

CAUSES OF SOIL MALFUNCTIONING IN DEGRADED AREAS OF EUROPEAN AND TURKISH VINEYARDS

**Edoardo A.C. Costantini^{(1)*}, Simone Priori⁽¹⁾, Brice Giffard⁽²⁾,
Emma Fulchin⁽³⁾, Javier Tardaguila⁽⁴⁾, Hans-Josef Schroers⁽⁵⁾,
Radojko Pelengić⁽⁵⁾, Erhan Akça⁽⁶⁾, Semih Tangolar⁽⁷⁾, Giuseppe Valboa⁽¹⁾**

⁽¹⁾ CREA-AA, Research Centre for Agriculture and Environment, Florence, Italy

⁽²⁾ INRA, UMR 1065 Santé et Agroécologie du Vignoble, ISVV, Université de Bordeaux, Bordeaux Sciences Agro, Villenave d'Ornon Cedex, France

⁽³⁾ Vitinnov-ADERA, France

⁽⁴⁾ Instituto de Ciencias de la Vid y del Vino, University of La Rioja, CSIC, Spain

⁽⁵⁾ Agricultural Institute of Slovenia, Ljubljana, Slovenia

⁽⁶⁾ Adiyaman University School of Technical Sciences, Turkey

⁽⁷⁾ Çukurova University, Faculty of Agriculture, Department of Horticulture, Turkey

* Corresponding author E-mail: edoardo.costantini@crea.gov.it

Abstract

A study was carried out in nineteen vineyards of five countries, well representative of major viticultural districts, which showed areas with fertility problems, consequence of strong soil erosion occurred during either pre-planting or ordinary cultivation. The comparison between degraded and non-degraded areas highlighted that the soil features limiting water nutrition and enhancing potential water stress were the most frequent discriminant soil conditions. Low nitrogen availability was the second most important cause of soil malfunctioning, together with low organic matter content. The degradation was also reflected in the very low values of the C/N ratio, pointing to a difficulty of microbiota in synthesizing humus. Other limiting factors were excessive lime content and poor drainage. Also nutrient imbalance or toxicity and low cation exchange capacity sporadically occurred. Since physical and hydrological limitations are hardly modifiable, especially in depth, the study underlines the difficulties to restore the fertility of degraded soils, and suggests caution in planning new vineyards.

Keywords: *soil degradation; indicators; organic viticulture; terroir; grape; wine*

Introduction

Most vineyards are established after several land preparation activities, which involve soil trenching, deep tillage, stone-breakage and clearing, and land-levelling, in order to adapt fields to mechanization and to create a good workable planting bed (Bignal and McCracken, 2000, Vaudour et al., 2015; Costantini et al., 2015). Slope reshaping activities, in particular, can move huge volumes of soil, with consequent strong variation of soil thickness and soil horizons mixing. In northern and central Italy, Bazzoffi et al. (2006) estimate an average mass moved by land levelling between 8,640 and 23,040 Mg·ha⁻¹, whereas soil burial ranged between 7,520

and 16,320 Mg·ha⁻¹. Earth movements affect the original natural profile of soil and can disturb the existing chemical, physical, biological and hydrological equilibrium (Bazzoffi et al., 2006; Costantini et al., 2006). In addition, most of the vineyards are situated on slopes, therefore they are strongly susceptible of soil loss by water erosion, in particular in the weeks and months just after vineyard planting (Bazzoffi et al., 2006). Also ordinary cultivation of vineyards located on slopes is usually accompanied by high values of soil water erosion (Le Bissonnais et al., 2002; Costantini and Barbetti, 2008; Prosdocimi et al., 2016).

Strong soil erosion, either caused by earth movements before plantation or produced by cultivation, can reduce soil fertility and grape production and quality (Costantini, 1992; Martínez-Casasnovas and Ramos, 2006, 2009). Southern Europe is more sensitive to this problem for two reasons: i) Spain, France, Italy and Turkey have about 40% of vineyard area of the world (3,115 million of hectares - OIV, 2012); ii) the erosion risk of Southern Europe countries is higher than those in central and northern Europe (Gobin et al., 2004).

Soil erosion affects both conventional and organically farmed vineyards. Although organic viticulture aims at sustainable management, organic farmers use the same methods of land preparation as conventional viticulture. The EU Regulation on organic farming (834/2007 and 889/2008) includes generic considerations on the maintenance of soil fertility and biodiversity, but so far the regulation does not include guidelines about land preparation for plantation and soil fertility maintenance in perennial crops.

