Properties, best management practices and conservation of terraced soils in Southern Europe (from Mediterranean areas to the Alps); a review

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Properties, best management practices and conservation of terraced soils in Southern Europe (from Mediterranean areas to the Alps): a review

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Abstract

Terrace soils are distinctive features of the agricultural landscape in Europe. Due to their historical and aesthetic significance, they are a resource for agriculture and tourism: however they are also a challenge for land conservation and management. The fundamental role of terrace soils for agricultural quality and natural hazard prevention has not been fully investigated.

In the past, terraced slopes became ideal sites for human settlement and agricultural activities. At present, they are often used for high quality crops that grow on soils with specific chemical and physical properties. In fact, the filling material used for building terraces is a man-reworked substrate, where pedogenesis occurs under a strong human influence. This leads to soils with a generally limited pedogenic development and coarse texture, although, often, with good productivity. When abandoned, terraces are subjected to progressive decay due to erosion processes and slope failures.

This review focuses on terrace soil properties, conservation and management. We report some examples from the NW Italian Alps, where terraced slopes are characterised by ancient origin and, presently, are subjected to specific practices for their preservation. In fact, the different effects of land degradation at hill slope scale may be mitigated through appropriate terrace management practices favoring the soil moisture conservation, drainage optimization, and the presence of spontaneous vegetation cover. These subjects require careful planning and conservation measures that could be collected in “best practices” guidelines for farmers, landowners and decision-makers.

1. Introduction

Terraced slopes are widely distributed in the world since ancient times both for aesthetic and productive purposes (Gardner and Gerrard, 2003). Well-known examples are the Arab gardens in Spain (Delgado et al., 2007), and the agricultural terraces in central and South America (Sandor et al., 1990; Sandor and Eash, 1995; Inbar and Llerena, 1999; Kemp et al., 2006; Branch et al., 2007; Londono, 2007; Goodman-Elgar, 2008) and Asia (Veek et al., 1995; Luedeling et al., 2005).

Terraced landscapes/agroscapes (Arbelo et al., 2006) are cultural landscapes (Farina, 2000; Rusjian et al., 2007) with considerable environmental and aesthetic value. Terraced soils represent a large portion of the world's cultivated slopes (Sandor, 1998), even if no global estimation of their extension is available, to our knowledge. They are considered anthropogenic soils due to the human-induced characteristics and landform changes (Sandor and Eash, 1995; Yaalon and Arnold, 2000; Posthumus and De Graaf, 2004; Van Dijk and Bruijnzeel, 2004; Hammad et al., 2004; Sang-Arun et al., 2006; Shi et al., 2004; Zornoza et al., 2009). . In Europe (see Table 1, reporting relevant literature on terraced soils), terraced agro-ecosystems cover considerable surfaces in marginal, steeply sloping areas, both in Alpine regions (ARPAV, 2006; Scaramellini & Varotto, 2008) and in the Mediterranean and Sub-Mediterranean areas (Oliveira, 2001; Duran Zuazo et al., 2005; Brancucci and Paliaga, 2005; Allen et al., 2006; Cots-Folch et al., 2006; Rusjan et al., 2007; Seeger & Ries, 2008; Llovet et al., 2009). Their origin is prehistoric and some sites date back to the Iron Age (Christopherson et al., 2007).

Terrace building required a complete slope reshaping that was carried out manually in the past. Currently some mechanization is used particularly in favorable environmental conditions (Veek et al., 1995), where roads and slope morphology allow access.

The "stepped topography" (Sandor, 1998) of terraced slopes, artificially constructed by humans (Sanchez et al., 2002; Delgado et al., 2007), requires frequent maintenance and high energy inputs (Veek et al., 1995; Farina, 2000) not only during construction, but also for terrace and wall structure preservation and reconstruction (Posthumus and De Graaf, 2005). A continuous effort is required because slope instability, excessive runoff velocity, rainfall infiltration, and the susceptibility of soil to erosion can threaten terrace stability, leading to soil loss and even slope failures (Yaalon and Arnold, 2000; Van Dijk and Bruijnzeel, 2003,2004; Duran Zuazo et al., 2005; Allen et al., 2006). Consequently, the maintenance of the vertical structures, the network of tracks and minor roads, and the drainage network is required.

The role of terracing in preventing and controlling laminar erosion is widely documented in the literature, for heterogeneous environments. Goodman-Elgar (2008), in a study area located in Peru on long-term cultivated slopes, observed that terracing plays an active role in mitigating soil erosion, even if the erosion process is not always completely controlled. In the study area, upslope terraces showed deeper soils than undisturbed surrounding areas, but less fine material (clay, silt), while sediment deposited on slopes indicated a downhill movement of the fine material (Goodman-Elgar, 2008). The relevance of terraced areas for slope stability has been underlined by several authors. In fact, terraces play an important role in gully erosion control, due to the slope gradient reduction: Martinez-Casanovas and Ramos (2006) reported that broad based vineyard terraces in the Mediterranean are commonly interspaced between vine rows in order to avoid the development of a permanent and deep gully network. Veek et al. (1995), after a survey conducted in loessal terraced slopes in China, concluded that terracing, together with minimum tillage, is one of most effective soil protection measures, preserving soil agricultural quality, as observed in multiple environments (Sanchez et al., 2002; Shi et al., 2004). Sang-Arun at al. (2006) reported that covering bare terraces in Thailand, on slopes up to 35%, with weeds and plant residues can mitigate erosion including rill and gully formation and reduce nutrient loss.

