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Dazzi C., Monteleone S.

in

Zdruli P. (ed.), Steduto P. (ed.), Kapur S. (ed.).
7. International meeting on Soils with Mediterranean Type of Climate (selected papers)

Bari : CIHEAM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 50

2002
pages 73-86

SOILS AND SOIL-LANDFORM RELATIONSHIPS ALONG AN ELEVATIONAL TRANSECT IN A GYPSIFEROUS HILLY AREA IN CENTRAL SICILY, ITALY

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Introduction

After the introduction of the "*catena*" concept by Milne (1935a, 1935b), in many areas of the world several studies on the soil-landscape relation were carried out. These studies showed that soil properties and landscape position are significantly related and that geomorphological and pedological processes interact on hillslopes, mainly where the movement of soil and water is considered (Gerrard, 1992; Nizeyimana and Bichi, 1992; Eash and Sandor, 1995; Alexander and Burt, 1996; Botschek et al., 1996; Dahlgren et al., 1997).

Such relationships were used in determining uniform mapping units for soil survey and for soil management and soil productivity determinations (Daniels and Hammer, 1992; McGregor and Thopson, 1995), and lead Conacher and Dalrymple (1977) to propose the name "pedogeomorphology" for that subject which considers the relation between soil and landform, and later Sommer and Schlichting (1997) to distinguish three main kinds of catena.

The aim of our study is to characterise soil features and soil-landform relationships along an elevational transect in a gypsiferous hilly area in central Sicily, Italy. The study made showed for the first time in Sicily, a region with a Mediterranean climate, the presence of soils with a gypsic horizon which meet the properties of the new definition for the gypsic horizon as reported in the 2^{nd} ed. of Soil Taxonomy (USDA-NRCS, 1999).

The pedons observed do not constitute a soil catena "*sensu strictu*" because they occur on the slope side of a hill, encompassing a 235-m range in elevation, in which parent material, but also rainfall and temperature vary somewhat.

Materials and Methods

Study area

We took into consideration an elevational transect of eight free-drained soils (Tab. 1), on the slope side of a hill in central Sicily (Fig. 1) in an area where extensive reforestation programmes, mainly with *Eucalyptus camaldulensis*, were carried out during the sixties and where the "Gessoso-Solfifera" formation outcrops, are particularly widespread.

The study area, is formed by a hillslope facing S.E. aspect and showing an average gradient of about 10 % and rising from 250 m to 485 m a.s.l.. The climate of the area is characterised as Mediterranean with cool to cold, wet winters and warm to hot, dry summers. Climatic data from 1985 to 1997 (climatic records started in 1985), show a mean annual air temperature ranging from 16.3 °C to 18.2 °C and a mean annual rainfall ranging from 440 to 480 mm (Regione Sicilia, 1997). The land use is represented by woodland, mainly with *Eucalyptus camaldulensis* but also with *Eucalyptus occidentalis*, *Pinus halepensis*, *Pinus pinea*, *Cupressus sempervirens* and *Cupressus horizontalis*.

Figure 1. Location of the study area.

Table 1. Soil and selected soil forming factor for the eight pedons composing the transect.

Landforms	Pedons	Parent material (Fm name)	Site elev. (m)	Slope (%)	Dominant vegetation at sampling site	Classification (Soil Taxonomy, 1999)
Dolina landform	MG3	Colluvial dpt on gypsum	478	4	Eucaliptus camaldulensis	Very fine, smectitic, superactive, thermic, Typic Haploxerert
	MG4	Colluvial dpt on gypsum	484	8	Eucaliptus camaldulensis	Very fine, smectitic, active, thermic Gypsic Vertic Haploxerept
Gypsum and gypsarenites landform	MG54	Gypsum	440	30	Eucaliptus camaldulensis	Fine, mixed, active, thermic, Gypsic Haploxerept
	MG75	Gypsare-nites	415	80	Eucaliptus camaldulensis	Fine, gypsic, active, thermic, Typic Xerorthent.
Hillslope landform	MG64	Marly and/or sandy clays	320	4	Eucaliptus camaldulensis	Fine, mixed, active, thermic Gypsic Calcixerept
	MG22	Clays and marly clays	280	15	Eucaliptus camaldulensis	Very fine, smectitic, semiactive, thermic, Gypsic Vertic Haploxerept
Terrace landform	MG1	Marly and/or sandy clays	260	2	Eucaliptus camaldulensis	Fine, smectitic, active, thermic, Vertic Haploxerept
	MG16	Alluvial dpt	254	2	Eucaliptus camaldulensis	Fine-loamy, mixed, active, thermic, Typic Xerofluvent

Lithology and geomorphic features

The study area is covered with outcrop deposits ranging in age from Tortonian to Holocene. In particular, starting from the bottom, the oldest are Terravecchia Fm., Gessoso-Solfifera Fm. and holocenic alluvial and colluvial deposits (Monteleone, 1993). The Gessoso-Solfifera Fm. includes Messinian evaporitic sediments deposited during the essication of the Mediterranean Sea, in consequence of relative sea level change, which has isolated the Mediterranean Sea from the open ocean.

