*EQA – Environmental quality / Qualité de l'Environnement / Qualità ambientale*, **25 (2017) 1-17**

# LANDSCAPE EVOLUTION AND GLOBAL SOIL CHANGE IN ALPINE VALLEYS: IMPACT OF ANTHROPEDOGENESIS ON TERRACED SOILS (BELLUNO, NORTHERN ITALY).

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## Abstract

During the last decades, increasing human influence on the environment has determined strong impacts on soils. Although the effects of global soil change are currently quantified, to study and understand how and at which intensity soils are modified by human activity is of capital importance in order to effectively manage the changing ecosystems. One of the most important man-induced land transformations since many centuries is the terraced landform, an agricultural technique that characterizes many agro-ecosystems all over the world. In this study, our objectives were: i) to assess and compare the morphology and the physical-chemical-biological soil parameters of 'natural' and terraced soils; ii) to identify new forms and processes of anthropedogenesis in relation to chronological scales of human action operating within the natural pedogenesis time scales; iii) to use the existing taxonomic models for the classification of the terraced soils investigated;

**Keywords**: *anthropedogenesis, terraced landscape, Alpine soils*

## Introduction

The increase in awareness of the influence of human activities on the environment occurred in the last two centuries has led Paul Crutzen, Nobel Prize for Chemistry, to suggest the emergence of a new geological era: the Anthropocene (Crutzen, 2002). During the new era, man is contributing significantly to the alteration of the environmental equilibria. In particular, the increase in population, the adoption of intensive farming techniques, the expansion of industrial activities and the development of infrastructures have caused, on a global scale, considerable changes of the soil resource, which have had direct consequences on the dynamics of the terrestrial environment (Dudal, 2004).

The increasing loss of "natural soils" provoked by different causes (e.g. erosion,

DOI: 10.6092/issn.2281-4485/7308

soil sealing, contamination, acidification, salinization) (Zanini, 2009), the reduced ability of soils to support agricultural production, and the gap between knowledge of the soil and its best use, are clear evidence of what has been defined by the international scientific community as one of the main indicators of Anthropocene: the Global Soil Change (Arnold et al., 1990; Zalaseiwicz, 2008).

One of the most important man-induced land transformation since many centuries is the terraced landform, an agricultural technique that characterizes many agro-ecosystems in marginal, steeply sloping areas all over the world (Sandor, 1998; Dudal, 2005; Sang-Arun et al., 2006). In southern Europe and in the whole Mediterranean basin, the terraced agricultural landscape is widely distributed (Freppaz et al., 2008; Olarieta et al., 2008; Scaramellini and Varotto, 2008; Lesschen et al., 2008; Lasanta et al., 2001), although no reliable quantitative inventory on its actual extension is available (Stanchi et al., 2012).

Terraced landscapes, due to their historical and aesthetic significance, are a resource for agriculture and tourism; moreover, they are also a challenge for land conservation and management (Stanchi et al., 2012). In this perspective, the soils of terraced landscapes represent a distinctive feature of the agricultural landscape in Europe and elsewhere in the world, and constitute one of the more widespread practices in the Alpine area (Scalenghe et al., 2002; Freppaz et al., 2008), where terracing has been implemented in the last centuries in order to increase soil’s availability for agricultural practices on steep slopes.

Among the changes affecting the soil resource on a global scale, there is the diffusion of "anthropogenic soils" (i.e. soils originated by human activities). With respect to the classic state factor equation (Jenny, 1941):

$$S = f\ (cl,o,r,p,t) \qquad [1]$$

the anthropogenic soils ($S_a$) originate from the following general factorial equation of anthropedogenesis, defined by Kosse (2005):

$$S_a = f\ (p_a, a_1, a_2, a_3, \dots)_{cl,o,r,p,t} \qquad [2]$$

where $p_a$ is the new parent material constituted of pebbles and earthy material used to build up the terraces and referred to as *Human Transported Materials* (ICOMANTH, 2006), and $a_{1,2,\dots}$ are all human activities that acted on the formation of anthropogenic soil (e.g. soil terracing, deforestation, terrain leveling, earth movements, etc.).

In the equation (2), the classic five pedogenetic factors considered by Jenny (Jenny, 1941) are taken constant or ineffective. In this way, it is possible to highlight the differences between anthropogenic soils and corresponding natural soils, and to stress the importance of dynamic soil properties (e.g. pH, soil organic matter, bulk density, water holding capacity) in the new soil genesis and in land use planning and management (Zilioli and Bini, 2009; 2011). The processes activated by anthropic activities, since few years, are considered by several researchers (Dudal, 2004) as responsible for soil formation, and the result of the anthropogenic impact is the transformation of soil from a “natural” to an “historical” body (Richter, 2007) and an actual cultural heritage (Bini and Zilioli, 2009).

In this work the main objective is to characterize the terraced soils of the piedmont belt in NE Italy (Belluno province), in order to highlight the role played by the soil in the landscape formation and transformation. A second objective of the study is to identify anthropogenic impact on dynamic soil properties that can reflect short-term soil changes in the investigated area.

In detail, this study aims at:

- increasing current information on morphological, physical, chemical and biological properties of 'natural' soils and anthropogenic terraced soils in the mountain regions;
- quantifying and predicting the effects of terracing on soils and the whole environment in a short time (<100years);
- identifying new forms and processes of anthropedogenesis induced by terracing in relation to the time scale of human action compared with the time scales of natural pedogenesis;
- exploring the existing taxonomic systems for the classification of terraced soils.

## Materials and Methods

### Study Area

The Belluno province (Fig.1), in Northern Italy, is characterized by a remarkable variability of soil landscapes due to the young geological structure. The whole territory is subdivided into three main landscapes: the Alpine orogenetic belt (up to 2700 m a.s.l.), the piedmont area and the alluvial plain of the Piave river.

**Figure 1.** *Study area and overview of the landscape where terraced soils have been studied.*

The lithology of the area is mostly calcareous, with minor sandstone and finer clastic material; active morphological dynamics (both erosion and landslides) affect a relevant part of the land. The piedmont area is characterized by gently undulating surfaces and steep slopes arranged as terraced landforms. Terraced soils of the mountain and piedmont belt are a peculiar example of anthropogeographic landscape (Sestini, 1947), built up in the last centuries for agricultural purposes, since steep slopes did not allow intensive agriculture. More recently, because of socio-economic issues, terraces have been gradually abandoned, posing a serious threat to local population and to the environment.

The investigated terraced systems are located in Valbelluna, in the Belluno province (Fig.1). The valley extends for over 50 kilometers, along the river Piave, between the pre-Alpine belt and the Dolomites, at elevation ranging between 200 and 700 meters. Geology and lithology influence the morphology of the investigated area, characterized by the prevalence of Quaternary glacial, alluvial and colluvial deposits composed of marly limestone with abundant silty-clay matrix. Both the last glacial events and the river Piave contributed widely to model the landscape morphology, formed of shallow hills and a large alluvial plain. Urban settlements are located on the hills, while industrial plants are nearly absent, and agriculture is widespread on the bottom valley.

