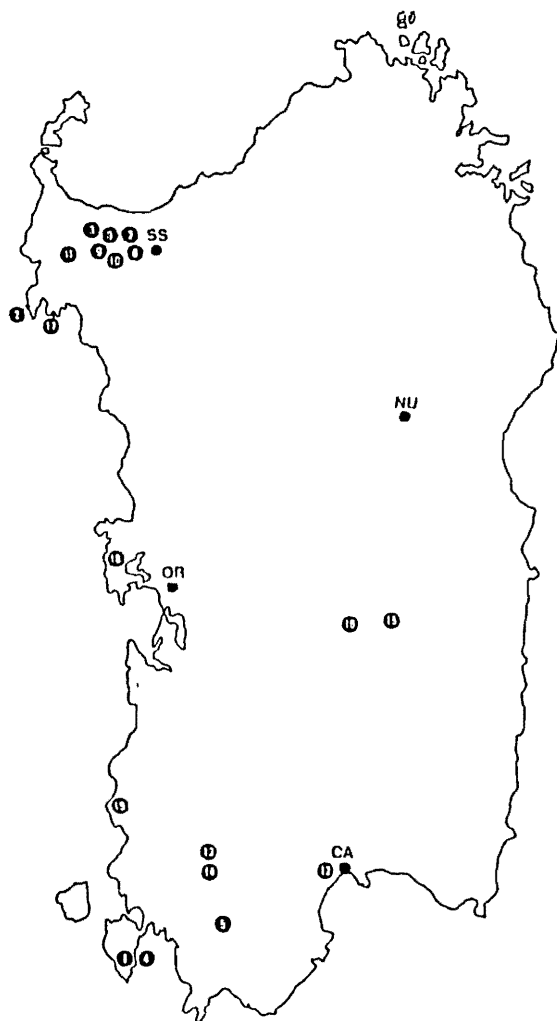


Fig. 2 - Profile location.

*Fig. 2 - Ubicazione dei profili.*

A certain rise in clay content occurs along profiles 5 and 10, which can be interpreted as an illuviation phenomenon, shown by the presence of clay coatings on the ped surfaces (table 2). Therefore, the presence of an argillic horizon justifies the classification of these soils as Typic Rhodoxeralfs. Movement of the finer fractions in the other Typic and Lythic Rhodoxeralfs is not excluded as morphological observations clearly indicate the presence of clay skins on the ped surfaces.

Table 3 - Particle size distribution after esamethaphosphate dispersion of treated samples (H<sub>2</sub>O<sub>2</sub> and DCB) and untreated samples (in brackets).

Tab. 3 - Granulometria dopo dispersione in esametafosfato dei campioni trattati (H<sub>2</sub>O<sub>2</sub> e DCB) e non trattati (tra parentesi).

PROFILE NUMBER AND HORIZON	COARSE SAND	FINE SAND	SILT	CLAY
	%	%	%	%
1 A	2.3	18.3	15.1	64.3
2 Bt	3.4 ( 2.4)	16.9 ( 8.8)	16.6 (36.8)	63.1 (52.0)
3 Bt	1.3 (1.3)	20.3 (12.5)	14.7 (28.4)	63.7 (57.8)
4 A	2.6	22.0	15.5	59.9
Bt	2.8	22.7	14.2	60.3
5 A	9.5 (13.9)	25.9 (19.4)	20.9 (40.0)	43.7 (26.7)
Bt1	6.5 ( 5.8)	16.2 (14.5)	15.6 (22.9)	61.8 (56.8)
Bt2	10.0 (12.5)	26.0 (19.0)	13.0 (23.8)	51.0 (44.7)
Bt3	10.3 (10.4)	18.0 (18.6)	12.2 (20.1)	59.4 (50.9)
Bt4	8.6 ( 8.4)	19.0 (17.4)	9.8 (23.2)	62.5 (51.0)
6 A	20.7	30.4	9.7	39.2
Bt	18.9	30.5	10.0	40.6
7 A	15.0	39.4	10.9	34.7
Bt	14.6	37.3	11.4	36.7
8 Bt	12.0 (11.4)	29.0 (21.2)	10.9 (29.8)	48.3 (37.6)
9 Ap	7.7	40.6	11.7	40.0
10 A	6.1	43.5	15.8	34.6
Bt	2.7	19.2	13.2	64.9
11 Bt	18.5	41.6	9.8	30.1
12 A	14.0	31.5	16.2	38.3
Bt	12.4	31.1	16.5	40.0
13 A	8.7 (10.1)	29.4 (31.2)	23.7 (30.1)	38.1 (28.6)
Bw1	6.8 ( 8.2)	34.1 (32.4)	19.1 (21.1)	40.0 (38.3)
Bw2	7.7 ( 9.1)	33.3 (30.1)	20.8 (26.8)	37.9 (34.0)
Bw3	31.7 (32.3)	29.1 (27.2)	8.9 ( 5.4)	30.3 (35.1)
14 A	3.8	18.2	25.7	52.2
Bw1	2.5	13.4	43.3	40.7
Bw2	3.5	13.7	42.3	40.5
Bw3	13.9	19.0	16.9	50.1
15 A	6.7	16.3	20.3	56.7
16 A	35.2	33.4	4.9	26.6
Bt	33.7	36.7	4.6	24.9
17 Bt	6.8	24.5	21.5	47.1
18 Bt	8.8	26.2	33.5	31.5
19 Bt	18.6 (20.2)	30.2 (28.6)	11.5 (16.6)	39.6 (34.5)
Bt	18.8 (20.3)	30.5 (28.2)	10.2 (13.3)	40.4 (38.2)