In the framework of the EU CORE Organic Plus research project “Restoring optimal Soil functionality in degraded areas within organic Vineyards - ReSolVe” (<http://resolve-organic.eu/>), a study was undertaken aimed at highlighting the features of soil profiles in degraded and non-degraded area of vineyards, so to understand which were the causes of soil malfunctioning.

Materials and methods

The study districts and farms were situated in: i) Italy, districts of Chianti (Fontodi) and Maremma (San Disdagio); ii) Spain, La Rioja (Bodegas Puelles); iii) Turkey (Table grape), Adana (Celebi) and Mersin (Evrans); iv) France, Saint Emillion (Château Maison Blanche) and Languedoc (Château Pech Redon); v) Slovenia, Primorska (Bonini and Prade). Nineteen organic vineyards have been selected, ranging in size 0.5-2.5 ha and in full production (more than 10 years from planting), where farmers had identified areas of soil degradation. Causes of soil malfunctioning were attributed to vineyard trenching and soil erosion, while other possible causes, such as waterlogging or localized parasitic infections, were excluded. These areas were reported to suffer from a higher frequency of vine diseases, lower grape yield and quality, missing vines, compared to the rest of the vineyard. Standard soil management was tillage in San Disdagio, Bodegas Puelles, and both Turkish farms, alternate natural grass cover / tilled rows in both French farms, and natural grass cover at Fontodi and both Slovenian farms. All vineyards were rainfed, apart from Turkish ones, which were occasionally irrigated.

After a very detailed soil survey, made with proximal sensors (Priori et al., 2013), we excavated soil profiles in both degraded and non-degraded area of vineyards, comparing the soil features and characteristics, to highlight differences that could have been the causes of different soil functionality and vine behavior. The experimental design provided three replicated comparisons in each farm, but in Slovenia and Turkey only one.

The soil profiles were dug up to about 1 m depth and described following the national and international references (Jahn et al., 2006; Costantini, 2007). Grapevine root distribution was described to highlight soil horizons with limitations to root deepening. Soil profile horizons were sampled and analyzed according to international standards (Van Reeuwijk, 2002; Burt, 2004). The studied soils were classified following the WRB system (IUSS working group WRB, 2015); soil limitation for grapevine were assessed according to Bucelli and Costantini (2009). The soil limitations encountered in describing and analyzing soil profiles were compared between degraded and non-degraded soils, to highlight the limitations that were present and the different degree (class) between the two soil conditions (Figure 1).

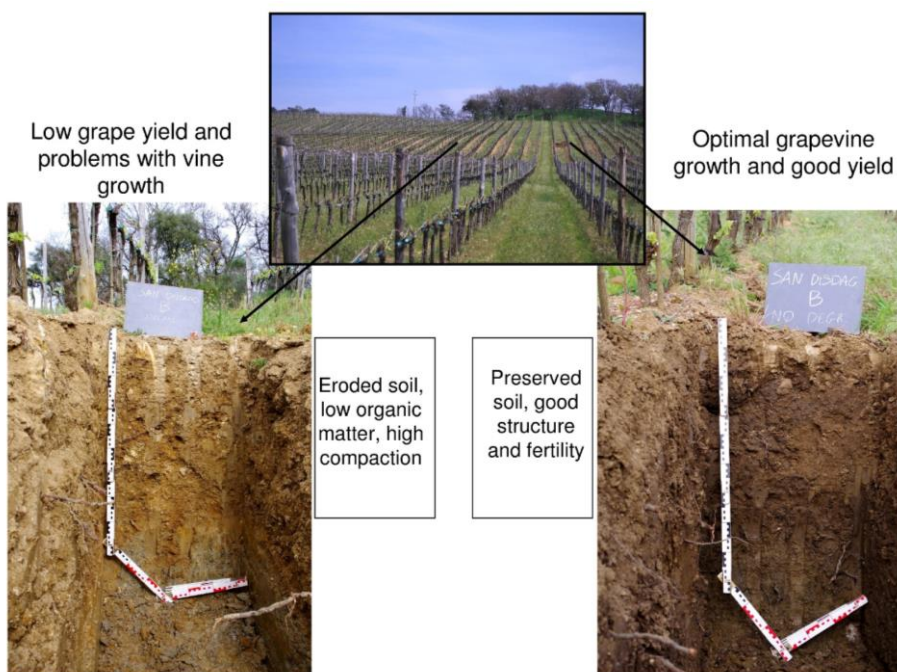


Figure 1. Degraded (left) and non-degraded (right) soils in an experimental vineyard (vineyard B) of San Disdagio (Italy). Soil types are Cambic Calcisols (Loamic, Stagnic) and Stagnic Eutric Cambisol (Loamic), respectively. Note that the eroded soil on left shows the effects of an enhanced pedological aridity, in the form of calcium carbonate accumulation in the subsurface horizon.