Based on Koppen classification (Pinna, 1977), the climate of the area is cool temperate. The mean annual temperature is 9.9°C and the mean annual precipitation is 1500 mm per year; rainfall is yearly distributed with two peaks in spring and autumn.

The vegetation coverage is composed of permanent meadows, pasture, shrubs and mixed hardwood forest. In terraced areas which were abandoned after decades of cultivation, a process of uncontrolled secondary vegetation succession has started, leading to heterogeneous units represented by neo-formation of post-agriculture vegetation series as mowing meadows, mixed shrubs and hornbeam. In cultivated terraces main crops are potato, bean and vineyard.

## Soil survey

The study area was preliminary investigated by observation of aerial photographs, that allowed identification of different landscape units. Afterwards, a systematic soil survey was carried out in the whole area. Thirtynine representative soil profiles from 24 terraced systems, under different land uses (mown meadows, abandoned agricultural land and forest), were described and sampled following the Italian guidelines (Costantini, 2007). Fourteen of the 24 terraced areas are located in Sospirolo (7) and Sovramonte (7) municipalities, in the west and east extremity of the Valbelluna, respectively. The terraced systems are generally organized with nearly 10 orders of small terraces, but some systems are composed of more terraces (up to 39). Most flat terraces are located along parallel belts, with few gentle slopes; the aspect is generally south-east but some terraces are facing south-west.

The land use of 12 terraced systems is grassland, while the others are abandoned since 50 or 20 years, and a secondary vegetation coverage is likely to occur.

Once recovered to the laboratory, soils were analyzed for the following soil properties:

- Physical: texture, bulk density, real density, porosity, AWC

- Chemical: pH, C.E.C., $CaCO_3$
- Biological: QBS-ar, soil organic matter (SOM).

Soil analyses were carried out according to the procedures described in the manual of the Italian Ministry of Agriculture and Forestry (MIPAF, 2000). Soil samples were air-dried and sieved to 2 mm. On the fine fraction the following parameters were determined: pH in water and in KCl (electrometric method described by Violante and Adamo (2000), carbonate (gas-volumetric measurement as described by Boero (2000), organic carbon and organic matter (oxidation at the temperature of reaction, as described by Walkley and Black (1934) and reviewed by Sequi and De Nobili (2000)), cation exchange capacity, total acidity, base saturation (Barium Chloride–Triethanolamine at pH 8.1, described by Gessa and Ciavatta (2000)), texture (pipette method preceded by destruction of organic matter pretreatment, described by Genevini et al. (1994). Moreover, the humus type (Jabiol et al., 2007) and the soil biological quality (QBS-ar; Parisi, 2001) were evaluated to estimate differences and correlations among the different sites.

Climate data provided by the Regional Meteorological Service Center in Teolo (PD) and related to the period 1995–2004 have been used. Data on monthly temperature and precipitation for the various areas were elaborated with the Thornthwaite and Mather model (1957), modified by Armiraglio et al. (2003) to calculate the soil water balance. Based on the water balance, soil moisture and temperature regimes have been defined according to the criteria of the latest edition of the American System of Soil Classification (Soil Survey Staff, 2010). Each soil profile was classified according to Soil Taxonomy (USDA, 2010) and WRB (IUSS, 2006), following ICOMANTH (2006) recommendations.

## Dedicated soil survey for identification of pedogenesis ages on terraced landscape

Subsequently to the previous soil survey, two pilot terraced areas located at Lasen (Feltre municipality, to the west) and at Pascoli (Sospirolo municipality, to the east), were selected. The two areas had the same characteristics (exposure, elevation, parent material, land use, abandonment degree and terrace conservation). In particularly, in the Pascoli area (Fig. 1 red circle), three terraced systems with different degree of abandonment and one natural non-terraced area have been identified, described and surveyed according to different pedogenesis ages (Fig.2):

- S-NAT (*n*=2): natural soils of not terraced slope with natural vegetation coverage (multi-millenia pedogenesis).
- S-TER1 (*n*=3 soil profiles): terraced slopes still cultivated with arable land and residential green (historical anthropedogenesis);
- S-TER2 (*n*=3): semi-abandoned terraced slopes (10-20 years) with only sporadically cutting wood (contemporary pedogenesis);
- S-TER3 (*n*=3): abandoned terraced slopes (50 years) with land use to mixed deciduous forest (contemporary pedogenesis).

DOI: 10.6092/issn.2281-4485/7308

The area S- NAT was chosen as "natural" term of comparison to evaluate differences in soil properties and soil profile with adjacent anthropogenic soils of terraced areas.

Besides the standard physical-chemical-biological soil analysis, the soils of pilot terraced areas were analyzed for significant physical dynamic soil properties (bulk density, real density and porosity), in order to highlight the dynamics of soil evolution (Ramos et al. 2007; Richter, 2007).

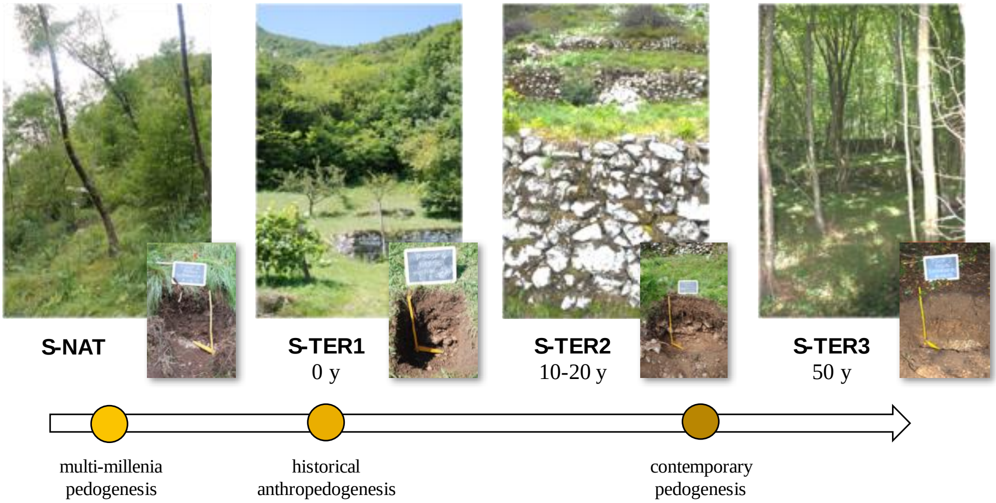

**Figure 2.** *Pascoli terraced pilot area and chronosequence of soil investigated in the pilot area: from natural soils (multi-millenia pedogenesis) to terraced soil (historical anthropedogenesis) with different years of abandonment (contemporary pedogenesis).*

## Statistical analyses

Multivariate statistical techniques with software STATISTICA 6.0 were applied to investigate the influence of different environmental factors on soil geography in the area.

According to the statistical approach PERMANOVA (Mcardle e Anderson, 2001), the simultaneous response of different variables (e.g. elevation, slope, soil chemical and physical properties), to one or more factors (e.g. present and past land use) is ascertained.