Soil terraces provide a stable topographic base for crops, and favor soil moisture conservation in the crop root zone, which is particularly important in the Mediterranean regions (Sandor et al., 1990; Ramos et al., 2007), and in coarse-textured soils. In general, the improved water availability, together with better nutrient conservation, is known to increase crop yield in arid or semi-arid environments. Posthumus and De Graaf (2005) found that after bench terracing crop yield increased by 50% and cultivable area increased by 20 to 40% . The benefits of terracing in terms of soil and fertility conservation are evident in a wide range of environments (Rueker et al.1998). Another example of terrace's benefits in soil water management is represented by the "discontinuous terracing", used to create favorable micro-environmental conditions for single trees (Apuani et al., 2008).

The presence of vertical building elements such as stone walls, with height varying from tenth of centimetres to several meters (Sandor and Eash, 1995), and the abrupt change in slope morphology determine remarkable changes in the terraced pedoenvironments (Sanchez et al., 2002), such as improving soil structure, physical quality, and even resilience properties (Goodman-Elgar, 2008). Terrace soils are also known to have improved properties in terms of fertility, organic matter, structure, and porosity (Sandor et al., 1990). These soils often have better agricultural quality when compared with the surrounding undisturbed soils, mostly due to manuring and fertilization, i.e. constant organic matter inputs (Sandor and Eash, 1995).

Terrace walls are often manually filled with soil collected from the surrounding area (Sandor and Eash, 1995), with a mixing and strong turbation of the original horizons (IUSS Working Group, 2006). This turbation and the addition of soil organic matter and nutrients or their redistribution along the profile, results in a heterogeneous mix of materials that undergoes pedogenesis on large time scales (Dazzi, 1995). Scalenghe et al. (2002) and Freppaz et al. (2008a) remarked that the presence of continuous anthropic disturbance due to agricultural and farming practices may determine a limited morphological differentiation in soil profiles. For all these reasons, terrace soils are now considered constructed pedoenvironments with typifying characteristics. Consequently the World Reference Base for Soil Classification (IUSS Working Group, 2006) has introduced the specific suffix, Escalic meaning "located on a terraced slope".

Some criteria for terrace spacing and slope/length ratios have been reported in literature, as they are fundamental not only for runoff control and agricultural reasons, but also for the aesthetic perception of the terraced slopes. Modern terraces sometimes require specific modifications in order to allow mechanization (Veek et al., 1995; Ramos et al., 2007), such as levelling and construction of linked benches on steep slopes. Mechanization is sometimes the only way to make terraced agriculture economically profitable (Veek et al., 1995; Cots-Folch et al., 2006). However, a compromise between economical and ecological sustainability is also required to preserve the tourist attractiveness of the landscape (Lasanta et al., 2001) as specified by a multi-purpose conservation policy. For example, the recent European Union policy sustaining less favored areas (LFA) supported intense terracing for the reclamation of abandoned areas now invaded by pioneer vegetation.

In this work, we reviewed the main literature available on the terraced soils with emphasis on the Southern Europe Region, from the Mediterranean areas to the Alps. In particular we considered the following themes:

a) the spatial distribution of terraced landscapes in Southern Europe and the main terrace typologies;
b) the main physical and chemical properties of terraced soils and their classification;
c) the phenomenon of terraced areas abandonment and its environmental consequences;
d) the conservation issues and best practices suggestions.