The Gessoso-Solfifera Fm. is constituted by two evaporitic events, the lower and the upper, which from a lithostratigraphical point of view show marked differences (Decima and Wezel, 1971; Catalano, 1986). Generally the "lower event" is constituted, from the bottom, by: a) diatomitic marls ("Tripoli" Fm.); b) limestone and dolomitic limestone ("Calcare di base"); c) gypsum and d) salts (halite and potash salts), the "upper event" is made up of a) gypsum and gypsarenites interbedded with marls and clays; b) arenaceous sandstones ("Arenazzolo" Fm). In the study area, along the slope, outcrop several lithotypes (Fig. 2). The oldest are clays, sands and conglomerates from Tortonian "Terravecchia" Fm. Above the unconformity boundary, follow selenitic gypsum and laminitic gypsum gradually passing to gypsarenites of the messinian "Gessoso-Solfifera" Fm., in the most Eastern sector of the slope.

The youngest deposits (Holocene in age) outcrop at the base of the slope and on its top. In the first case are constituted by alluvial deposits, mainly conglomerate and sands, with a variable degree of cementation. In the second ones, are colluvial deposits of a *dolina*, which reach 6 metres depth, made up by clays, marly-clays and silts, accumulated in a continental environment by washing waters flowing into a scarcely drained area.

From a geomorphological point of view, following the slope from its highest point down (Fig. 2), both dolinas and areas in counterslope with characteristics of semi-open depression may be found on gypsum. These forms show a low grade of evolution. The microform "*karren*" types are well developed. On steeper slope, it is also possible to find gypsarenites, which show a morphological evolution mainly connected to rill and/or gully erosion. On the lower-middle part of the slope, where outcrops "Terravecchia" Fm. deposits, morphologies linked to processes due to gravity and/or to water erosion may be found.

The first process is distinguished in active and inactive surfaces according to the evolutive state of the landslides, which are trigger and heavy due to prolonged rainfall, and may move again, even partially. The processes linked to surface running waters, occur as sheet, rill and gully erosion. In particular sheet erosion is mainly marked in the middle part of the slope, as inferred by the presence of several bared areas; processes of rill erosion, were identified particularly in the middle and in the bottom part of the slope; gully erosion erodes consistently in depth, resulting in small, symmetrical V-shaped valleys.

In the valley floor area, near the Salito river there are two sublevel areas (terraces), which correspond respectively to: a) a surface levelled by the river (orographical terrace) when its bed was higher; and b) an alluvial terrace a bit lower than the first one (about 7 metres below).

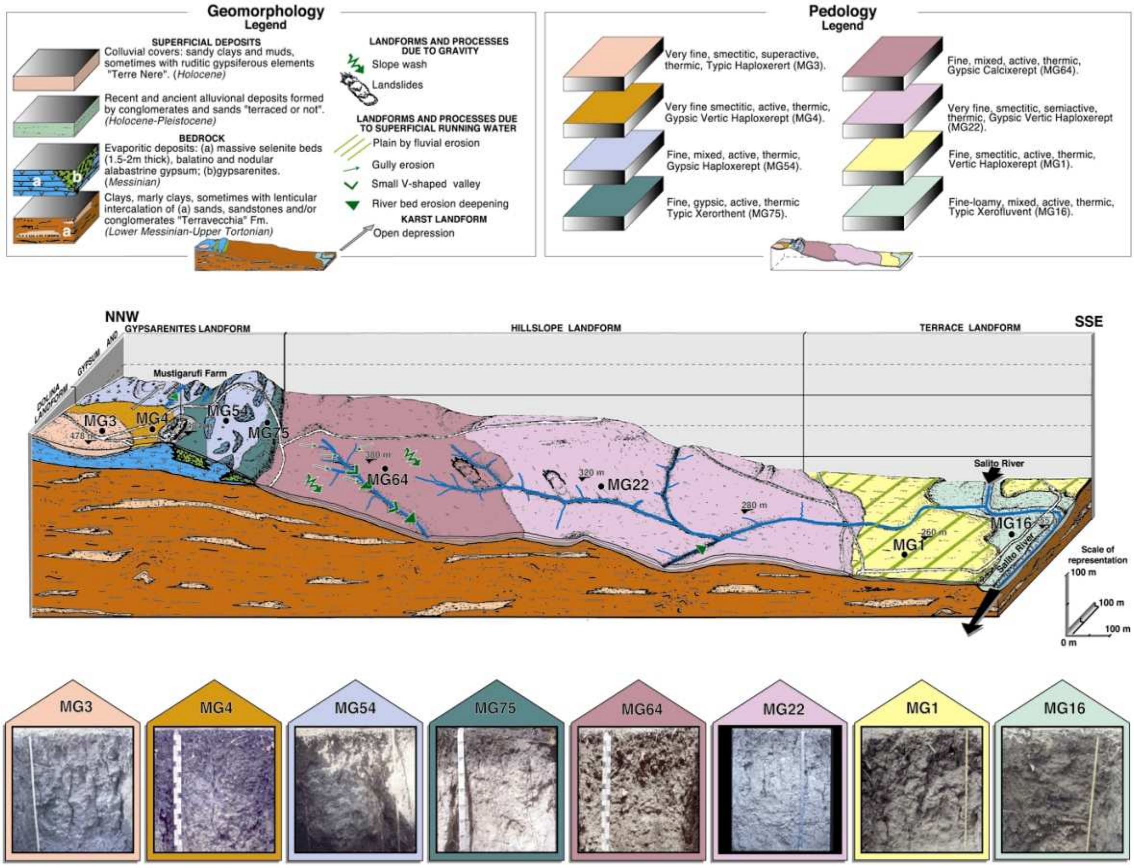

Figure 2. Morphological representation of the study area, showing landform position, parent material, location and photos of the pedons composing the transect.