The statistical analysis was carried out ordering variables according two factors (land use and geographic position), and modelling was performed with a distance-based linear model (DISTLM) joined with a distance-based redundancy analysis (dbRDA). (Legendre and Anderson, 1999; Mcardle and Anderson, 2001).

To study the effect of terracing on soil dynamic properties and identifying new forms and processes of anthropedogenesis, linear regression and correlation analyses were performed between soil properties of natural and terraced soils. In particular, Zar - $\chi 2$ test has been used to assess the differences between correlation coefficients of different soil dynamics properties belonging to two different sample population: natural and terraced soils.

## Results and Discussion

### Pedogenic environment

In this study, 39 soil profiles have been analysed, including 24 profiles chosen as representative of terraced systems and subsystems, and 15 profiles considered to be indicative of the non-terraced slopes. The soils of the terraced areas always lay on a level of stony material of the same lithology than the geological substrate (mostly marly limestone). Basic geographical and environmental information is summarized in Table 1.

In the investigated area, a total of 3 orders and 7 suborders of the Soil Taxonomy system (USDA, 2010) have been identified. In particular, the soil Orders are:

- Entisols;
- Inceptisols;
- Mollisols.

Lower taxonomic categories indicate differences in soil moisture, depth, base saturation and other specific properties of investigated soils.

Field observations allowed identifying different pedogenic environments at selected sites, based on different lithology, morphology, climate and vegetation cover.

As shown in Table 2, 15 profiles at not terraced sites are represented mostly (10 out of 15 soils) by slightly developed soils, with typical profile A- AC- C (Lithic and Typic Udorthents / Regosols ). In general, they are located at sites with a slope gradient between 15 % and 90 %, are shallow (50 cm on average) and are characterized by sub-alkaline or neutral reaction. The representative humus types are Dysmoder, Amphimus or Oligomull, depending on the reaction of the soil.

Only one third of the not terraced soils (5 out of 15), instead, show a greater degree of differentiation of the profile, with typical A- Bw -BC- C (Typic Eutrudepts / Haplic Cambisols ) and mainly sub-alkaline or neutral reaction (the only exception is represented by a Dystric Eutrudept / Dystric Cambisol, with slightly acidic reaction due to a local outcrop of sandstone. In general, these profiles are located at sites with lesser slope than the previous (between 5 % and 70 %) and are characterized by a greater depth (60 - 70 cm on average). The humus types of these soils are extremely variable depending on the soil reaction, ranging from Dysmoder, Amphimus, Mesomull and Oligomull .As for the remaining 24 profiles placed on terraced slopes, it can be observed that 18 of them are represented by little developed soils, with typical profile ^A1- ^A2 - ^ AC - ^ C (Lithic and Typic

**Table 1**. *List of soil profiles described, the municipality where they are located, geographic coordinates and environmental factors (Elevation, Slope, Aspect and Land*

*Use).*

| Site | Municipality | Gauss Boaga | | Elevation (m) | Slope (%) | Aspect (°) | Land Use |
|---|---|---|---|---|---|---|---|
| | | Latitude N | Longitude E | | | | |
| PSOSP1 | Sospirolo | 5,116,171 | 1,737,560 | 580 | 10 | 90 | Primary vegetation |
| PSOSP2 | Sospirolo | 5,116,296 | 1,737,577 | 580 | 60 | 90 | Natural slope |
| PSOSP3 | Sospirolo | 5,115,923 | 1,737,527 | 575 | 30 | 90 | Primary vegetation |
| PSOSP4 | Sospirolo | 5,116,114 | 1,737,670 | 520 | 0 | 45 | Secondary vegetation |
| PSOSP5 | Sospirolo | 5,115,370 | 1,739,997 | 390 | 0 | 135 | Secondary vegetation |
| PSOSP6 | Sospirolo | 5,115,436 | 1,740,102 | 390 | 20 | 135 | Primary vegetation |
| PSOSP7 | Sospirolo | 5,116,737 | 1,738,591 | 544 | 5 | 180 | Secondary vegetation |
| PSOSP8 | Sospirolo | 5,116,673 | 1,738,529 | 550 | 10 | 360 | Primary vegetation |
| PSOSP11 | Sospirolo | 5,116,542 | 1,738,979 | 475 | 15 | 180 | Natural slope |
| PSOSP12 | Sospirolo | 5,114,949 | 1,738,715 | 400 | 15 | 135 | Natural slope |
| PSED1 | Sedico | 5,117,289 | 1,741,640 | 420 | 5 | 180 | Primary vegetation |
| PSED2 | Sedico | 5,117.232 | 1,741,772 | 420 | 20 | 135 | Natural slope |
| PSED3 | Sedico | 5,117,627 | 1,740,790 | 420 | 5 | 225 | Secondary vegetation |
| PGREG1 | San Gregorio | 5,111,226 | 1,732,722 | 890 | 0 | 135 | Primary vegetation |
| PGREG2 | San Gregorio | 5,111,257 | 1,732,721 | 900 | 35 | 175 | Natural slope |
| PGREG3 | San Gregorio | 5,112,455 | 1,734,975 | 590 | 0 | 180 | Primary vegetation |
| PGREG4 | San Gregorio | 5,112,334 | 1,735,044 | 590 | 45 | 180 | Natural slope |
| PGIUST1 | Santa Giustina | 5,110,744 | 1,732,224 | 610 | 10 | 135 | Primary vegetation |
| PSOVR1 | Sovramonte | 5,101,647 | 1.714.036 | 475 | 20 | 225 | Secondary vegetation |
| PSOVR2 | Sovramonte | 5,101,995 | 1,714,282 | 475 | 55 | 270 | Natural slope |
| PSOVR3 | Sovramonte | 5,105,366 | 1,714,358 | 700 | 20 | 225 | Secondary vegetation |
| PSOVR4 | Sovramonte | 5,105,459 | 1,714,377 | 700 | 90 | 225 | Natural slope |
| PSOVR5 | Sovramonte | 5,105,006 | 1,718,178 | 800 | 15 | 135 | Primary vegetation |
| PSOVR6 | Sovramonte | 5,100,821 | 1,714,280 | 525 | 30 | 270 | Secondary vegetation |
| PSOVR7 | Sovramonte | 5,100,700 | 1,714,349 | 525 | 60 | 225 | Natural slope |
| PSOVR8 | Sovramonte | 5,106,186 | 1,718,330 | 975 | 15 | 135 | Natural slope |
| PSOVR9 | Sovramonte | 5,105,808 | 1,718,150 | 915 | 15 | 135 | Secondary vegetation |
| PSOVR10 | Sovramonte | 5,105,165 | 1,718,302 | 950 | 70 | 135 | Natural slope |
| PSOVR11 | Sovramonte | 5,105,304 | 1,714,360 | 650 | 30 | 225 | Primary vegetation |
| PSOVR12 | Sovramonte | 5,104,870 | 1,717,817 | 750 | 5 | 135 | Secondary vegetation |
| PPEDA1 | Pedavena | 5,104,137 | 1,721,332 | 650 | 10 | 370 | Secondary vegetation |
| PPEDA2 | Pedavena | 5,104,068 | 1,721,331 | 680 | 45 | 180 | Natural slope |
| PPEDA3 | Pedavena | 5,103,597 | 1,721,993 | 500 | 10 | 135 | Secondary vegetation |
| PPEDA4 | Pedavena | 5,103,753 | 1,722,009 | 550 | 45 | 135 | Natural slope |
| PFELT1 | Feltre | 5,106,433 | 1,725,182 | 650 | 10 | 135 | Secondary vegetation |
| PFELT2 | Feltre | 5,106,619 | 1,725,196 | 750 | 5 | 135 | Primary vegetation |
| PFELT3 | Feltre | 5,106,904 | 1,725,380 | 725 | 45 | 135 | Natural slope |
| PCESIO1 | Cesiomaggiore | 5,108,955 | 1,730,679 | 650 | 5 | 180 | Secondary vegetation |
| PCESIO2 | Cesiomaggiore | 5,109,288 | 1,730,495 | 700 | 45 | 180 | Natural slope |