The increase in the clay content in the treated samples is correlated neither to the amount of organic matter ( $r = -0.14$ ) nor to oxalate extractable iron ( $r = 0.25$ ) or dithionite extractable iron (FeDCB - Fe<sub>ox</sub>) ( $r = 0.25$ ). This indicates that the strong structure of these soils (table 2) does not depend on the amount of these cements but on the complex interactions which they establish with each other.

The main clay mineral constituents, identified by X-ray diffraction analysis of the oriented DCB-treated clay fractions, are reported in table 5. All Rhodoxerals show similar X-ray patterns: that relative to profile 2 is reported as an example in fig. 3. Illite and kaolinite are the main constituents with a great prevalence of the former. The presence and persistence of a reflection at 14Å at temperatures as high as 550 °C indicates the presence of chlorite.

X-ray patterns of the profiles characterized by a lower evolution degree (Xerochrepts 13, 14 and 16; Xerorthent 15) show a well defined peak at 14Å which does not shift upon ethylene glycol solvation and does not completely collapse to 10Å when heated to 550 °C, but changes into a more or less pronounced band between 14 and 10Å, indicative of interlayer material (fig. 4). The treatment with NH<sub>4</sub>F 1N (23) produces a partial collapse of the 14Å reflection and an enhancement of the 10Å reflection due to the removal of some interlayer material. This suggests the presence of 2:1-2:2 intergrades in these samples. The persistence of the reflection at 14Å at 550 °C is indicative of the presence of chlorite. Illite and kaolinite are easily distinguishable. X-ray diffraction analysis of powdered samples indicates that the crystalline iron oxides are goethite and hematite, identified, after destruction of kaolinite by the NaOH treatment, by the reflections at about 2.45 and 2.51 Å, respectively (fig. 5), whose position varies slightly from sample to sample due to aluminum substitution. Selective dissolution analyses were carried out on the <2mm fraction (table 4). The amount of DCB extractable iron seems to be related to the age of the parent rock, being generally greater as the age of the parent rock increases. On the other hand, the soil iron content could be also related to the concentration of this element in the parent rock. Data is lacking to allow us to draw up definitive conclusions, but this hypothesis is partly supported by the high iron content (2508 ppm) of the cambrian parent rock of profile 5, which reflects the high iron concentration of this soil (9). The Fe<sub>ox</sub>/FeDCB-Fe<sub>ox</sub> ratios, indicated in table 4 as activity ratios (8), show that crystalline iron phases prevail over poorly ordered compounds, their concentration being higher than 90%. The lack of significative differences among samples characterized by different amounts of organic matter suggests this did not interfere with the formation of iron minerals either because they were inherited from the parent rock or because organic matter quickly oxidizes under the xeric climatic conditions which characterize the region.