Laboratory methods

All pedons sampled were genetically consistent with only a very scarce evidence of human perturbations due to the afforestation operations. Field description of the soils was in hand-dug pits (pedons) and samples were collected from each horizon for laboratory analysis (SSS, 1993, USDA-NRCS, 1996).

Air-dried samples were gently crushed and passed through a 2 mm sieve and analysis were done using fine earth. Soil texture was analysed using the pipette method following desalinization with distilled water (FAO, 1990) and dispersion through 3-hours shaking with Na-hexametaphosphate. Reaction was measured potentiometrically in 1:2.5 suspension (soil : 1M KCl and soil : H_2O) using a Metrohm 691 with a glass electrode (AC 9101).

Electrical conductivity was measured in a 1:5 suspension (soil: H_2O) using an Orion 101 conductivity meter (conductivity cell 012001). The analysis of organic carbon was conducted using the Walkley-Black Wet Oxidation method (Nelson and Sommer, 1982); total N was determined by Kjeldahl method (Bremner and Mulvaney, 1982); carbonates were determined by treating the soil samples with HCl and by measuring the evolved CO_2. Cation exchange capacity (CEC) was determined by ammonium saturation method at pH 7 (USDA-NRCS 1996). The exchangeable bases were measured using a Varian 1275 spectrophotometer.

Mineralogical analyses were performed by X-ray diffractometry for the qualitative identification of the phases present. Semi-quantitative estimates of bulk mineralogy were made using the methods of Schultz (1964). Statistical analysis was performed using the "Statistica 5.0" software (Statsoft Inc., USA, 1997).

Results and Discussions

Soils and landforms

With reference to Fig. 2, which is the physiographic representation of the hillslope showing landform position, parent material and the location of the sampling sites, going from top to bottom there are (Tabs. 1, 2 and 3): dolina landform; gypsum and gypsarenites landform; hillslope landform; terrace landform.

In the top area of the hill, the landforms are linked to processes of gypsum dissolution which, in the long run, have resulted in a dolina partially filled by colluvial material varying from 6 meters depth in the central zone to 0.5 m at the edges. Two different pedons correspond to this morphology. Almost at the centre of the dolina is found the pedon MG3, which from a mineralogical point of view shows a considerable homogeneity. Towards the edge of the dolina, the shallow colluvium and the relatively low depth of the substratum made up of clays with gypsum, has produced the pedon MG4 that shows a deep profile with typical vertic characteristics.

Close to the dolina, at about 440 metres a.s.l. gypsum outcrops and, with a lateral facies variation, gypsarenites outcrop with a modest grade of cementation. On gypsum develop the MG 54 pedon, while, few meters down where gypsarenites outcrop, the MG75 pedon developed.

Below the landforms characterised by gypsum and gypsarenites outcrops, the oldest deposits of the study area belong to the "Terravecchia" Fm. outcrop. The low-lying parts are made up of clayey deposits but, in the first section of the slope, the sandy-clays prevail. Pedon MG64 was studied here. In the second part of the hillslope, where the "Terravecchia" Fm. shows marly-clay characteristics was studied the pedon MG22.

At the end of the slope, there is an orographic terrace shaped by the Salito River and set on a marly clay belonging to the "Terravecchia" Fm. This lithomorphology is at the origin of the MG1 pedon. Lastly, on the very sandy terraced alluvium, the MG16 pedon was thoroughly examined.

Soil morphology and classification

The pedons surveyed were classified according to the Soil Taxonomy (USDA-NRCS, 1999). Considering the "normal year" definition, the Soil Moisture Regime (SMR) was calculated according to Billaux (1978) using storages (ST) of 25, 50, 100 and 200 mm, for a 13-year period. The SMR for all pedons studied resulted "xeric". After confirming the xeric regime, data on soil temperature, allowed the definition as "thermic" of the Soil Temperature Regime (STR) (USDA-NRCS, 1999).

It should be pointed out however, that, soils with storage of 50 mm tend towards an aridic regime as the dry period of their moisture control section borders on 180 consecutive days/year, in a period when soil temperature is over 8 °C. It should be believed that such soils, as well as others with a storage <50 mm, have a longer dry period and therefore a greater aridity, characteristic of "xeric" soils in transition with "aridic" ones.

The main morphological and physico-chemical properties of the pedons surveyed which allow for their classification (Tables 2 and 3), are strongly linked not only to the climate but also to their position in the landscape. In the central area of the dolina, pedon MG3 showed considerable vertic features (mainly cracks and slickensides), which are responsible for the formation of a quite homogeneous O-A-Ass-C soil profile, black coloured.

Table 2. Field descriptions for the eight pedons composing the transect.