Udorthents/Transporti Technic Regosols (Escalic)).

In general, they are located at sites sloping considerably less (0 % - 30%) than the corresponding not terraced profiles. These soils are characterized by thickness between 50 and 70 cm, although some of them may be shallower. The reaction is neutral and the presence of free carbonate is scarce, suggesting a partial desaturation of the profile. The humus type is extremely variable and closely related to the reaction of the soil. Of the 24 profiles on terraced slopes, the remaining 6 all show a greater differentiation of the profile, with a typical horizon sequence ^A - ^Bw - ^BC - ^C (Transport Technic Cambisols (Escalic) / Typic Eutrudepts and Transporti Technic Phaeozems (Escalic)/Typic Haprendolls).

**Table 2**. *List of the studied soils with indication of taxonomy (WRB and USDA) and humus type. The soil profiles representative of terraced land are characterized by Human Transported Material (HTM), and the WRB is the only taxonomic system that emphasizes*

*the anthropogenic materials.*

| Site | WRB 2006 | Soil Taxonomy 2010 | Humus type | Land Use |
|---|---|---|---|---|
| **PSOSP1** | **Transporti Technic Regosol (Escalic)** | **Typic Udorthent** | **Amphymus** | **Primary vegetation** |
| **PSOSP2** | **Haplic Cambisol** | **Typic Eutrudept** | **Amphymus** | **Natural slope** |
| **PSOSP3** | **Transporti Technic Regosol (Escalic)** | **Typic Udorthent** | **Amphymus** | **Primary vegetation** |
| **PSOSP4** | **Transporti Technic Regosol (Escalic)** | **Typic Udorthent** | **Oligomull** | **Secondary vegetation** |
| **PSOSP5** | **Transporti Technic Regosol (Escalic)** | **Typic Udorthent** | **Eumull** | **Secondary vegetation** |
| **PSOSP6** | **Transporti TechnicCambisol (Escalic)** | **Typic Eutrudept** | **Eumull** | **Primary vegetation** |
| **PSOSP7** | **Transporti Technic Regosol (Escalic)** | **Typic Udorthent** | **Mesomull** | **Secondary vegetation** |
| **PSOSP8** | **Transporti Technic Regosol (Escalic)** | **Typic Udorthent** | **Oligomull** | **Primary vegetation** |
| **PSOSP11** | **Lithic Regosol** | **Lithic Udorthent** | **Oligomull** | **Natural slope** |
| **PSOSP12** | **Dystric Cambisol** | **Dystric Eutrudept** | **Mesomull** | **Natural slope** |
| **PSED1** | **Transporti TechnicPhaeozem (Escalic)** | **Typic Haprendoll** | **Oligomull** | **Primary vegetation** |
| **PSED2** | **Haplic Phaeozem** | **Typic Haprendoll** | **Oligomull** | **Natural slope** |
| **PSED3** | **Transporti Technic Regosol (Escalic)** | **Lithic Udorthent** | **Oligomull** | **Secondary vegetation** |
| **PGREG1** | **Transporti Technic Regosol (Escalic)** | **Typic Udorthent** | **Oligomull** | **Primary vegetation** |
| **PGREG2** | **Lithic Regosol** | **Lithic Udorthent** | **Oligomull** | **Natural slope** |
| **PGREG3** | **Transporti TechnicCambisol (Escalic)** | **Typic Eutrudept** | **Oligomull** | **Primary vegetation** |
| **PGREG4** | **Haplic Cambisol** | **Typic Eutrudept** | **Oligomull** | **Natural slope** |
| **PGIUST1** | **Transporti Technic Regosol (Escalic)** | **Lithic Udorthent** | **Oligomull** | **Primary vegetation** |
| **PSOVR1** | **Transporti TechnicCambisol (Escalic)** | **Typic Eutrudept** | **Oligomull** | **Secondary vegetation** |
| **PSOVR2** | **Haplic Cambisol** | **Typic Eutrudept** | **Dysmoder** | **Natural slope** |
| **PSOVR3** | **Transporti Technic Regosol (Escalic)** | **Lithic Udorthent** | **Dysmoder** | **Secondary vegetation** |
| **PSOVR4** | **Lithic Regosol** | **Lithic Udorthent** | **Dysmoder** | **Natural slope** |
| **PSOVR5** | **Transporti Technic Regosol (Escalic)** | **Typic Udorthent** | **Oligomull** | **Primary vegetation** |
| **PSOVR6** | **Transporti Technic Regosol (Escalic)** | **Typic Udorthent** | **Mesomull** | **Secondary vegetation** |
| **PSOVR7** | **Lithic Regosol** | **Lithic Udorthent** | **Oligomull** | **Natural slope** |
| **PSOVR8** | **Lithic Regosol** | **Lithic Udorthent** | **Dysmoder** | **Natural slope** |
| **PSOVR9** | **Transporti Technic Regosol (Escalic)** | **Typic Udorthent** | **Oligomull** | **Secondary vegetation** |
| **PSOVR10** | **Lithic Regosol** | **Lithic Udorthent** | **Amphymus** | **Natural slope** |
| **PSOVR11** | **Transporti Technic Regosol (Escalic)** | **Typic Udorthent** | **Amphymus** | **Primary vegetation** |
| **PSOVR12** | **Transporti Technic Regosol (Escalic)** | **Typic Udorthent** | **Amphymus** | **Secondary vegetation** |
| **PPEDA1** | **Transporti Technic Regosol (Escalic)** | **Lithic Udorthent** | **Oligomull** | **Secondary vegetation** |
| **PPEDA2** | **Lithic Regosol** | **Lithic Udorthent** | **Oligomull** | **Natural slope** |
| **PPEDA3** | **Transporti Technic Regosol (Escalic)** | **Lithic Udorthent** | **Eumull** | **Secondary vegetation** |
| **PPEDA4** | **Lithic Regosol** | **Lithic Udorthent** | **Amphymus** | **Natural slope** |
| **PFELT1** | **Transporti TechnicCambisol (Escalic)** | **Typic Eutrudept** | **Oligomull** | **Secondary vegetation** |
| **PFELT2** | **Transporti TechnicCambisol (Escalic)** | **Typic Eutrudept** | **Oligomull** | **Primary vegetation** |
| **PFELT3** | **Haplic Regosol** | **Typic Udorthent** | **Amphymus** | **Natural slope** |
| **PCESIO1** | **Transporti Technic Regosol (Escalic)** | **Typic Udorthent** | **Oligomull** | **Secondary vegetation** |
| **PCESIO2** | **Haplic Regosol** | **Typic Udorthent** | **Oligomull** | **Natural slope** |

They are located at gently sloping sites (between 0% and 30%) and are characterized by greater depth (up to100 cm). The reaction is sub-alkaline or alkaline, and the humus types vary from Eumull to Oligomull and Dysmoder.