As crystalline aluminum phases were not identified by the XRD analysis, it is held that most aluminum is not present as a separate phase, but as a vicariant ion in the

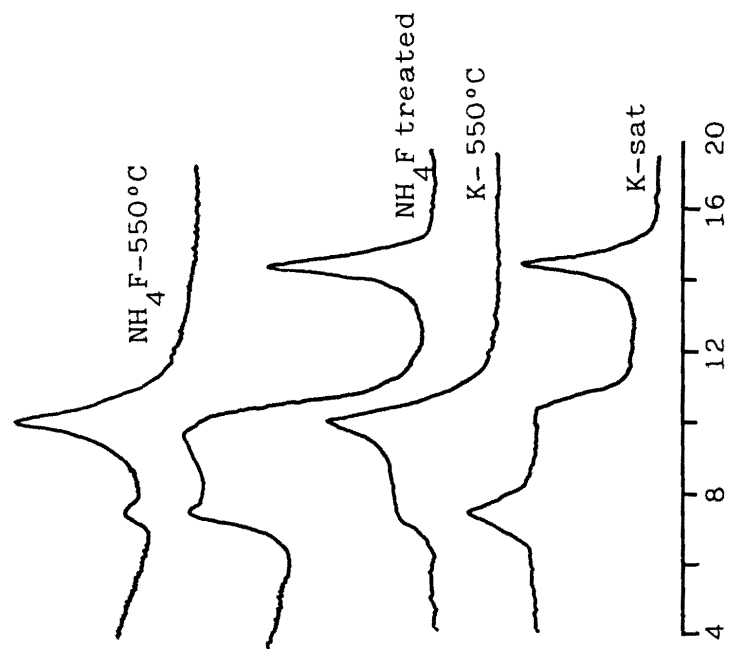


Fig. 4 - X-ray diffraction patterns of the oriented  $< 2 \mu\text{m}$  DCB-treated fraction of profile 13Bw3.

Fig. 4 - *Diffrazionigrammi RX della frazione orientata  $< 2 \mu\text{m}$  del profilo 13Bw3 dopo trattamento a DCB.*

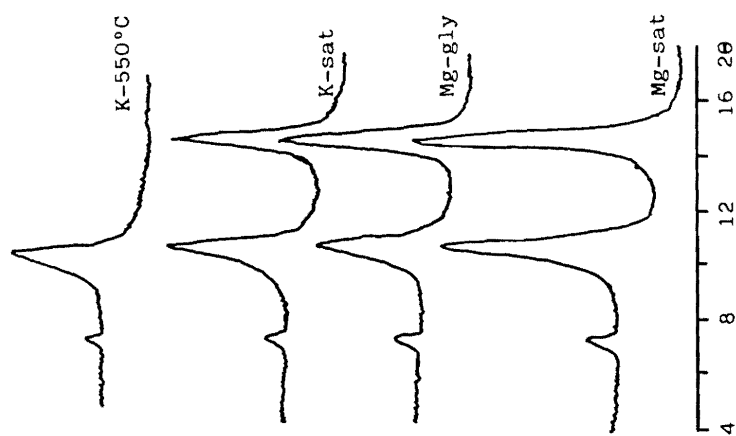


Fig. 3 - X-ray diffraction patterns of the oriented  $< 2 \mu\text{m}$  DCB-treated fraction of profile 2.

Fig. 3 - *Diffrazionigrammi RX della frazione orientata  $< 2 \mu\text{m}$  del profilo 2 dopo trattamento a DCB.*