Soil horizons	Depth (cm)	Boundary	Color		Texture	Structure			Consistence		Roots
			dry	moist		shape	size	grade	dry	moist	
MG3	(478 m)										
Oi/Oe	2-0										
A	0-10	C-S	2.5Y3/2	2.5Y2/1	C	gr-sbk	f-m	3	h	fr	2-f/m
Ass$_1$	10-30	C-S	2.5Y3/2	2.5Y2/1	C	abk-pr	m	3	vh	fr	1-f/m
Ass$_2$	30-60	G-S	2.5Y3/2	2.5Y2/1	C	pr	c	3	vh	fr	1-f
Ass$_3$	60-120	G-S	2.5Y3/2	2.5Y2/1	C	pr	vc	3	vh	fr	1-f
Ass$_4$	120-150+		2.5Y3/2	2.5Y2/1	C	ma	-	-	vh	fr	1-vf/f
MG4	(484 m)										
Oi/Oe	4-0										
A$_1$	0-30	C-S	5Y5/4	5Y3/2	C	cr-sbk	f-m	3	h	fr	3-f/m
A$_2$	30-55	G-I	5Y5/4	5Y3/2	C	abk-pr	m	3	sh	fr	3-f/m
Byss	55-125	G-S	5Y7/4	5Y6/6	C	abk-pr	f-m	3	h	fr	1-f
BCy	125+		5Y6/4	5Y6/6	C	pr	c	3	vh	fr	1-f
MG54	(440 m)										
Oi/Oe	2-0										
Ay	0-20/25	C-S	2.5Y5/4	2.5Y4/4	C	cr-sbk	vf-f	3	sh	fr	2-f/m
By	20/25-70	A-S	2.5Y6/6	2.5Y5/6	CL	abk	m	2	mh	fr	1-f/m
BCy	70+		2.5Y7/6	2.5Y6/4	CL	ma	-	-	so	fr	1-f
MG75	(415 m)										
Oi/Oe	1.5-0										
Ay	0-30	C-S	2.5Y5/2	2.5Y4/2	C	cr-sbk	vf-f	3	sh	vfr	2-f/m
Cy$_1$	30-100	D-S	2.5Y8/2	2.5Y7/4	CL	-	-	-	so	fr	2-f
Cy$_2$	100-170+		10YR8/1	10YR7/1	CL	-	-	-	so	fr	2-f
MG64	(320 m)										
Oi/Oe	1.5-0										
A	0-14	C-S	2.5Y4/2	2.5Y3/2	C	cr-sbk	vf-f	3	so	fr	3-f/m
Bk$_1$	14-60	G-S	2.5Y4/4	2.5Y4/4	C	abk	m	3	sh	fr	2-f/m
Bk$_2$	60-80	G-S	2.5Y4/4	2.5Y4/4	C	abk-pr	m-c	3	h	fr	1-f/m
BCy	80-100+		2.5Y5/4	2.5Y5/6	C	ma	-	-	h	fr	1-f
MG22	(280 m)										
Oi/Oe	2-0										
A	0-20	A-S	2.5Y5/2	2.5Y4/2	C	sbk	f-m	3	sh	fr	3-f
Bkss	20-50	C-S	2.5Y6/6	2.5Y6/4	C	abk-pr	m	2	h	fr	1-m
Byss	50-80	G-S	2.5Y7/4	2.5Y7/2	C	pr	m-c	3	h	fr	1-c
C$_1$	80-95	D-S	2.5Y6/2	2.5Y6/2	C	pr-ma	c	3	vh	fr	1-c
C$_2$	95-110+		2.5Y6/2	2.5Y6/2	C	ma	-	-	vh	fr	1-c
MG1	(260 m)										
Oi/Oe	2-0										
A	0-30	C-S	2.5Y5/2	2.5Y4/2	C	cr-sbk	f-m	3	mh	fr	3-f/m
Bwss$_1$	30-70	G-S	2.5Y5/2	2.5Y4/2	C	abk-pr	m-c	3	h	fr	3-f/m
Bwss$_2$	70-125	G-S	2.5Y5/4	2.5Y4/4	C	pr	vc	3	h	fr	1-f
C	125+					ma	-	-		fr	1-f
MG16	(255 m)										
Oi/Oe	1.5-0										
A	0-15	A-S	10YR6/3	10YR5/3	SL	sbk	f	2	so	fr	3-f/m
2A	15-30	C-S	10YR5/6	10YR5/4	SCL	sbk	m	3	so	fr	3-f/m
3A	30-50	C-S	10YR5/6	10YR5/4	SL	sbk	f	1	so	fr	3-f/m
4A	50-90+		10YR5/6	10YR5/4	SCL	abk	f	1	lo	vfr	3-f/m

Abbreviations:
Boundary: A=*abrupt*; C=*clear*; G=*gradual*; D=*diffuse*; S=*smooth*; I=*irregular*.
Texture: S=*sand*; L=*loam*; C=*clay*.
Structure: 1=*weak*; 2= *moderate*; 3=*strong*; vf=*very fine*; f=*fine*; m=*medium*; c=*coarse*; vc=*very coarse*; cr=*crumby*; gr=*granular*; pr=*prismatic*; abk=*angular blocky*; sbk=*subangular blocky*; ma=*massive*.
Consistence (dry): lo=*loose*; so=*soft*; sh=*slightly hard*; mh=*moderately hard*; h=*hard*; vh=*very hard*.
Consistence (moist): vfr=*very friable*; fr=*friable*; fi=*firm*.
Roots: 1=*few*; 2=*common*; 3=*many*; vf=*very fine*; f=*fine*; m=*medium*; co=*coarse*.

In this pedon, which can be classified as *Very fine, smectitic, superactive, thermic Typic Haploxerert*, gypsum is present in traces in the first horizons and appear in the lower part of the profile. Its presence is mainly linked to water movement in the dolina landform. In wintertime gypsum is dissolved and leached downward by the rainfall percolating water.