2. Terraced landscapes in Europe: presence, distribution, and terraces characteristics

The terraced agricultural landscape is widely distributed in Southern Europe (for further details see the conclusions of the EU-INTERREG IIIB project ALPTER: www.alpter.net), although no reliable quantitative inventory on the total extension is readily available. Varotto & Ferrarese (2008) reported that terraces are a “widespread but cartographically invisible heritage”. A large part of them falls into the EU definition of LFA “less-favored areas” (http://ec.europa.eu/agriculture/glossary/index_en.html), i.e marginal areas (hilly or mountainous), where farmers may receive compensatory allowances in the framework of EU Axix 2 for Rural Development (improving the environment and the countryside). The program’s main aim is to promote sustainable farming and forestry, even when these activities are not economically profitable. Terraced landscape displays different degrees of modification from their original state (Sandor, 1998; Bonardi, 2008). Some stepped slopes are very close to the original natural landforms, while others show a more pronounced anthropic intervention. The average hill slope in terraced areas can exceed 100%, as observed in Valle d’Aosta Region (NW-Italy) (Freppaz et al., 2008a, b, Figure 1). Slopes from 25 to 40% and more can be found in the Mediterranean basin (Duran Zuazo et al., 2005; Koulouri and Giourga, 2007), while average slopes of 15% were reported by Rusjian et al. (2007) for terraced vineyards in Slovenia. Terrace structure is also very diverse. The two basic elements forming a terrace are risers, i.e. retaining walls, and treads, i.e. interwoven fields (Sandor, 1998). Risers or walls may be from few decimetres to several meters high, with continuous or discontinuous structure, from single walls to a complex series. The building material can be very different, depending on the local availability of rocks and stones, earth, and organic material (Sandor, 1998). Also terrace density may vary greatly. Terranova (1989) reported, for steep slopes in Cinque Terre (Liguria, Italy) a density of 3300-3500 meters of walls per ha, where walls are 4-5 m high, and a density of 5000-6000 m/ha when they are only 1.5-2 m high. This author estimated that dry stone walls in this study area measure about 6700 km (total stripes length), corresponding to about 8 400 000 m^3/ha. Bonardi (2008) reported a density of 2 km of walls per ha, on very steep slopes (more than 60%) in the Alps. He calculated that building a wall 2.5 m long and 1 m high in Maritime Alps required about 1.5 m^3 stones for the face, 1 m^3 stones plus 0.25 m^3 of earth for the filling of the volume behind the dry stone wall. Varotto & Ferrarese (2008) reported the conclusions of the INTERREG Alpter Project on terraced landscapes of the Alps, indicating some relevant indices.

The total surface of the terraced study areas, distributed across the Alpine Region, ranged between a few hectares to about 500 ha (Valais region, Switzerland, and Cinque Terre, Italy), with a relative terraced surface (terraced surface/regional surface) ranging from 0.3 to about 65%. The absolute wall lengths ranged from about 100 km to 40000 km (Liguria Region, Italy) and different types of terraced landscapes were classified depending on the ratio between terraces length and total terraced area : low intensity (5-200 m/ha; medium intensity (200-800 m/ha), high intensity (>800 m/ha).

Different construction techniques are documented, depending on parent material and geomorphology, available materials and energy. However, the most significant aspect is building the walls and filling it with soil (Bonardi, 2008). Treads are typically constructed from local soil materials, and the quality of the substratum plays a fundamental role in determining the entity of building operations (stones cutting, transportation, preparation etc.). However, before building the walls it’s fundamental to prepare foundations and drainage channels. Finally, the filling is carried out, sometimes using transported materials to improve soil properties or nutrient status, (Bonardi, 2008).

The magnitude of the slope morphology changes and the amount of displaced material increased considerably in modern terracing methods, due to the use of machines to replace manual labor or animals (Cots-Folch et al., 2006). In intensive terraced vineyard plantations the soil material displacement can reach about 9500 t/ha (Ramos et al., 2007), while in marginal alpine areas the terracing operation involves the displacement of a small amount of material, about 1850 t/ha (Arpav, 2006). The lower amount of earth movement usually results in a milder effect on the landscape structure.

Olarieta et al. (2008) reported that vineyards in Catalunya (Spain) were often planted outside the theoretical suitability limits as a result of terraces building. These terraces required a huge labor both for building and maintenance, estimated from 200 to 500 work-days/ ha. These authors estimated 120 work-days/year per each adult inhabitant, corresponding to about 100 years to create the terraced landscape in the region (about 600 ha). Bonardi (2008) reported building times of 200-300 days/ha.

The most common typologies of terracing (table 2) for the Alpine area were collected in the Alpter database (www.alpter.net, Scaramellini & Varotto, 2008), They include: building typology (dry stone, wooden, concrete, solid wall), foundation (on rock, sediments, terrain, mixed material), wall length (from decimetres to hundreds meters), height (from 2-3 decimetres to several meters), wall and tread slope, tread width (very diverse, terracing density, average terrain slope (often more than 100%). Terraces can be linked by ramps, stairs (parallel or perpendicular to walls), suspended stairs, mobile stairs, or mixed systems. The drainage network may be parallel or perpendicular to treads, sometimes overlapping with paths and main accesses (Scaramellini & Varotto, 2008). Figure 2 illustrates some of these features for the terraced area of Aosta Valley Region (NW-Italy).

3. Properties and classification of terraced soils

While most literature on terraces focuses on the landscape or building aspects, the studies on terraced soils are relatively scarce, and they focus on a few regions (Figure 3). Many studies on terraced soils were carried out in Southern Spain, while a few examples are available for the rest of Southern Europe.

Soil properties may vary considerably since the origins of terraces are quite ancient (Yaalon and Arnold, 2000). The management history and the soil development processes may be rather complex, as evidenced by the frequency of buried layers (Delgado et al., 2007). However, some common characteristics may be found. Among them, Ap horizons are commonly observed (Arpav, 2006; Freppaz et al., 2008a), and several artefacts and debris materials can be identified (Sandor et al., 1990; Freppaz et al., 2008a). Nevertheless the chemical and physical properties of terrace soils may be quite variable depending on climate, vegetation, and management history (Rusjian et al., 2007).