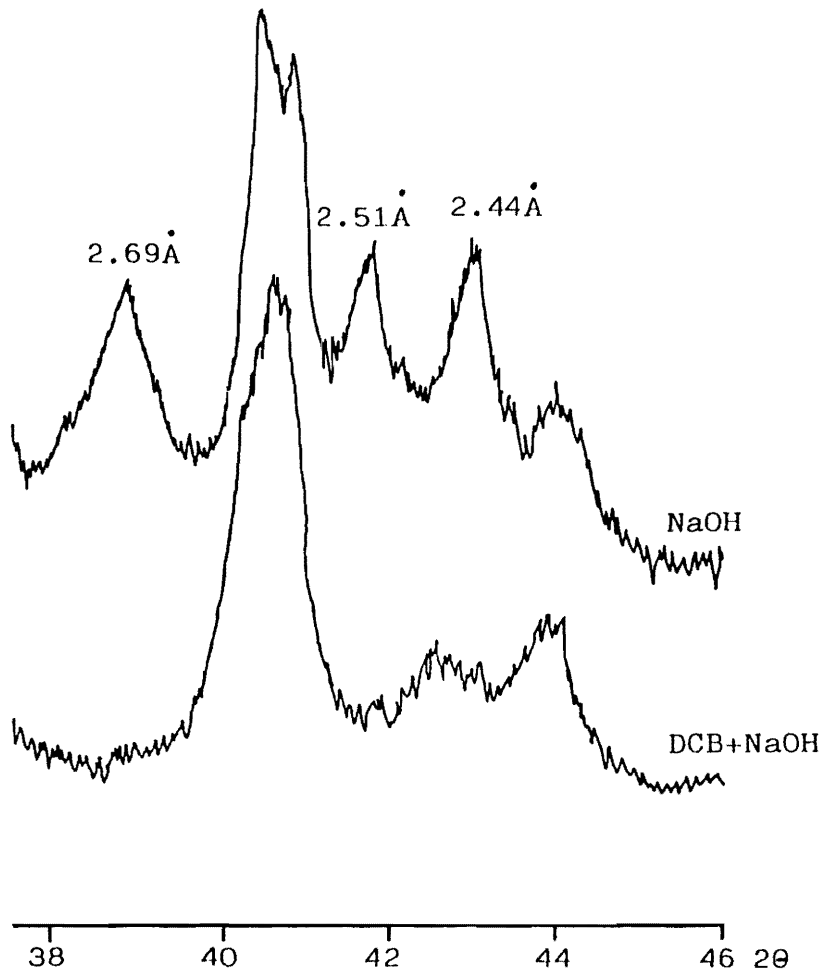


Fig. 5 - X-ray diffraction patterns of the powdered  $<2 \mu\text{m}$  fraction of profile 5Bt1.

Fig. 5 - *Diffratogrammi RX della frazione in polvere  $<2 \mu\text{m}$  del profilo 5Bt1.*

iron octahedral positions of goethite and hematite. A detailed study on some of these samples allowed us to attribute an Al substitution degree varying between 5 and 16 mol% Al (9), values similar to those found in soils of the same geographic area derived from granite (13).

Since the correlation between the Fe(DCB-ox)- and Al(DCB-ox)-dithionite extracted was good enough ( $r=0.68$ ), we estimated the theoretical Al substitution degree (table 4). The presence of small amounts of aluminum in the lattice of goethite and hematite

Table 4 - Oxalate and DCB extractable Fe,Al e Mn in the &lt;2mm fraction.

Tab. 4 - Fe, Al e Mn estratti in ossalato e DCB nella frazione &lt;2mm.

PROFILE NUMBER AND HORIZON	Fe			Al			Mn	
	ox %	DCB %	Activity ratios	ox %	DCB %	SD* moli %	ox %	DCB %
1 A	0.25	2.5	0.11	0.29	0.65	24	0.08	0.08
2 Bt	0.09	3.0	0.04	0.20	0.54	24	0.02	0.03
3 Bt	0.09	3.3	0.03	0.16	0.57	21	0.05	0.07
4 A	0.15	2.8	0.06	0.25	0.50	16	0.05	0.10
Bt	0.08	2.8	0.04	0.23	0.55	25	0.04	0.08
5 A	0.57	6.4	0.10	0.29	0.66	12	1.00	1.03
Bt1	0.48	10.3	0.05	0.18	0.66	9	1.00	1.08
Bt2	0.39	7.2	0.06	0.14	0.64	13	0.64	0.75
Bt3	0.44	8.4	0.05	0.13	0.67	12	0.85	1.14
Bt4	0.56	11.9	0.05	0.13	0.73	10	1.10	1.41
6 A	0.07	2.0	0.04	0.13	0.40	23	0.08	0.09
Bt	0.09	2.6	0.04	0.17	0.50	21	0.08	0.10
7 A	0.10	2.2	0.05	0.14	0.45	21	0.06	0.07
Bt	0.07	2.3	0.03	0.12	0.45	23	0.05	0.07
8 Bt	0.15	3.5	0.04	0.14	0.50	18	0.05	0.08
9 Ap	0.10	2.4	0.04	0.15	0.45	21	0.07	0.11
10 A	0.11	3.1	0.04	0.09	0.60	25	0.10	0.12
Bt	0.09	4.8	0.02	0.13	0.70	20	0.07	0.09
11 Bt	0.14	3.4	0.04	0.11	0.45	18	0.07	0.08
12 A	0.09	1.9	0.05	0.26	0.35	9	0.03	0.04
Bt	0.08	1.9	0.04	0.30	0.30	0	0.03	0.04
13 A	0.30	6.0	0.05	0.36	1.15	22	0.88	1.10
Bw1	0.43	7.0	0.06	0.44	1.50	25	0.97	1.30
Bw2	0.33	7.0	0.05	0.34	1.50	26	0.77	1.37
Bw3	0.35	7.0	0.05	0.35	1.24	21	0.79	1.16
14 A	0.34	7.2	0.05	0.67	1.10	12	1.15	1.25
Bw1	0.32	10.0	0.03	0.63	1.36	14	1.20	1.40
Bw2	0.30	9.5	0.03	0.40	1.22	16	1.16	1.37
Bw3	0.18	7.6	0.02	0.24	0.90	16	0.95	1.24
15 A	0.17	4.0	0.04	0.40	0.90	21	0.27	0.32
16 A	0.08	2.4	0.03	0.26	0.34	7	0.04	0.05
Bt	0.05	2.2	0.02	0.24	0.34	9	0.03	0.05
17 Bt	0.06	3.0	0.02	0.17	0.38	13	0.05	0.05
18 Bt	0.09	1.8	0.05	0.18	0.38	20	0.04	0.06
19 A	0.10	3.7	0.03	0.19	0.47	13	0.51	0.56
Bt	0.10	4.2	0.02	0.18	0.46	12	0.54	0.59