The edge of the dolina is characterised by the MG4 pedon, in which are particularly evident soil processes linked to the influence between the shallow colluvium and the clays with gypsum substratum. This pedon shows an O-A-Byss-BCy profile with an ochric epipedon, which lies on a cambic horizon, characterised not only by vertic features but also by an accumulation of gypsum (Tab. 3) which allows for its definition as a gypsic horizon (USDA-NRCS, 1999).

Table 3. Selected soil characteristics for the eight pedons composing the transect.

Soil		Sand	Silt	Clay	CEC	ex. K	ex. Na	ex. Mg	ex. Ca	EC	Ca-CO_3	Gyp-sum	Clay	Cal-cite	Qua-rtz	Feld-spars
pedon	horiz.	$g\ Kg^{-1}$			$cmol_+\ Kg^{-1}$					$dS\ m^{-1}$	%	%	%	%	%	%
MG3	Oi/Oe															
	A	200	210	590	45	0.13	0.43	0.40	44.04	0.16	10.7	-	73	9	15	3
	Ass_1	150	250	600	42	0.13	0.43	0.45	40.99	0.19	12.0	-	66	17	15	2
	Ass_2	150	250	600	38	0.13	0.43	0.55	36.89	0.67	11.6	-	75	10	12	3
	Ass_3	160	230	610	38	0.13	0.65	0.80	36.42	0.85	13.5	0.10	76	10	13	1
	Ass_4	180	280	540	35	0.13	0.86	1.20	32.81	1.73	13.6	1.65	75	10	12	1
MG4	Oi/Oe															
	A_1	80	300	620	41	0.22	0.51	1.47	38.81	0.16	18.6	-	74	11	7	7
	A_2	50	350	600	34	0.16	0.48	1.42	32.44	0.66	18.1	2	70	13	11	3
	Byss	130	270	600	27	0.12	3.47	6.35	17.21	1.35	14.7	12	61	13	10	4
	BCy	-	-	-	-	-	-	-	-	-	14.0	19	53	16	9	4
MG54	Oi/Oe															
	Ay	210	320	470	22	0.45	0.59	2.50	18.46	1.91	8.4	34	25	10	10	4
	By	300	330	370	16	0.26	1.10	3.29	11.35	1.75	8.4	40	32	17	6	2
	BCy	270	400	330	12	0.16	1.86	5.05	4.93	1.97	9.7	55	8	18	5	2
MG75	Oi/Oe															
	Ay	350	220	430	19	0.13	0.43	1.50	16.94	2.57	9.4	19	58	14	9	2
	Cy_1	-	-	-	17	0.14	0.43	2.00	14.43	2.21	7.3	21	22	32	25	1
	Cy_2	-	-	-	18	0.13	0.43	2.50	14.94	2.70	12.9	56	29	11	4	1
MG64	Oi/Oe															
	A	290	210	500	36	0.26	0.63	2.11	33.00	0.28	3.4	-	76	4	17	3
	Bk_1	190	340	470	32	0.14	0.85	5.19	25.82	0.28	9.8	-	76	5	14	5
	Bk_2	180	200	620	25	0.13	0.93	5.37	18.57	0.37	12.4	-	75	5	16	4
	BCy	200	240	560	24	0.07	1.01	6.72	16.20	2.19	10.9	11	59	8	20	2
MG22	Oi/Oe															
	A	90	300	610	27	0.90	0.63	0.62	25.18	2.77	18.1	tr	73	19	8	tr
	Bkss	40	260	700	21	0.08	0.60	1.21	18.44	4.65	19.1	2	67	18	11	2
	Byss	60	270	670	21	0.06	1.55	2.96	17.08	6.09	19.3	5	63	22	8	2
	BC	140	220	640	16	0.22	5.65	4.44	5.69	5.93	9.8	3	75	7	12	3
	C	60	270	670	16	0.22	6.12	5.31	5.84	5.50	9.5	1	83	7	9	tr
MG1	Oi/Oe															
	A	170	260	570	27	0.25	0.34	1.98	24.36	0.20	18.1	-	71	15	12	2
	$Bwss_1$	210	240	550	23	0.22	0.44	1.73	20.86	0.26	18.1	-	56	17	17	7
	$Bwss_2$	260	310	430	23	0.17	0.54	2.05	20.03	0.33	15.7	-	56	11	18	12
	C	-	-	-	-	-	-	-	-	-	-	-	-			
MG16	Oi/Oe															
	A	680	110	210	28	0.21	0.51	2.10	25.18	0.26	19.8	-	45	28	21	6
	2A	480	100	420	24	0.13	0.50	1.48	21.89	0.39	20.1	1	38	27	25	9
	3A	670	140	190	16	0.11	0.51	1.37	14.00	1.23	20.0	1	44	23	21	11
	4A	550	150	300	17	0.12	0.79	1.79	14.51	1.66	17.8	1	34	24	35	6

The presence of gypsum in the profile is linked to gypsum nodules, which characterise the clay substratum. The pyramidal shape usually showed by gypsum crystals found in this pedon, indicates that such mineral originates mainly by precipitation of solution rich in sulphates, present in the soil (Bellanca and Neri, 1993). The lack of gypsum in the topsoil is due to leaching. MG4 pedon was classified as *Very fine, smectitic, active, thermic, Gypsic Vertic Haploxerept*.