The geomorphic processes resulting from terracing and the consequent management practices induce metapedogenetic changes in soil properties and evolution (Dudal, 2005), i.e. man-directed changes that don't depend directly on pedogenetic processes (Yaalon & Yaron, 1966).. Terrace building can be regarded as an artificial "entisolization" process (Dazzi, 1995), restarting pedogenesis. Such alterations may have different intensity depending on the properties of the original soils, duration of management, and environmental sensitivity. However, some common driving processes may be identified, such as the thickening of surface horizons from local redistribution of topsoil (Sandor et al., 1990), the burial of original soils accompanied by deposition due to severe erosion, and the addition of organic matter.

While terraced soils often display high organic matter and nutrients content, when compared with non-terraced agricultural plots (Arpav, 2006; Freppaz et al., 2008a); in abandoned terraces the organic C content may be very low. Romero Diaz et al. (2007) reported values mostly under 5 g/kg, due to the paucity of plant residues produced by xerophytic vegetation in abandoned terraces in Spain under a Mediterranean climate. Crust formation in recently abandoned plots was also observed. In this study area (Romero Diaz et al, 2007), the exchange complex was often dominated by Mg and Na, the latter (more abundant in deeper horizons) facilitating clay dispersion and transportation of suspended matter. The clay content was high, with an abundance of expanding clay minerals, causing soil cracks due to soil volume variation. The structural stability was low and decreased with increasing depth, due to the combined effect of the scarcity of organic matter and the sodium deflocculating action on the clay fraction. No significant aggregating action of carbonates could be observed. As a whole, the soils of abandoned terraces displayed limited infiltration capacity and low physical and hydrological qualities.

Terrace walls are commonly filled with earthy material collected in nearby areas and often mixed with manure. Consequently, terraced soils can create challenging classification issues, as remarked by Delgado et al. (2007). In fact, even if they show a strong human influence, this is not always enough to classify them as Anthrosols according to the WRB, as soil material can not be classified as anthropopedogenic or anthropogeomorphic *sensu stricto* (FAO, 1998), since it shows evidences of pedogenesis and at the same time modifications related to tillage. Delgado et al. (2007) classified man-made historical garden soils in La Alhambra, Spain, as *cumulimollihumic-calcaric Regosols (hypereutric, anthric)* according to WRB (FAO/ISRIC/ISSS, 1998), and as *Oxyaquic Hapludolls* according to Soil Taxonomy (Soil Survey Staff., 2010). Rusjan et al. (2007) classified Slovenian vineyard soils as *Anthrosols*, or *Calcaric Leptosols*, while *Calcaric Regosols* prevailed in flat alluvial or colluvial areas.

In a recent work, Freppaz et al. (2008a), studied terraced vineyards in Valle d'Aosta, Italy (Figure 1,4), and classified these soils as Technic Cambisols Escalic. Some of the soil properties analyzed during this study were rather homogeneous (Table 3), e.g the presence of coarse or very coarse texture (up to 80% sand); abundance of skeleton that increased with increasing soil depth; and good organic C content in the A horizons, often due to constant manure inputs. No significant limitations were observed in terms of nutrient availability and chemical properties, while a very rapid drainage could represent a problem.

Scalenghe et al. (2002) reported a terrace soil in western Italian Alps that classified as a *sandy, magnesic, nonacid, frigid Typic Cryorthent*. This soil was characterised by an A-AC profile that showing elements of man-induced disturbance related to land use practices (grazing and manuring. The main recognized pedological processes of acidification, removal of carbonates and weathering of Mg-bearing minerals took place in the A horizon. The presence of easily decomposable organic matter derived from manuring was also observed.

Duran Zuazo et al. (2005) found soils classified as *Typic Xerorthents* in Mediterranean climate. The soil properties observed were very rapid drainage, sandy-loam texture, and organic matter and total nitrogen contents of 9.4 g/kg and 0.7 g/kg, respectively.

4. Terrace abandonment and its effects: soil erosion and natural hazards

Land abandonment has widely affected terraced areas in Southern Europe, particularly in marginal regions. As remarked by Arbelo et al. (2006), the causes are mainly due to socio-economic changes, rather than related to soil fertility limitations.

Abandonment is often followed by slope recolonization by pioneer species, terrace degradation, hydrogeological hazard, and slope instability phenomena (Brancucci & Masetti, 2008). Many cases of terrace abandonment and their effects on natural hazard, soil quality, fertility and vegetation cover have been considered in literature. Abandonment is generally followed by immediate structural decay of terraces and wall failures (Arpav, 2006; Freppaz et al., 2008a). This causes a loss of soil physical and structural properties. The soil chemical properties, such as organic C content and cation exchange capacity are maintained in the first decades of abandonment (Freppaz et al., 2008a).