The anthropogenic soils showed a clear process of entisolization and have been classified as Transporti Technic Regosols (WRB, 2006) and Lithic and Typic Udorthents (USDA, 2010). They consist of an ^Ap horizon (earthy material, 30-40 cm) and ^C horizon (Human-Transported Natural Materials with artifacts, no fine earth and pebbles percentages always close to 100%). The non-terraced soils, instead, have a higher degree of development, with Lithic and Typic Udorthents (Regosols) moving to Typic Eutrudepts (Haplic Cambisols), and higher root penetration depth (50-55 cm). The fact that on HTM soils we found thickness less than the natural soils is likely depending on crops that were cultivated on these terraces. Another factor limiting the depth of the fertile layer is related to the possibility of transporting and locating on site the earthy material.

**Table 3.** *Physical-chemical parameters of 7 selected profiles of the investigated soils.*

| Size | Horizon | Depth | pH-W | CEC | $CaCO_3$ | TOC | TIC | Sand | Clay | C.Silt | F.Silt | Tot.Silt | ρa | ρs | φ | CIP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | cm | | CmolKg | g/Kg | % | % | % | % | % | % | % | $Kg/m^3$ | $Kg/m^3$ | % | % |
| PFELT1 | | | 8.0 | 12.5 | 305 | 2.0 | 3.5 | 36 | 21 | 22 | 21 | 43 | 860.76 | 2279.92 | 62.4 | 39.3 |
| | ^A | 6 | 7.6 | 16.0 | 316 | 3.8 | 3.6 | 37 | 21 | 21 | 21 | 42 | 646.97 | 2192.34 | 70.5 | 59.6 |
| | ^Bw1 | 34 | 8.1 | 10.9 | 313 | 1.9 | 3.5 | 36 | 20 | 23 | 21 | 43 | 829.44 | 2270.39 | 63.4 | 40.6 |
| | ^Bw2 | 59 | 8.2 | 13.2 | 293 | 1.4 | 3.5 | 36 | 21 | 22 | 20 | 42 | 992.81 | 2325.53 | 57.3 | 27.5 |
| | ^Bw3 | 100 | 8.0 | 10.0 | 296 | 1.1 | 3.4 | 34 | 23 | 20 | 23 | 43 | 973.84 | 2331.41 | 58.2 | 29.3 |
| PFELT2 | | | 7.9 | 11.8 | 135 | 2.7 | 1.4 | 33 | 35 | 14 | 17 | 31 | 1104.06 | 2261.50 | 51.3 | 34.0 |
| | ^A | 11 | 7.6 | 2.6 | 63 | 3.8 | 1.1 | 31 | 37 | 18 | 14 | 32 | 984.20 | 2177.88 | 54.8 | 44.7 |
| | ^BC | 60 | 8.1 | 27.8 | 149 | 1.9 | 1.0 | 31 | 35 | 14 | 19 | 33 | 1200.27 | 2351.61 | 49.0 | 27.0 |
| | ^Bw | 37 | 7.9 | 4.9 | 194 | 2.3 | 2.0 | 35 | 33 | 10 | 19 | 29 | 1127.70 | 2255.01 | 50.1 | 30.4 |
| PFELT3 | | | 7.9 | 30.1 | 322 | 1.9 | 2.9 | 49 | 19 | 17 | 15 | 32 | 842.69 | 2203.11 | 61.8 | 33.6 |
| | A | 17 | 7.3 | 34.6 | 0 | 3.7 | 0.2 | 33 | 31 | 14 | 22 | 36 | 808.99 | 2106.16 | 61.7 | 39.3 |
| | AC | 42 | 8.1 | 26.1 | 370 | 1.8 | 1.7 | 44 | 23 | 14 | 19 | 33 | 876.40 | 2300.07 | 61.9 | 27.8 |
| | C | 82 | 8.3 | 29.6 | 595 | 0.2 | 6.7 | 69 | 3 | 23 | 5 | 28 | | | | |
| PSOSP1 | | | 7.8 | 17.2 | 608 | 3.9 | 6.3 | 53 | 14 | 12 | 21 | 33 | 544.15 | 2131.06 | 74.7 | 56.2 |
| | ^A | 15 | 7.6 | 24.3 | 427 | 3.9 | 5.1 | 49 | 17 | 8 | 25 | 34 | 414.91 | 2030.92 | 79.6 | 67.4 |
| | ^AC | 28 | 7.9 | 19.1 | 516 | 3.0 | 5.7 | 44 | 15 | 11 | 29 | 39 | 673.39 | 2231.19 | 69.8 | 45.0 |
| | ^C | nr | nr | nr | nr | nr | nr | nr | nr | nr | nr | nr | | | | |
| | 2Bwb | 66 | 7.9 | 13.6 | 704 | 1.5 | 7.6 | 58 | 12 | 13 | 16 | 29 | | | | |
| | 2BCb | 80 | 8.0 | 11.7 | 786 | 7.2 | 7.1 | 59 | 12 | 17 | 13 | 30 | | | | |
| PSOSP2 | | | 7.8 | 40.4 | 70 | 3.7 | 0.6 | 25 | 19 | 23 | 32 | 55 | 636.74 | 2013.21 | 68.7 | 59.7 |
| | A | 30 | 7.8 | 76.0 | 105 | 4.6 | 0.8 | 19 | 23 | 41 | 16 | 57 | 437.95 | 1935.41 | 77.4 | 71.9 |
| | B&C | 60 | 7.8 | 20.2 | 68 | 3.1 | 0.5 | 31 | 15 | 12 | 41 | 52 | | | | |
| | Bw | 53 | 7.8 | 25.0 | 37 | 3.5 | 0.3 | 23 | 20 | 16 | 39 | 55 | 835.53 | 2091.02 | 60.0 | 47.5 |
| PSOSP3 | | | 7.9 | 18.4 | 221 | 4.0 | 2.2 | 50 | 10 | 12 | 27 | 39 | 667.43 | 2231.26 | 69.8 | 46.3 |
| | ^A1 | 4 | 7.7 | 25.7 | 0 | 3.6 | 0.5 | 43 | 8 | 15 | 33 | 49 | 524.11 | 2073.88 | 74.7 | 72.5 |
| | ^A2 | 29 | 7.8 | 17.9 | 58 | 2.5 | 0.7 | 43 | 11 | 12 | 31 | 43 | 785.54 | 2178.86 | 63.8 | 40.0 |
| | ^C1 | 46 | 8.1 | 11.6 | 605 | 5.8 | 5.4 | 64 | 10 | 7 | 18 | 26 | 689.65 | 2387.04 | 70.9 | 26.5 |
| PSOSP4 | | | 7.7 | 27.0 | 111 | 4.1 | 1.1 | 40 | 9 | 18 | 32 | 50 | 566.80 | 1977.27 | 71.6 | 88.7 |
| | ^A1 | 12 | 7.5 | 33.7 | 0 | 5.1 | 0.2 | 44 | 8 | 17 | 30 | 47 | 452.24 | 1865.74 | 75.8 | 120.7 |
| | ^A2 | 40 | 7.9 | 20.4 | 222 | 3.0 | 1.9 | 36 | 10 | 18 | 35 | 53 | 681.36 | 2088.80 | 67.4 | 56.8 |