Pedon MG54 which evolve on gypsum, shows an O-A-By-BCy profile, with the presence of an ochric epipedon, rich in gypsum, which lies on a gypsic horizon, is classified as *Fine, mixed, active, thermic, Gypsic Haploxerept*. Pedon MG75 evolve on gypsarenites and due to its physiographic position (slope of 80%), soil erosion do not allow for the evolution of diagnostic horizons. It shows an O-Ay-Cy profile and can be regarded as a *Fine, gypsic, active, thermic Typic Xerorthent.*

Pedons MG64 and MG22 notwithstanding evolve on substrata in which gypsum is absent ("Terravecchia" Fm) and show a gypsic horizon. Pedon MG64 is characterised by an O-A-Bk-BCy profile with an ochric epipedon, overlying on a calcic horizon, which itself overlies a gypsic one. Owing to these morphological features, it can be classified as *Fine, mixed, active, thermic, Gypsic Calcixerept*. Pedon MG22 show a similar morphological sequence (O-A-Bkss-Byss-C), however in it, the vertic features are very well expressed. It can be regarded as a *Very fine, smectitic, semiactive, thermic Gypsic Vertic Haploxerept.*

Finally, in the flat area, pedon MG1 shows an O-A-Bwss-C profile characterised by an ochric epipedon, followed by a cambic horizon with vertic features. It can be classified as, *Fine, smectitic, active, thermic, Vertic Haploxerept*. Pedon MG16 shows an O-A-C profile, with all the features, which allow for its classification as a *Fine-loamy, mixed, active, thermic Typic Xerofluvent.*

Organic carbon and nitrogen

In forest soils, organic matter (O.M.) concentration depends on the interaction of several factors and mainly the quantity and quality of litter falls, climate features and specific soil properties (Pritchet and Fisher, 1987). In the present study, all soils appeared undisturbed and, since their afforestation ages during the 60-s, according to Pritchet and Fisher (1987), they can be considered as "forest soils".

Except for only one survey, which considered the influence on soil of forest floor under *Pinus halepensis* and *Cedrus atlantica* (Dazzi et al, 1996), till today, no studies have been carried out in Sicily on the characteristics of forest floor under Eucalyptus and on its influence on soils. Field observations for the pedons examined made evident that the average organic horizon thickness is around 2 cm and that parallels closely the standing biomass and annual litter fall inputs.

Organic C concentration in the topsoil ranges from 10.8 g Kg^{-1} in the pedon MG54 to a maximum of 19.6 g Kg^{-1} in the pedon MG75 (Fig. 3), and, even it generally increase with increasing elevation (Fig. 4a), the trend was not significant (r=0.318). Nitrogen concentration in the topsoil (Fig. 3), showed about a 5-fold increase between pedon MG54 (0.39 g Kg^{-1}) and pedon MG75 (1.90 g Kg^{-1}) but showed no significant relationship (r=0.290) with elevation (Fig. 4b).