Olarieta et al. (2008) studied land use change in Catalunya (Spain) from 1850 to present time. They reported a 50% reduction of agricultural land mainly affecting terraced vineyards on steep slopes, originally outside the suitability limits which caused severe effects on the landscape.

Cyffka & Bock (2008) observed a generalized abandonment of terraced slopes in the Maltese Islands starting around the 1960s, resulting in wall failures and consequent intensive soil erosion, favored by seasonal flash-flood episodes. Meerkerk et al. (2009) reported a trend of widespread abandonment of terraced areas in Mediterranean semi-arid areas starting about 100 years ago. In most cases, terrace maintenance ceased, and stone walls were removed, causing concentrated overland flow during storms. Such processes were sometimes mitigated through the colonization by pioneer vegetation (Arbelo et al., 2006; Meerkerk, 2009), but in most cases high peak discharges were observed, with frequent flooding of downstream urbanized areas (Meerkerk et al., 2009), and negative effects on the hydraulic connectivity. Bellin et al. (2009) observed a decrease in terracing density in South East Spain of 27% from 1956 to 2005, followed by quick decay and terrace disruption. This resulted in an increase of the distance between step terraces, a degradation of the drainage network, and subsequent water erosion.

Abandonment, together with slope gradient, has been indicated as the key factor of soil erosion and mass movements in terraced areas not only in the Mediterranean Regions (Zgaier & Inbar, 2005; Koulouri and Giourga, 2007; Brancucci, 2008; Meerkerk et al., 2009), that are particularly prone to desertification, but also in the Alps (Arpav, 2006; Freppaz et al., 2008a).

In Southern Spain, Lesschen et al. (2008) estimated a rate of erosion (in form of gullies) after abandonment of about 87 t/ha y, and observed that further abandonment in the Mediterranean basin can be expected in the future. Rueker et al. (1998) estimated erosion rates on Spanish abandoned terraces from 0.6 to 2.2 t t/ha y, depending on abandonment age and plant colonization stage.

Koulouri and Giourga (2007) found that soil loss by water erosion on abandoned terraces with slope > 40% depends only on slope gradient. However, on smoother slopes the colonizing vegetation and the continuous land cover might control the intensity of the erosion processes and could help considerably the conservation of the soil physical properties. Duran Zuazo et al. (2005) found that soil erosion may be severe, with soil losses of 9.1 t/ha y, high values of the rainfall erosivity index (E_i =219.7MJ mm/ha), and runoff coefficients ranging from 6 to 31%, on terraced soils with up to 65° slope in Southern Spain. In addition to observations of sheet and rill erosion processes (Ramos & Porta, 1997), piping erosion has been sometimes reported in the Mediterranean Region. In abandoned terraces of Southeast Spain, Romero Diaz et al. (2006)

found that low aggregate stability and poor soil structure as a combined effect of scarcity of organic matter and flocculating effect of Na on the clay minerals affected the soil quality.

Another limitation that can affect terraces is the very rapid drainage that may produce water stress, not only in Mediterranean or Submediterranean climates (Rusjian et al., 2007; Freppaz et al, 2008b) but also in xeric microclimatic conditions in the Alps, where water irrigation is sometimes necessary (Freppaz et al., 2008a). In some cases, rapid drainage is associated with shallow soils (<30cm depth) (Arpav, 2006), but it has been observed also in deeper terraced soils, exceeding 1 m depth (Freppaz et al., 2008a).

Other effects on soil properties can be found in the literature. Arbelo et al. (2006) reported that, from the ’50s, terrace abandonment in Tenerife Island first involved degradation of the upper part of slopes, despite their better fertility and physical quality, and then the areas surrounding the settlements. In this study area, different effects of abandonment were observed, depending on soil orders (according to Soil Taxonomy): Anthracambids in the lower part of slopes were prone to sodification and crusting; Haplocambids and Torriarents were severely eroded (sheet, rill, gullies and rocky outcrops) and degraded (surface sealing/crusting); Ustorthents, Dystrudepts, Udarents and Ustarents were mainly affected by laminar erosion.

5. Best practices suggestions

Brancucci and Masetti (2008) reviewed the main deterioration phenomena involving terrace structures: a) internal phenomena depending on defects in the wall’s construction, or natural deterioration; b) external phenomena (natural or man-induced). Among natural deterioration they identified: partial wall failure due to increasing strain, shifting of the wall base (incorrect building/animal action), and bulging. Among man-induced deterioration, they considered all the affects of farming and abandonment, i.e. lack of maintenance.