The physical properties have been investigated in the two pilot areas of Sospirolo (Leys) and Feltre (Lasen), sampling a total of 7 profiles:

- PSOSP 1 (on the terraced semi- abandoned area);
- PSOSP 2 (not terraced area);
- PSOSP 3 (on abandoned terraced slope)
- PSOSP4 (on terraced slopes)
- PFELT1 (on terraced slopes)
- PFELT 2 (on abandoned terraced slope)
- PFELT 3 (not terraced area)

The average values of the chemical and physical parameters of the seven representative profiles are reported in Table 3.

In case of horizons not sampled due to the excessive amount of skeleton, the density values were estimated by the CNCP. The results showed that either the bulk density and the real density increase with depth, while porosity decreases.

## Statistical analysis

Multivariate analysis (dbRDA) and variance analysis with PERMANOVA have been conducted on 318 soil samples for the physical and chemical properties, and on the 65 samples of the pilot areas for the physical and biological properties.

The results revealed that the topographic parameters "elevation, exposure and slope" are not related to chemical properties and to soil texture. In contrast, PERMANOVA analysis showed a significant correlation between the geographic area and the land use. The geographic area is also correlated in particular with pH values, which in the terraced areas are quite uniform along the profile, while in not terraced areas they are more variable. Bulk density in not abandoned areas increases, and porosity decreases.

## Relationship between environmental and pedological parameters

The gravel content is generally abundant but is highly variable along the profile of terraced soils. All anthropogenic soils showed a loam textural class (Fig. 3). Carrying-on material for the construction of terraces, human action leads to a loss of fine components. Terraced soils showed AWC values significantly lower than natural soils. The reaction of all soils is moderately alkaline (from 7.6 to 8.1). The role played by anthropic remixing of parent material is strictly evident from the presence of carbonate along the profile. Natural soils present lower carbonate than terraced ones, which also present a notable variability along the soil profile. Organic carbon and C.E.C. of natural soils are significantly higher, along the whole profile, than terraced soils. In anthropogenic soils, SOC is relatively abundant even in the deeper horizons (Fig. 4). The subsurface horizons of terraced soils contain SOC equivalent to approximately 50% of surface horizons (^A or ^Ap). Unlikely, the natural ones contain only 20% of the top mollic horizons (A). This points out how the construction of anthropogenic soils and their subsequent cultivation has prompted the initiation of a well-defined *in situ* pedogenetic process: the incorporation of organic matter along the whole profile. Therefore, SOC seems to increase in the upper horizons with the increase of years of abandonment, together with the development of carbonation/decarbonation, melanization and clay eluviation processes.

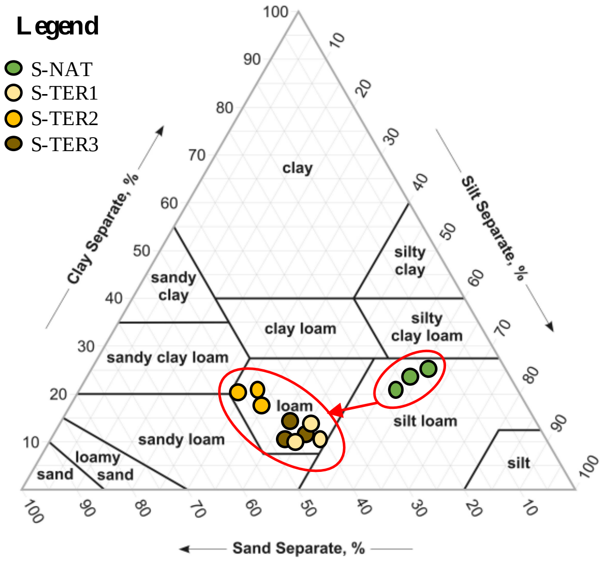

**Figure 3**
*Direction and magnitude of anthropedogenesis with regard to textural classes of soil horizons.*

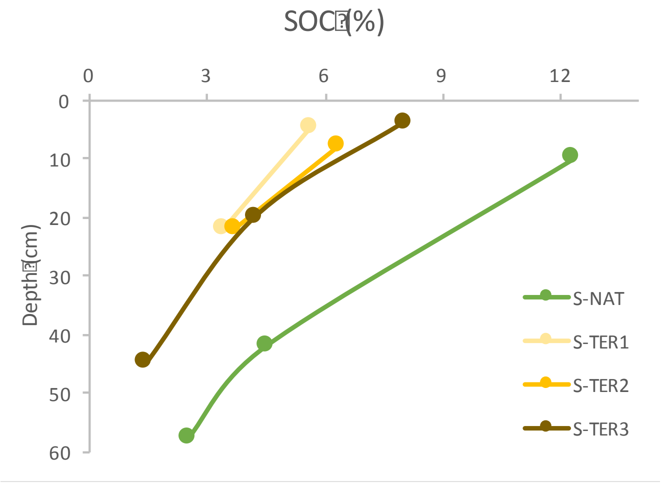

**Figure 4**
*Soil organic carbon content (%) distribution along the profile of selected soils.*

## Anthropedogenesis processes on terraced soils

In terraced soils we observed the occurrence of entisolization process (Fig. 5). This anthropedogenetic process is evident with terracing since the number of soil horizons is reduced up to one single human-constructed soil horizon (^A or ^AC). The horizons ^C of terraced soils resulted human–constructed and on average of 25 cm (Fig.5). After 50 years from abandonment terraced soil (S-TER3) showed the occurrence of a natural A horizon (Fig. 5).