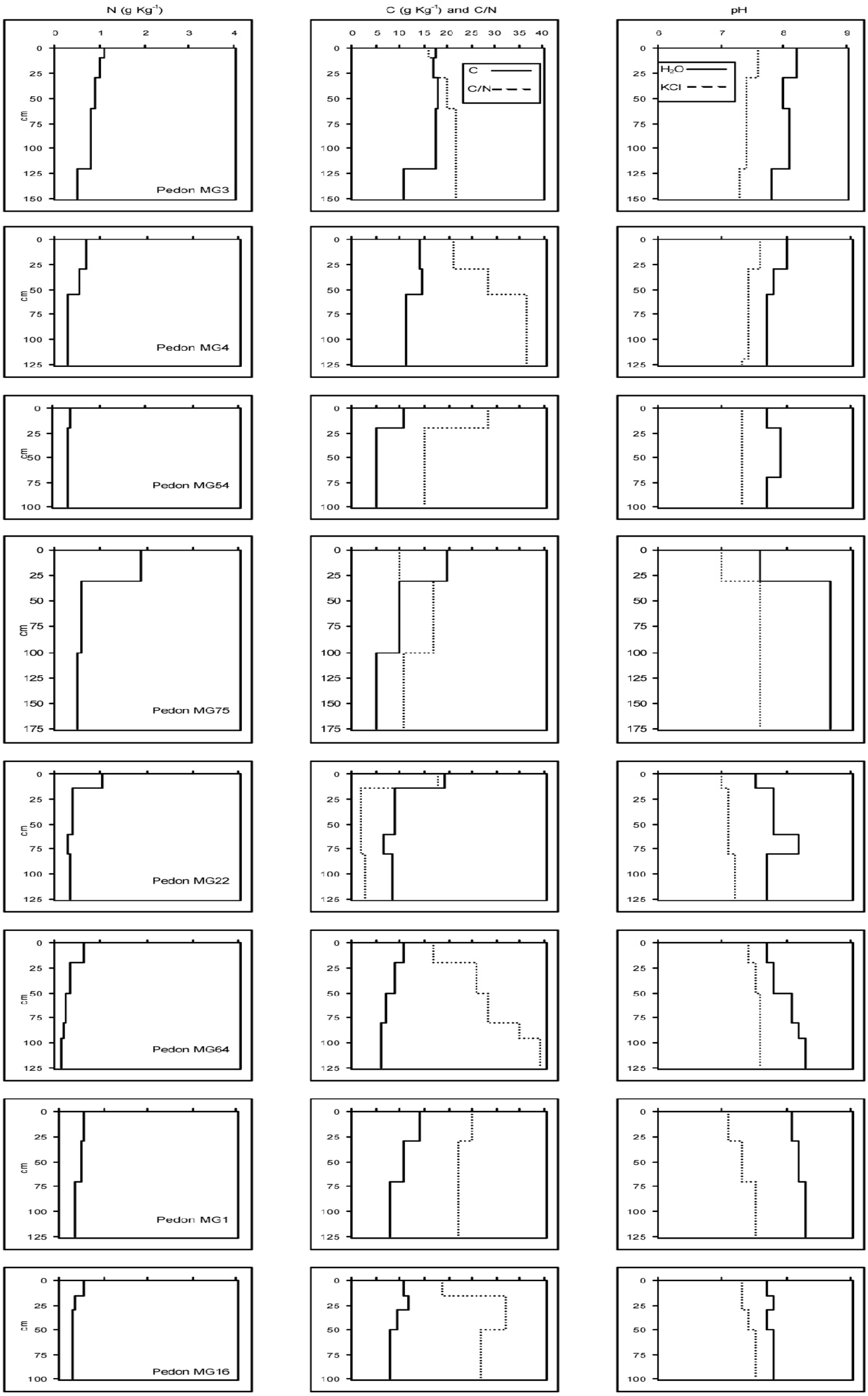

Figure 3. Vertical distribution of N, C, C/N ratio and pH for the pedons of the transect.

The C/N ratio of organic matter in the topsoil (Fig. 3), ranged from 10 (pedon MG75) to 28 (pedon MG54), whereas in the subsoil ranged from 15 (pedon MG54) to 32 (pedon MG16). Statistical analysis both for the topsoil and the subsoil did not show any significant association level with elevation (r= -0.120 and r= -0.360 respectively) (Fig. 4c and 4d).

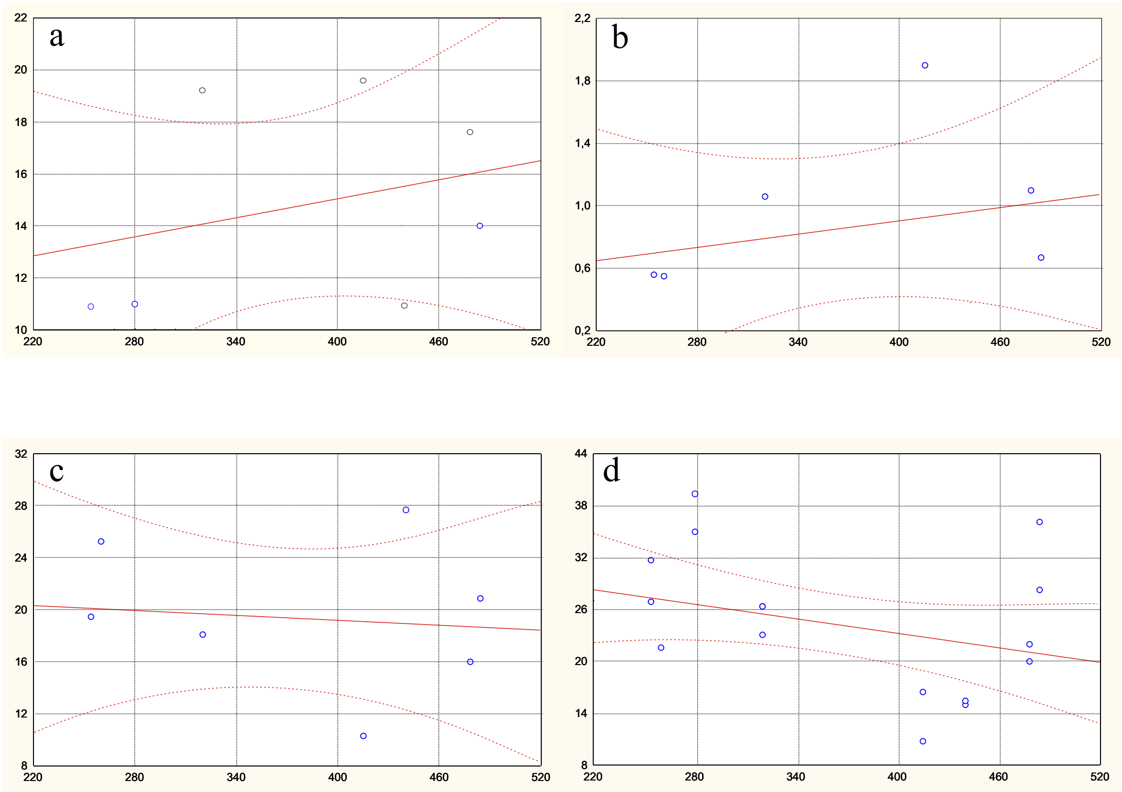

Figure 4. Organic carbon (a), nitrogen (b) and C/N ratio for the topsoil (c) and for the subsoil (d) for the pedons composing the transect.

pH, CEC and exchangeable cations

Due to the presence of carbonates, pH(H_2O) show values ranging from 7.4 (A horizon of pedon MG64) to 8.5 (C horizon of pedon MG75). Trends in pH(H_2O) and pH(KCl) within the profiles were almost the same, with the pH(KCl) values, an average of 0.64 units lower than corresponding pH(H_2O) values (Fig. 3). The differences in pH values in the A horizons and in the B horizons are mainly linked to the interaction between gypsum and calcium carbonate (Boyadgiev, 1974; FAO, 1990; Herrero Isern, 1991).