Terrace decay after abandonment can happen rapidly (Arbelo et al., 2006; Freppaz et al., 2008a; Seeger & Ries, 2008), and, therefore, planning strategies for erosion mitigation and recovery are necessary (Duran Zuazo et al., 2005) in order to preserve the landscape and to mitigate natural hazards. A review of the main initiatives involving terraces of the last decades, can be found in Scaramellini & Varotto (2008), starting from the French initiative called ProgrammeTerrasses (1982), to the foundation of the Societé Scientifique Internationale pour l'Etude de la Pierre Sèche (1988), the Proterra Project in 1996, the Ipogea Association in 1998, and, finally, the first park for terrace landscape conservation (Cinque Terre National Park, IT). Among EU initiatives, the Interreg Projects "Patter" and "Terrisc" are focused on terracing (Scaramellini & Varotto, 2008). Also the United Nation underlined the importance of terrace landscapes against desertification, during the Nairobi Conference in 2006. The INTERREG III B Alpter Project (Scaramellini and Varotto, 2008) focused on terraced landscapes from a multidisciplinary perspective and a multifunctional idea of landscape. The project also presented some examples of terraces conservation projects (Fontanari & Patassini, 2008) including some recommendations for agricultural suitability.

Suggestions for planning and management of terraced areas are present in the literature. Lesschen et al. (2008) suggested two mitigation options: 1) terrace walls and earth dam conservation, i.e. continuous land maintenance after extreme rainfall events; 2) revegetation with indigenous species, to prevent erosion and to improve drainage. Arbelo et al. (2006), suggested shrub forestation as a mitigating strategy for erosion. Financial support from European Union, in the framework of the EU policy for vineyard restructuring promoted in 2000, is reported by Lesschen et al. (2008) for terrace conservation in Almeria province (Spain), Even if terracing in some marginal areas is not more profitable, some cost-benefit analyses on terrace maintenance is justified for both physical and social reasons. For example, Arbelo et al. (2006) suggested productive terrace management even in non-profitable areas, as an important added value to agroecosystem management that promotes soil and landscape preservation. ARPAV (2006) gave suitability indications for berry and aromatic plants cultivation on Alpine terrace slopes, in order to increase the rentability of terraced areas in the Alps.

Many papers provide recommendations for slope shaping and distancing and terrace preservation. Ramos and Porta (1997) suggested a distance of 28 m between terraces with 6% slope, and 20 m with 8% slope, in order to reduce water erosion. Continuous vegetation cover is assumed to play an important role in preventing erosion for mild slope gradients, while for steep slopes (>40%) the effect of topography prevails (Koulouri and Giourga, 2006). Duran Zuazo et al. (2005), following soil erosion modelling in a terraced area, suggested some conservation measures for taluses of orchard terraces. Considering the high costs of terrace rebuilding, these authors proposed the use of vegetative covers against water erosion. Annual species and aromatic shrubs plantation are recommended instead of natural colonization. In experimental plots, the sediment release diminished by 40% or 30% with respect to bare soil. In addition nutrient losses by erosion, that could represent a potential source of pollution, were reduced considerably.

Mechanization may help in terrace management and reduce abandonment due to non-profitable cultivation, but negative effects can also be observed due to modern terracing methods and minimal landscape planning. Cots-Folch et al. (2006) discussed the EU policy for terraced vineyards restructuring, which subsidized up to 50% of the construction costs of terraces. This caused a sudden increase of terraced surface in some Mediterranean mountain areas (about 36 ha/y between 1998 and 2003, according to Cots-Folch et al., 2006), with a displacements of earth materials up to 9 t ha^{-1} that may develop into future environmental problems.

Brancucci (2008) remarked that terrace maintenance alone is not enough and some guidelines are needed. In fact, he observed that restoration techniques are not always adequate, particularly for drainage and wall permeability, and these techniques may result in a worsening of slope instability phenomena.

6. Conclusions

We reviewed a considerable number of papers on terraced systems and soils, with a focus on the South-European area. To our knowledge, no complete inventory of terraced areas is available and the total terraced surface is therefore unknown. We found a remarkable diversity of terrace ages, land use and management history. Abundant information can be found on terraced landscapes, cultural aspects, terrace structures and building, but limited data on soil properties are available. The information on the terraced soils is quite diverse and often fragmentary, focusing on specific case-studies. Most of the study sites have a Mediterranean climate, and their distribution probably does not reflect the extent of terraced slopes. We observed an increasing debate on terrace soil classification, indicating that these anthropogenic soils are becoming more and more relevant to soil scientists. Even if terraced soil properties are not completely understood, all the authors agree on the potential reduction of chemical, physical and fertility properties after the abandonment of terraces. Most of the literature on soil terraces deals with management and conservation issues, in order to prevent erosion and soil fertility loss. Terrace conservation seems to be one of the most relevant steps for slope conservation and erosion mitigation. However, in consideration of terrace recovery or creation with modern techniques and machinery, attention should be paid to environmental issues, aesthetics, and landscape planning.