\* Aluminum substitution degree (moli%) in crystalline iron compounds calculated by hypothesizing all Al substituting Fe.

could also explain the low values of oxalate extractable iron as it is known that partial substitution increases the stability of poorly crystalline iron oxides against dissolution (12)(22).

Concentrations of dithionite extractable manganese higher than those reported in literature (7) were detected in some profiles, particularly in profile 5, where the high Mn content is partly related to the composition of the parent cambrian limestone, in whose insoluble residue were detected 756 ppm of Mn (9).

Slightly lower Mn concentrations were determined in the oxalate extracts, similar to the findings of Blume and Schwertmann (8).

The soil organic matter content (table 5) is related to the phytocenotic type which develops under different pedoclimatic conditions. Under well developed mediterranean scrub or *Quercus* stands high amounts of organic matter occur in the upper horizons (Xerochrepts and Xerorthents). Lower amounts are generally found in the Rhodoxeralfs, where the scarce vegetation debris is subjected to photochemical oxidation processes, catalysed by iron oxides and hydroxides (16).

The low value of the HU/HF ratio in most soils indicate that the humification process is moderate. The lowering of the HU/HF ratios in the deep horizons demonstrates the scarce mobility of humic compounds through the profile, presumably bound to Ca and Fe.

In the majority of Rhodoxeralfs the C/N ratio varies between 10 and 13 and in some deep horizons, where the scarce organic matter is quickly oxidized, ratios below 10 occur. Ratios above 13 are found in Rhodoxeralfs under a well developed vegetation and in most horizons of Xerochrepts.

The soil reaction is characterized by neutral or poorly alkaline values; the CaCO<sub>3</sub> content (not reported) in the Rhodoxeralfs is lower than 1.0% . Slightly higher values are found in profiles 5 and 12 which are probably related to the presence of more or less minute fragments of skeletal debris, particularly abundant in these soils, which could have passed into the <2mm fraction during the preparation of the sample to be analysed.

The values of the cation exchange capacity are fairly high (table 5) if we consider that the clay fraction is mainly illitic, but the great influence that organic matter and iron compounds have on CEC under the reaction conditions of these soils should be taken into account. Thus, the horizons characterized by the highest amounts of organic matter also show the highest CEC values and a decrease throughout the profile is registered as the organic matter content decreases.

Furthermore, amorphous and crystalline iron compounds may contribute to the CEC by supplying sites active in cationic adsorption. In fact, since iron minerals such as hematite and goethite commonly have zpc values in the range of pH 7.0-8.0, at pH 8.2 (value of the exchange solution) they show a net negative surface charge which contributes to cationic adsorption.

Table 5 - Chemical characteristics and clay minerals of the examined profiles.