For natural soils, many soil properties are significantly correlated ($P<0.01$) (e.g. clay with C.E.C. ($r$ = 0.85) and with S.O.C. ($r$ = 0.89), or sand with AWC (r = -1.00) and with bulk density (0.93)). Using Zar - $\chi^2$ test to assess the differences between correlation coefficients of soil properties for natural and terraced soils, we noted that the 56% of Pearson Coefficients ($r_i$), calculated for terraced soils, are significantly different than $r_i$ for natural soils. The creation of terraced soils has reduced the degree of correlation between soil properties (e.g. clay vs S.O.C. (0.89 → -0.22) and clay vs C.E.C. (0.85 → -0.26)). This increase in entropy in soil system can be attributed to a loss of "natural" correlation for soil properties along the soil profile. Furthermore, for terraced soils, 80% of the combinations of $r_i$ (depth $_{vs}$ soil parameter) are statistically different ($P<0,05$). This is a clear indication of anthropic mixing. The new anthropedogenetic properties are highly variable and vary randomly.

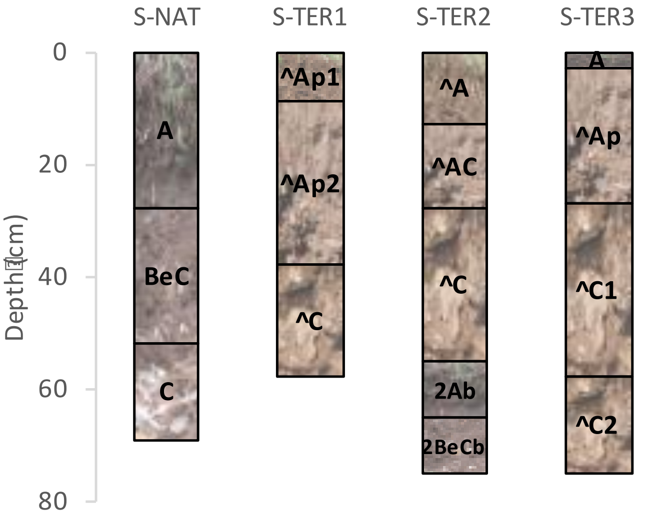

**Figure 5**
*Natural (S-NAT) and terraced soils profiles (S-TER 1-2-3).*
*Note the use of the prefix "^" to indicate the HTM (Human Transported Materials).*

## Terraced landscape ecosystems conservation status

Three developing stages have been recorded in terraced soils:
- Not degraded soils, with no signal of abandonment, under current permanent meadow, are characterized by strong crumb structure, good natural status, no structural terrace degradation and no ecological degradation;
- Strongly degraded soils under new afforestation and partly mown meadows (20 to 50 years of abandonment) showed slow biological activity, reduced forest floor, no structural terrace degradation and moderate ecological degradation, with loss of biodiversity;
- Moderately degraded soils under mature forest (more than 50 years of abandonment), are characterized by abundant skeleton, little water retention, increasing biological activity and ticker forest floor. There is a structural terrace degradation but no ecological one.

DOI: 10.6092/issn.2281-4485/7308

The obtained results are consistent with our previous findings (Bini et al., 2010)**,** suggesting that the chemical and biological properties could be useful for discriminating pedogenic and anthropogenic horizons, and enhance identification of processes responsible for the formation of different soil types, and may be a useful tool to outline soil evolutionary trends.

## Conclusions

This study confirms the high environmental heterogeneity of the soils of the Dolomites. This heterogeneity can be explained with the considerable variability in the intensity of actions and interactions among different soil forming factors, and results in a wide range of soil typologies. Years of research in the Dolomites area, allowed to better understand the different roles of environmental factors in the evolution of soils of this Alpine region. The importance of climate and parent material as soil forming factors emerges from the whole study. The reason can be found in the short time of soil formation due to the relative short historical geomorphology of Dolomites, after the last glacial maximum (approx 12,000 years B.P.), and to the environmental conditions under which soils develop. Moreover, steep slopes cause erosion problems and therefore soil rejuvenation acts against the formation of more developed soils, contributing to the formation of thin soils with a lithic contact within few centimeters. Furthermore, anthropic contribution to pedogenesis should be emphasize.

Statistical analyses such as Permanova proved to be a useful tool to examine relationships between environmental and pedological variables; analysis of correlation coefficients instead highlighted soil evolution in relation to anthropic landforms.

Knowledge of historical memory and use of dynamic/relational soil properties enabled the identification of three pedogenesis ages on terraced soils of the area:

1. "*Multi-millennial pedogenesis*" of natural soils (Haplic Phaeozems)
2. "*Historical anthropedogenesis*" with terracing and cultivation where man acted as sixth factor of pedogenesis creating new pedological entities (Technic-Alloic Regosols (Escalic, Transportic, Skeletic)). WRB proved to be more useful than Soil taxonomy to classify these terraced soils.
3. "*Contemporary pedogenesis*" after crop abandonment of terraces which is moving the anthropogenic soils towards original Mollisols with carbonation, melanization and clay eluviation processes.

During the "historical anthropedogenesis" the human activity with terracing promoted two anthropedogenetic processes: entisolization and incorporation of soil organic matter along the profile.

The impact of terracing and cultivation determined an alteration of the degree of naturality achieved from natural pedogenesis; accordingly, an increase of disorder and entropy occurs in the soil system. Man has reversed the anisotropic trend of soil formation making soil simpler (haploidization), less organized, and more homogeneous.

Our observations showed how abandonment caused loss of biodiversity, but long term processes seem to proceed towards an improvement of environmental quality. The conservation of terraced landscapes, therefore, represents a strategic issue in mountain areas in order to prevent soil erosion and environmental risks.

## References

ARMIRAGLIO S, CERABOLINI B., GANDELLINI F., GANDINI P., ANDREIS C. (2003). Calcolo informatizzato del bilancio idrico del suolo. Natura Bresciana - Annali Museo Civico di Scienze Naturali di Brescia, 33:209–216.

ARNOLD R.W., SZABOLCS I., TARGULIAN V.C. (1990) Global soil change. U.N. Environment Program and International Institute for Applied Systems Analysis. Laxenburg, Austria.

BINI C., ZILIOLI D.M. (2009) Are soil and soilscape a cultural heritage? Proc. III Int. Conf. "Unicity, uniformity and universality in the identification of the landscape and cultural mosaic." Agribusiness, Paesaggio & Ambiente, XII(3):256, 260. ISSN 1594-784X.

BINI C., ZILIOLI D.M., WAHSHA M. (2010) Soils as a target of anthropogeographic landscape changes in alpine areas (Dolomites, northern Italy). Proceedings 19th World Congress of Soil Science. Published on DVD, Brisbane, Australia, pp. 103–105.

BOERO V. (2000) Metodi di analisi chimica del suolo. Carbonati e gesso. Ministero per le Politiche Agricole e Forestali, Osservatorio Nazionale Pedologico e per la Qualità del Suolo. Franco Angeli Ed., Milano, pp. 1–5.

COSTANTINI E.A.C.(ed.) (2007) Linee guida dei metodi di rilevamento e informatizzazione dei dati pedologici. CRA-ABP Firenze, Italia, p. 293.

CRUTZEN P.J. (2002), Geology of mankind. Nature 415: 23.

DUDAL R. (2004), The sixth factor of soil formation. Proceedings of International Conference "Soil Classification 2004," Petrozavodsk, August 3–8, Russia.