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Table 1: selected papers reporting information on terraced soils, their management and conservation in Southern Europe

Author	Year	Study area	Main topic
Ramos and Porta	1997	North East Spain	Design criteria for vineyard terraces
Rueker et al.	1998	Spain	Soil and vegetation evolution after terraces abandonment
Arbelo et al.	2006	Spain (Tenerife)	Plant recolonization dynamics on abandoned terraces
Scalenghe et al.,	2002	Italy (Alps)	Pedogenesis in disturbed alpine soils (e.g. man-made terraces)
Sanchez et al.	2002	Spain	Soil quality and land use change in Mediterranean mountain environments
Duran Zuazo et al.	2005	Spain	Impact of erosion on agricultural terraces with subtropical fruit cultivations
Arpav	2006	Italy (Veneto)	Terraced soils properties; land use history
Martinez-Casanovas & Ramos	2006	Spain	Cost of soil erosion, role of broadbase terraces in erosion mitigation
ARPAV	2006	Italy	Soil agricultural properties

			and fertility
Cots Folch et al.	2006	Spain	European Union policies for new wineyard plantation on terraces
Ramos et al.	2007	Spain	Sustainability of modern terracing in a Mediterranean mountain environment (vineyards)
Kolouri & Giourga	2007	Greece	Abandonment and erosion
Romero Diaz et al.	2007	South-East Spain	Piping erosion in abandoned agricultural terraces
Dealgado et al.	2007	Spain	Man-made soils in garden terraces of Arab influence
Rusjan et al.	2007	Slovenia	Vineyard soil properties
Cyffka & Bock	2008	Malta	Degradation processes in terraced areas
Lesschen et al.	2008	Spain	Terrace failure after abandonment
Olarieta et al.	2008	Spain	Land use transformations and soil conservation
Freppaz et al.	2008a, 2008b	Italy (Valle d’Aosta)	Terraced soils properties
Seeger et al.	2008	Spain	Soil degradation after terrace abandonment
Bellin et al.	2009	Spain	Terrace abandonment (erosion and water

			management)
Meerkerk et al.	2009	Spain	Impact of terrace failure after abandonment on runoff

Table 2. Terraces main typologies (Alpter database, 1 : 5000 detail)

Building typology	Foundations	Vertical links	Water channel system	Stripes inclination
Dry stone	substratum	Fixed : ramp	trasversal channels (perpendicular to the stripes)	Uphill
Wooden	rock	Fixed: stairs parallel to the	trasversal channels	Downhill

		wall	(parallel to the stripes)	
Concrete	terrain	Fixed: stair perpendicular to the wall	Pypes system	Horizontal
Solid wall	mixtum	Fixed: suspended stairs		
Other		Mobile		
		Mixed		

Table 3 : average chemical and physical properties in terraced soils in Valle d'Aosta (standard deviations in brackets, n=14 for A horizons, 30 for Bw horizons)

Soil properties	A horizons (n=14)	Bw horizons (n=30)
pH	6.1 (0.88)	6.5 (1.12)
Organic C (g/kg)	41.7 (30.16)	11.6 (5.2)
N (g/kg)	3.2 (2.2)	0.84 (0.53)
Skeleton (%)	18.4 (8.3)	24.5 (12.3)
Coarse sand (%)	30.9 (9.5)	24.7 (4.9)
Medium sand (%)	17.5 (4.1)	13.4 (2.1)
Fine sand (%)	37.0 (7.4)	40.0 (3.7)
Silt (%)	14.1 (5.9)	20.9 (5.4)
Clay (%)	0.58 (0.50)	0.63 (0.31)

Figure 1: terraced pergola vineyards in Pont-Saint-Martin (Valle d'Aosta, Italy)

Figure 2: terraced slopes in Valle d'Aosta. Structural typologies and details (Photos M. Freppaz). a) wall foundation; b) connection between terraces; c) example of restored wall; d) terraced slope - vineyard; d) terraced slope – chestnut wood; e) detail of wall structure