Owing to changes in clay content, in clay mineralogy and in OM content, since the pedons surveyed do not constitute a soil catena because they evolve on different parent material, there are not sharp trends in CEC along the transect. The CEC of A horizon ranged from 19 to 45 $cmol_+ Kg^{-1}$ (Tab. 3), and is statistically not correlated with any of the parameters under study. The CEC showed an association level with organic C concentration not significant for the topsoil (r=0.260) but significant for the subsoil (r=0.840). Simple correlation analysis indicated a slight relationship between CEC and the amount of total N (r=0.680) and OM (r=0.840).

Except for the C horizon of the pedon MG22, in which the exchangeable cation composition follows the trend Ca > Na > Mg > K, for all other horizon of the soils surveyed, the exchangeable cation composition follows the trend Ca > Mg > Na > K. The dominance of Na compared to Mg in pedon MG22, may reflect differences in the chemical composition of the parent material or cation selectivity due to variation in the clay mineralogy.

Conclusions

The consideration of the relationship between soils and landforms give us a common testing base for studies on soil genesis together with studies on the evolution of the landscape (Eash and Sandor, 1995). The geomorphological and pedological processes interact on the hillslopes especially where water dynamic is considerable.

In this sense, the geomorphological processes may create particular forms such as erosion or deposition surfaces, which greatly influence the characteristics and distribution of the soils (Daniels and Hammer, 1992; Gerrard, 1992; Nizeyimana and Bichi, 1992). This was confirmed along the slope studied and especially regarding the soils from the dolina and from the hillside (Herrero, 1991). The characteristics of the MG3 and MG4 pedons are strongly dependent on processes of gypsum dissolution, which resulted in a dolina partially, filled by colluvium material, which constitute their parent material.

Pedon MG3 is characterised by a good presence of shrinking and swelling clays, which are responsible for a particularly evident process of argillopedoturbation (Fanning and Fanning, 1989). In this soil the presence of low amounts of gypsum, which till the investigated depth do not allow for the definition of a gypsic horizon (USDA-NRCS, 1999), should be putted in relation with the water circulation inside the dolina: in wintertime gypsum, coming from the edge of the dolina, is dissolved and carried down by the percolating rainfall water.

Going from the centre towards the edge of the dolina, the thickness of the colluvium material become thinner and thinner, and the influence of the underlied gypsum become stronger and stronger. The genetic features of the MG4 pedon are linked to such a situation: an A horizon, dark coloured, which rest on a B horizon, grey coloured, originated by the colluvium material strongly influenced by the underlied gypsum, which shows vertic features and fits the properties of a gypsic horizon (USDA-NRCS, 1999). In this sense and also considering the open and flexible characteristics of the Soil Taxonomy, pedon MG4 can be classified as a Gypsic Vertic Haploxerept.

The soils on gypsum and gypsarenites landform do not show particular genetic features. Both (MG54 and MG75 pedons) are characterised by the presence of gypsic horizons with high level of gypsum. Because used for woodland, these pedons, like the others surveyed, can be regarded as "forest soils" (Pritchet and Fisher, 1987) for which, by field observation, Mardoud's conclusion (1980) can be confirmed, that it is very difficult or impossible for the roots of the forest species, to penetrate layers of more than 60% gypsum.

The MG64 and MG22 pedons, which are found along the hillslope landform show genetic features which are particularly linked to: a) the parent material which belong to the Terravecchia Fm., b) to the movement of water along the slope and c) to the interaction between gypsum and calcium carbonate (Boyadgiev, 1974; FAO, 1990; Herrero Isern, 1991).

Pedon MG64 shows a profile in which, below a calcic horizon, there is a gypsic horizon with some gypsum accumulation coming from the gypsiferous outcrops which altimetrically overlying the Terravecchia Fm. Such horizon sequence could be explained by the fact that gypsum, which is more soluble than calcite is leached first to form a gypsic layer, to be followed above by lime nodules (FAO, 1990).

Therefore, CaCO3 accumulates in the middle part of the profile in form of calcareous concretions with a gypsic horizon at the depth (FAO, 1990). For the pedon MG22, which shows some vertic features linked to a more clayey parent material, can be made the same consideration: also in this case a gypsic horizon follows a calcic one.

In the valley floor area, on an orographic terrace formed after flooding when the riverbed of Salito River was in a higher position than present, the MG1 pedon shows genetic features (argillopedoturbation) mainly linked to the clayey parent material belonging to the Terravecchia Fm., while, on the alluvial terrace, about 7 meters lower than the previous, the MG16 pedon shows genetic features linked to alluvial deposits of the river during the time.

The scarce presence of gypsum could be reasonably put in relation with the protrusion of the water of the Salito river in wintertime which, as showed by a previous survey (Fierotti et al., 1995), also in this period of the year shows an average EC of 24.2 dS m^{-1} and an average content of $SO_4^{=}$ of 66 cmol(+) L^{-1}

Acknowledgements

We would like to thank Prof. A. Bellanca and Prof. R. Neri for their support in the mineralogical analytical work and Dr. Alessandra Carrubba for her support in the statistical analysis.

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