FREPPAZ M., AGNELLI A., DRUSI B., STANCHI S., GALLIANI C., REVEL CHION V., ZANINI E. (2008) Productive and environmental problems of the terraced areas in the Alpine Space. In: Scaramellini and Varotto (Eds.) Terraced landscapes of the Alps, Atlas. Marsilio Editori, Italy, ISBN 978-88-317-9520. pp. 61-67.

GARCÍA-RUIZ J.M., RUIZ-FLAÑO P., LASANTA T., MONSERRAT G., MARITNEZ-RICA J.P., PARDINI P. (1991) Erosion in abandoned fields, what is the problem? Soil Erosion Studies in Spain, 3:97–108.

GENEVINI P.L., MANSTERETTA M., MECELLA G. (1994) Metodi ufficiali di analisi chimica del suolo. Granulometria. Ministero delle Risorse Agricole, Alimentari e Forestali, Osservatorio Nazionale Pedologico e per la Qualità del Suolo, Franco Angeli Editore, Roma, pp. 41–57.

GESSA C., CIAVATTA C. (2000) Metodi di analisi chimica del suolo. Complesso di scambio. Ministero per le Politiche Agricole e Forestali, Osservatorio Nazionale Pedologico e per la Qualità del Suolo, Franco Angeli Editore, Milano, pp. 1–31.

ICOMANTH (2006) Circular letter #6 revisited. International Committee on Anthropogenic soils. Available on: http://clic.cses.vt.edu/icomanth.

IUSS Working Group WRB. (2006) World reference base for soil resources 2006. 2nd edition. World Soil Resources Reports No. 103. FAO, Roma.

JABIOL B., BRÊTHES A., PONGE J.F., TOUTAIN F., BRUN J.J. (2007) L'Humus sous Toutes ses Formes, 2e édition revue et corrigée. ENGREF, Nancy.

JENNY H. (1941) Factors of soil formation. McGraw-Hill Book Co., New York, USA.

KOSSE A. (2005) The time factor in understanding in Anthropogenic soil changes. In: IUSS-UIS- IBO, Proceedings of International Conference "Global Soil Change: Time-Scales and Rates of pedogenic processes", 10-18 march, Mexico City.

LASANTA T., ARNAEZ J., OSERIN M., ORTIGOSA L.M. (2001) Marginal lands and erosion in terraced fields in the Mediterranean mountains. Mountain Research Developments, 21:69-76.

LEGENDRE P., ANDERSON M. J. (1999) Distance-based redundancy analysis: testing multispecies responses in multifactorial ecological experiments. Ecological Monographs, 69:1-24.

LESSCHEN J.P., CAMMERAAT L.H., NIEMAN T. (2008) Erosion and terrace failure due to agricultural land abandonment in a semi-arid environment. Earth Surface Processes and Landforms, 33:1574-1584.

MCARDLE B.H. ANDERSON M. J. (2001) Fitting multivariate model to semi-metric distances: a comment on distance-based redundancy analysis. Ecology, 82: 290-297.

OLARIETA J.R., RODRÍGUEZ-VALLE F.L., TELLO E. (2008) Preserving and destroying soils, transforming landscapes: soils and land-use changes in the Vallès County (Catalunya, Spain) 1853e2004. Land Use Policy, 4:474-484.

PARISI V. (2001). La qualità biologica del suolo. Un metodo basato sui microartropodi, Ateneo Parmense, Acta Naturalia, 37: 97-106

PINNA M. (1977) Climatologia. Utet, Torino

RAMOS M.C., COTS-FOLCH R., MARTINEZ-CASASNOVAS J.A. (2007). Effects of land terracing on soil properties in the Priorat region in Northeastern Spain: A multivariate analysis. Geoderma, 142 : 251–261.

RICHTER D.D. (2007) Humanity's transformation of hearth soil: Pedology's new frontier. Soil Sci., 172(12): 957-967.

SANDOR J., BURRAS C.L., THOMPSON M. (2005) Human impact on soil formation. In: HILLEL D., Encyclopedia of soil in the environment, Vol. 1, pag.520-532. Elsevier Ltd., Oxford, U.K.

SANG-ARUN J., MIHARA M., HORAGUCHI YAMAJI Y. (2006) Soil erosion and participatory remediation strategy for bench terraces in Northern Thailand. Catena, 65:258-264.

SCALENGHE R, BONIFACIO E, CELI L, UGOLINI FC, ZANINI E (2002) Pedogenesis in disturbed alpine soils (NW Italy). Geoderma, 109:207-224

SCARAMELLINI C., VAROTTO M. (2008). Terraced landscapes of the Alps, Atlas. Marsilio Editori, Italy, ISBN 978-88-317-9520.

SEQUI P., DE NOBILI M. (2000). Metodi di analisi chimica del suolo. Carbonio Organico. Ministero per le Politiche Agricole e Forestali, Osservatorio Nazionale Pedologico e per la Qualità del Suolo. Franco Angeli Editore, Milano, pp. 1–26.

SESTINI A. (1947) Il paesaggio antropogeografico. Le Monnier, Firenze.

SOIL SURVEY STAFF (2010). Keys to Soil Taxonomy, 11th ed. USDA Natural Resources Conservation Service, Washington, DC 338 pp.

STANCHI S., FREPPAZ M., AGNELLI A., REINSCH T., ZANINI E. (2012). Properties, best management practices and conservation of terraced soils in Southern Europe (from Mediterranean areas to the Alps): A review. Quaternary International. DOI 10.1016/j.quaint.2011.09.015.

THORNTHWAITE C.W., MATHER J.R. (1957) Instructions and tables for computing potential evapotraspiration and the water balance. Climatology 10:181–311.

VIOLANTE P., ADAMO P. (2000) Reazione. Ministero per le Politiche Agricole e Forestali, Osservatorio Nazionale Pedologico e per la Qualità del Suolo, Metodi di analisi chimica del suolo. Franco Angeli Editore, Milano, pp. 1–13.

WALKLEY A., BLACK I.A. (1934) An examination of the Degtjareff method for determining soil organic matter, and proposed modification of the chromic acid titration method. Soil Science, 37:29–38.

ZALASIEWICZ J. (2008) Are we now living in the Anthropocene? GSA Today: v. 18, no. 2.

ZANINI E. (2009) Le problematiche attuali di una moderna pedologia. Disponibile su: www.societapedologia.it. (verificato il 6/2/2010)

ZILIOLI D., BINI C. (2009) Dieci anni di ricerche pedologiche in ambiente alpino: considerazioni sulla distribuzione e sull'evoluzione dei suoli nella regione dolomitica. Studi Trentini di Scienze Naturali 85 Special Issue. 169 pp..

ZILIOLI D., BINI C., WAHSHA M., CIOTOLI G. (2011) The pedological heritage of the Alps: Considerations on features, distribution and evolution of soils in the Dolomites (Italy). Geomorphology, 232-247.

DOI: 10.6092/issn.2281-4485/7308