*Tab. 5 - Caratteristiche chimiche e minerali argillosi dei profili esaminati.*

PROFILE NUMBER AND HORIZON	pH		OM %	HU/HF %	N	C/N %	CEC AEC		Clay minerals*
	H <sub>2</sub> O	KCl					meq/100 g		
2 Bt	7.8	7.1	0.9	0.46	0.05	10.4	17.1	8.9	I,K,Chl
3 Bt	7.9	6.9	1.2	1.01	0.08	8.7	21.5	8.9	I,K,Chl
4 A	7.9	7.3	4.3	1.68	0.18	13.8	30.9	9.1	I,K,Chl
Bt	7.9	7.1	1.9	1.54	0.11	10.0	28.8	8.6	I,K,Chl
5 A	7.6	6.8	3.9	2.46	0.18	12.5	27.6	8.5	I,K,Chl
Bt1	7.6	6.9	0.7	1.02	0.03	13.7	19.0	8.6	I,K,Chl
Bt2	7.8	7.4	0.6	0.96	0.05	14.0	19.6	10.4	I,K,Chl
Bt3	8.2	7.5	0.3	0.90	0.04	4.2	19.3	12.8	I,K,Chl
Bt4	8.2	7.4	0.3	0.92	0.04	4.2	20.1	12.2	I,K,Chl
6 A	7.8	6.8	2.2	2.40	0.11	11.6	21.4	5.9	I,K,Chl
Bt	7.8	6.8	1.6	1.40	0.08	11.6	20.3	6.5	I,K,Chl
7 A	7.6	7.2	3.0	1.70	0.16	10.8	22.8	6.2	I,K,Chl
Bt	6.9	6.8	1.4	0.81	0.06	13.5	17.4	6.4	I,K,Chl
8 Bt	7.4	7.2	3.3	1.60	0.17	11.2	17.4	6.2	I,K,Chl
9 Ap	7.4	7.1	1.5	1.20	0.06	14.5	18.4	7.1	I,K,Chl
10 A	7.0	6.1	2.9	2.40	0.11	15.3	18.9	3.5	I,K,Chl
Bt	7.4	6.4	1.1	0.80	0.07	9.1	17.5	8.4	I,K,Chl
11 Bt	7.8	6.9	2.1	2.03	0.11	11.1	18.3	6.2	I,K,Chl
12 A	7.9	7.3	6.2	1.25	0.40	9.0	35.9	7.2	I,K,Chl
Bt	8.0	7.2	1.2	1.16	0.23	3.0	32.0	8.2	I,K,Chl
13 A	7.1	6.6	16.6	2.89	0.54	17.8	44.1	9.5	I,K,Ig,Chl
Bw1	7.2	6.4	1.3	1.61	0.04	18.7	17.8	11.8	I,K,Ig,Chl
Bw2	7.1	6.3	0.4	1.26	0.01	23.0	13.3	9.6	I,K,Ig,Chl
Bw3	7.2	6.0	0.2	0.66	0.01	23.2	14.3	9.7	Ig,I,K,Chl
14 A	7.7	7.2	8.6	1.08	0.50	10.0	38.3	14.2	Ig,I,K,Chl
Bw1	7.8	7.0	1.9	0.72	0.12	9.2	27.4	15.5	I,K,Ig,Chl
Bw2	8.0	7.1	0.6	0.40	0.02	17.4	21.2	13.2	I,K,Ig,Chl
Bw3	7.7	7.0	0.7	0.20	0.02	20.3	19.0	10.3	I,K,Ig,Chl
15 A	7.5	6.7	7.4	1.58	0.37	11.6	40.2	10.4	Ig,I,K,Chl
16 A	7.7	7.6	8.7	1.70	0.32	15.8	33.5	9.7	Ig,I,K,Chl
Bt	8.0	7.8	3.8	1.30	0.14	15.7	21.5	7.6	Ig,I,K,Chl
17 Bt	7.3	6.6	5.7	1.81	0.22	15.0	26.4	5.6	I,K,Chl
18 Bt	7.9	7.1	1.4	1.04	0.06	13.5	22.3	9.2	I,K,Chl
19 A	7.3	7.0	4.8	1.50	0.16	17.4	22.9	7.6	I,K,Chl
Bt	6.8	6.2	2.3	1.00	0.11	12.1	16.9	7.1	I,K,Chl

\* I=illite; K=kaolinite; Chl=chlorite; Ig=2:1-2:2 intergrades.