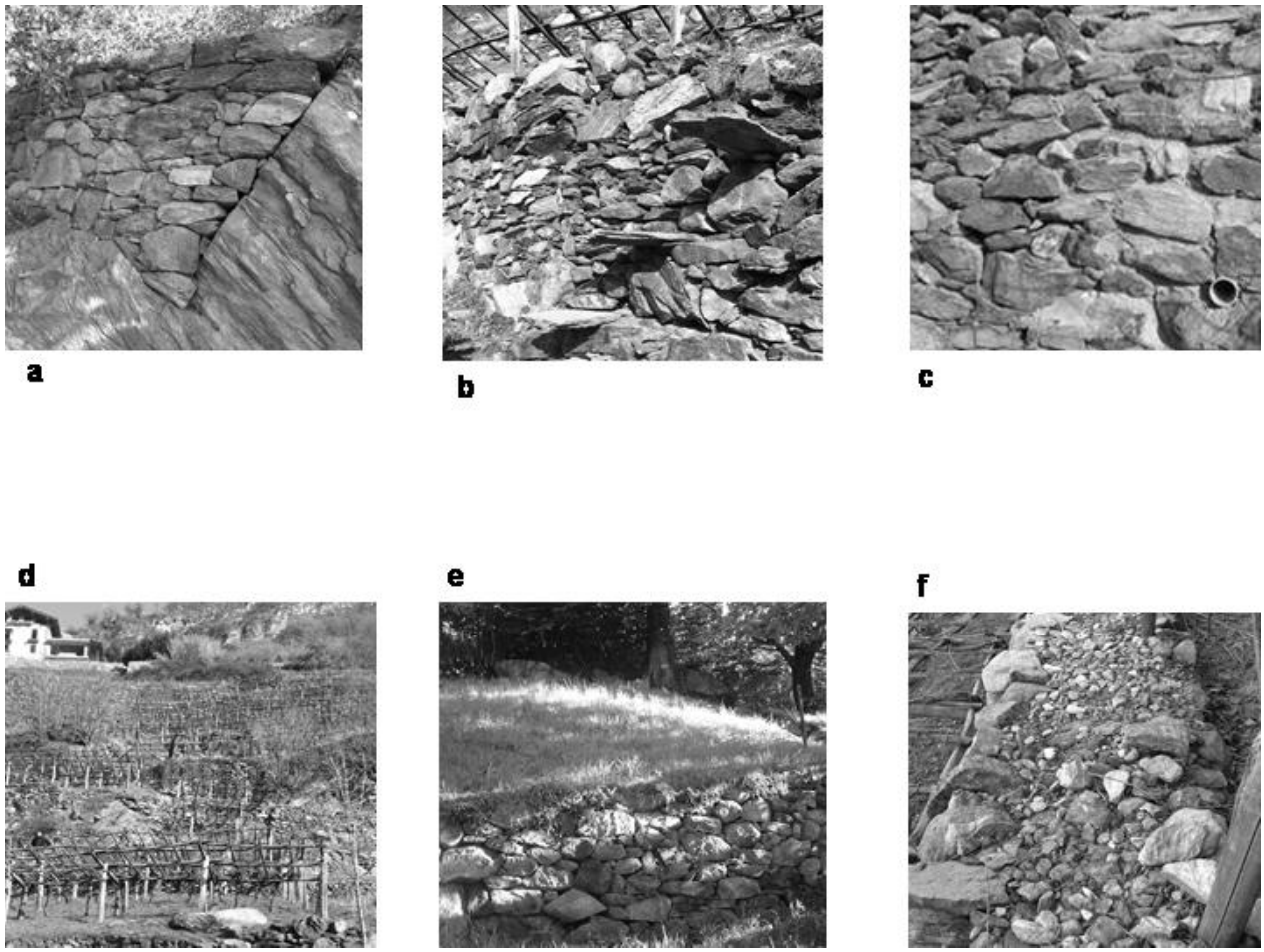

Figure 3: relevant literature on terraced soils in Southern Europe. The map represents the study area

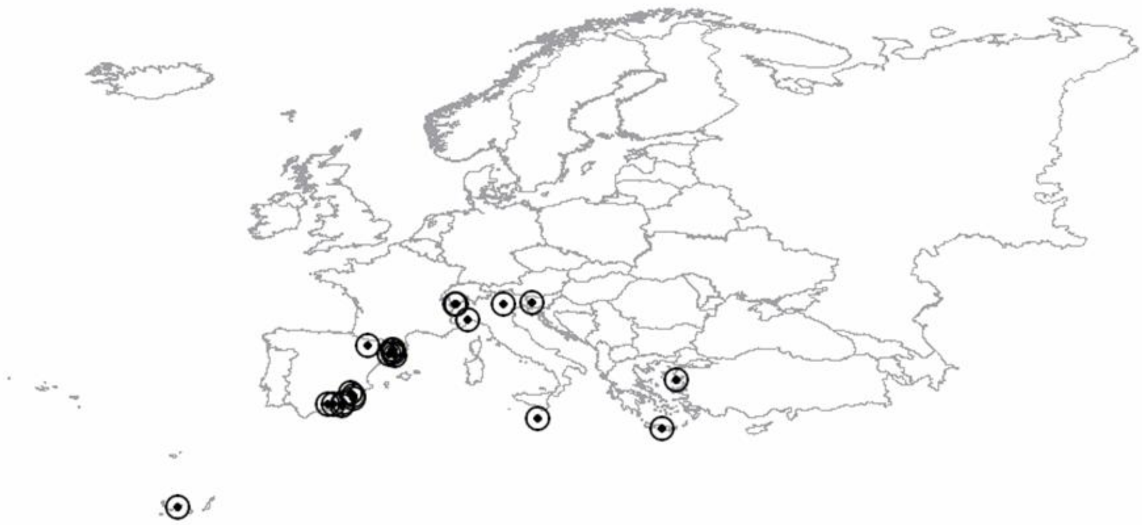

Figure 4: the terraced landscape of Pont-Saint-Martin (Valle d'Aosta, Italy) in the XIX Century (G. Ladner, 1847, courtesy Mrs. Ardissone)