Table 6 - Exchangeable cations and base saturation degree of some examined profiles.  
 Tab. 6 - *Cationi scambiabili e grado di saturazione in basi dei profili esaminati.*

PROFILE NUMBER AND HORIZON	Exchangeable cations meq/100 g				Total exch. cations	Base saturation degree %
	Ca	Mg	Na	K		
4 A	25.33	3.17	0.60	1.80	27.19	88
Bt	20.98	2.54	0.60	1.80	25.92	90
6 A	16.25	0.80	0.06	0.50	17.60	82
Bt	16.25	0.68	0.06	0.50	17.50	86
7 A	18.10	1.40	0.06	0.45	20.01	88
Bt	13.00	0.95	0.05	0.43	14.41	84
12 A	30.53	2.35	0.27	1.31	34.46	96
Bt	27.63	2.46	0.20	0.75	31.04	97
13 A	18.51	13.00	0.40	1.55	33.51	76
Bw1	7.90	3.60	0.60	0.56	12.70	72
Bw2	4.50	3.06	0.90	0.43	8.90	67
Bw3	5.50	3.35	0.13	0.37	9.35	65
16 A	18.60	7.80	0.24	0.54	27.13	81
Bt	12.50	5.95	0.25	0.42	19.13	89
19 A	9.80	6.10	0.90	1.30	18.09	79
Bt	7.21	3.60	0.85	1.00	12.67	75

The base saturation degree is between 65 and 97%: Ca and Mg ions prevail in the exchange complex (table 6). In some cases, the saturation is higher in the surface horizon, in others a slight base leaching occurs, with accumulation in the lower horizon.

The values of anion exchange capacity depend on the iron oxide and oxihydroxide content. It appears that they decrease as the organic matter content increases. As expected, in the deep horizons, samples characterized by a similar content of the active (Fe<sub>ox</sub>) fraction show comparable adsorption characteristics.

## CONCLUSIONS

After examining the differences in morphology and genesis among the profiles, soils belonging to three orders of xeric subgroups were identified: Entisols, Inceptisols and Alfisols.

Classification of some Rhodoxeralfs was sometimes rather difficult due to the limitation of the classification criterium concerning the colour. A hue redder than 5 YR, the condition for enclosement in the Great Group of Soil Taxonomy, is unlikely in the presence of organic matter in the argillic horizon.

The results of the chemical analyses suggest that some similarities exist among these different taxonomic types, mainly in that they show a clay texture and the carbonate has been washed out. The clay constituents are related to the soil evolution degree, the profiles characterized by a lower evolution degree being characterized by discrete amounts of 2:1-2:2 intergrade and the others by the absence of this component.

The total iron concentration varies with the age and composition of the substratum and is not related to the taxonomic type, but all profiles show a high crystallinity of iron minerals. The scarce variability of this latter parameter among profiles, characterized by different evolution degrees, suggests that iron crystalline compounds were partially inherited from the parent rock or formed from iron released by carbonate and silicate weathering under pedoenvironmental conditions favourable to rapid crystallization and stability of these compounds.

Nowadays management of these soils is represented by sclerophyllae forests more or less altered by pasture. Agricultural management is limited by the extremely variable soil thickness, rockiness or slope. In particular, thickness is the main limiting factor for Rhodoxeralfs, but where the soil is deep enough fertility is good. Therefore, agricultural use of these soils is possible only where these limitations are not too serious.

#### LITERATURE CITED

- 1) ARANGINO F., ARU A., BALDACCINI P., VACCA S. (1986): I suoli delle aree irrigabili della Sardegna. Regione Autonoma Sardegna, Ass. Programm., Cagliari.
- 2) ARRIGONI P.V. (1968): Fitoclimatologia della Sardegna. Webbai no. 23, Firenze.
- 3) ARU A., BALDACCINI P. (1965): I suoli della Sardegna meridionale. Studi Saresesi, sez.III, 13: 73-209.
- 4) ARU A., BALDACCINI P., PIETRACAPRINA A.(1967): I suoli della Sardegna. Studi Saresesi, sez.III, 15: 308-362.
- 5) ARU A., DELOGU G. (1982): Quelques considerations sur l'etat de la conservation des sols sur les surfaces calcaires-dolomitiques de la Sardaigne avec reference particuliere au Mt. Albo (Sardaigne centre-orientale). Colloques phytosologiques XI, Strasbourg.
- 6) ARU A., BALDACCINI P., VACCA A. (1990): Carta dei suoli della Sardegna. In corso di stampa.
- 7) AUBERT H. and PINTA M. (1977): Trace elements in soils. Elsevier N.Y. 47-51.
- 8) BLUME H.P. and SCHWERTMANN U. (1969): Genetic evaluation of profile distribution of Aluminum, Iron and Manganese oxides. Soil Sci. Soc. Am. Proc. 33: 438-444.
- 9) BOERO V., PREMOLI A., MELIS P., BARBERIS E., ARDUINO E. (1990): Influence of climate on the mineralogy of terra rossa. Clays and Clay Min. In press.
- 10) FAO (1977): Guidelines for Soil Profile Description. Second ed. FAO, Rome.
- 11) FAO-UNESCO (1988): Soil Map of the World. Revised Legend, FAO, Rome.
- 12) FEY M.V. and DIXON J.B. (1981): Synthesis and properties of poorly crystalline hydrated aluminous goethites. Clays and Clay Min. 29: 91-100.

- 13) GESSA C., MELIS P., SOLINAS V., MICERA G., BURRIESCI N., (1984): Iron distribution in the clay fraction of Cambisols as determined by Mossbauer spectroscopy, X-ray diffractometry and selective dissolution. *Zeit. Pflanzen. Bodenk.* 147: 218-31.
- 14) KAMPF N. and SCHWERTMANN U. (1982): The 5M NaOH concentration treatment for iron oxides in soils. *Clays Clay Miner.* 30: 401-8.
- 15) KONONOVA M.M. (1966): Soil organic matter, pages 378-82. Pergamon Press N.Y.
- 16) LOTTI G. and RIFFALDI R. (1978): I colloidi inorganici non argillosi del suolo. *Agrochimica XXII*: 179-214.
- 17) MEHLICH A. (1960): Charge characterization of soils. *Trans. 7th Int. Congr. Soil Sci. Madison 2*, 292-302.
- 18) MEHRA O.P. and JACKSON M.L. (1960): Iron oxide removal from soils and clays by a dithionite system buffered with sodium bicarbonate. *Clays Clay Min.* 5: 317-27.
- 19) PASSINO A.M., PIETRACAPRINA A., PULINA M.A. (1977): Raffronto fra i suoli rossi calcarei e la "terra rossa" della Sardegna nord-occidentale: prime considerazioni. *Studi Sassaesi, sez.III*, 25: 307-54.
- 20) PIETRACAPRINA A. (1964): I suoli della Sardegna nord-occidentale. *Studi Sassaesi, sez.III*, 12: 3-100.
- 21) PIPER C.S. (1950): *Soil and Plant Analysis*, pages 65-8. Intersc. Publ. N.Y.
- 22) PREMOLI A., MELIS P., GESSA C., DELANA S., PETRERA M. (1984): Effects of Al substitution on goethite formation. *Studi Sassaesi, sez.III*, 31: 55-68.
- 23) RICH C.J. and Obenshain S.S. (1955): Chemical and clay mineral properties of a red-yellow Podzolic soil derived from muscovite schist. *Soil Sci.Soc.Am.Proc.* 19: 334-39.
- 24) SANESI G. (1977): Guida allo studio dei suoli in campagna. CNR, Progetto Finalizzato Conservazione del Suolo, Firenze.
- 25) SCHWERTMANN U. (1964): Differenzierung der Eisenoxide des Bodens durch photochemische Extraction mit saurer ammoniumoxalat-Losung. *Z. Pflanzen. Dueng. Bodenk.* 105: 194-202.
- 26) SISS (1976): I metodi normalizzati di analisi chimica del suolo. Societa' Italiana Scienza del Suolo, Ed. Capponi, Firenze.
- 27) U.S.D.A. (1952): Soil Survey Staff. *Soil Survey Manual*, handbook no.18.
- 28) U.S.D.A. Soil Survey Staff (1975): *Soil Taxonomy*. Soil Conservation Service, Agric. Handbook no. 436, Washington D.C.
- 29) U.S.D.A. (1988): Agency for International Develop. Soil Management Support Service. *Keys to Soil Taxonomy* by Soil Survey Staff. SMSS Technical monography no.6, 4th ed., Cornell University Ithaca N.Y.
- 30) THORNTHWAITE C.W. (1948): An approach toward a rational classification at climate. *Geo. Rev.* 38: 55-94.
- 31) WALKLEY A. and BLACK I.A. (1934): An examination of the Degtjareff method for determining soil organics matter and a proposed modification of the chromic acid titration method. *Soil Sci.* 37: 29-38.

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