Eleven soil limitations and limiting conditions were considered, as follows:

1. Shallow rooting depth: depth to which vine roots can penetrate the major soil volume less than 100 cm (Costantini, 2007);
2. Low available water capacity (AWC): difference between water content at conventional field capacity (0.33 bar) and wilting point (15 bar) less than 100 mm to rooting depth;
3. Poor internal drainage: presence of a perched water table within rooting depth, limiting oxygen availability;
4. High compaction: packing density of soil particles higher than 1.4 g cm^{-3} in topsoil;
5. Excessive lime: total lime content higher than 30%, active lime higher than 10% to rooting depth;
6. Low nitrogen: total nitrogen content TN lower than 1 g kg^{-1} in topsoil;
7. Low soil organic carbon content: SOC lower than 10 g kg^{-1} in topsoil;
8. Low carbon nitrogen ratio: C/N lower than 7 in topsoil;
9. Low cation exchange capacity: CEC lower than 10 cmol[+]/kg in topsoil/rooting depth;
10. Sodic properties: $(\text{Na}+\text{Mg})/\text{CEC}$ more than 10 in topsoil/rooting depth;
11. Potassium unbalance: Mg/K more than 7 in topsoil/rooting depth.

Results and Discussion

The climate of the studied sites, according to the Köppen classification (Peel et al., 2007), was Temperate Oceanic in Bodegas Puelles, Maison Blanche and both Slovenian vineyards, while it was Warm Mediterranean in the remaining sites. The studied vineyard soils were similar for morphological setting, since they laid on gentle slopes, but varied notably for parent materials. Soils of Maison Blanche and Bodegas Puelles formed from alluvial deposits of Pleistocene, while San Disdagio soils formed from marine deposits of the Pliocene. Carbonate clastic rocks of marine deposits of Miocene were the parent material of Turkish soils, while sandy-calcareous flysch of Eocene was found in both Slovenian vineyards. Older formations characterized soil parent materials at Fontodi (clayey-calcareous flysch) and Pech Redon (limestone, marl and gypsum) both Cretaceous in age.

Soil classification was rather uniform in Slovenia, at Pech Redon and Evran, where only a soil typology was found. Two main types were reported in all the other farms, apart from Maison Blanche, where soil variability was higher, and five soil types were classified.

The most common soil types were Cambic and Haplic Calcisols, present in all farms, apart the more humid Slovenian sites where only Calcaric Cambisols were found. Calcaric and Eutric Cambisols were also present in some Fontodi, San Disdagio, Bodegas Puelles, and Maison Blanche vineyards, although under the Temperate oceanic climate of Maison Blanche Luvisols dominated. In general, soil classification somehow reflected pedoclimatic conditions, pointing to an increase lime accumulation in the profile along with climatic and soil aridity. Table 1 compares the limitations in the soil profiles of degraded and non-degraded plots.

Table 1. Presence of a stronger soil limitation in degraded vs non-degraded vineyard soils.

Profile Code	Rooting depth	AWC*	Drainage	Compaction	Limn	TN	SOC	C/N	Notes
Italy farm 1:Fontodi, Panzano in Chianti (FI)									
FON1 vs FON2	Yes	Yes	Yes	Yes	Yes	No	No	Yes	
FON3 vs FON4	Yes	Yes	No	Yes	No	Yes	Yes	Yes	
FON5 vs FON6	Yes	Yes	No	Yes	No	No	No	No	
Italy farm 2:San Disdagio, Civitella Marittima (Gr)									
SD1 vs SD2	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Sodic properties, K unbalance Mg excess
SD3 vs SD4	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	
SD5 vs SD6	No	No	No	Yes	Yes	Yes	Yes	Yes	
France farm 1:Maison Blanche, Montagne Saint Emilion (Gironde)									
MB1 vs MB5	Yes	Yes	Yes	Yes	No	No	No	No	
MB6 vs MB10	Yes	Yes	Yes	Yes	No	No	Yes	No	
MB11 vs MB15	Yes	Yes	No	Yes	No	No	No	No	
France farm 2:Pech Redon, Narbonne (Aude)									
PR1 vs PR5	No	Yes	No	Yes	No	Yes	Yes	Yes	
PR8 vs PR10	No	Yes	No	Yes	No	Yes	Yes	No	
PR11 vs PR15	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Spain: Bodegas Puelles, Abalos (Logrono)									
LOG1 vs LOG2	No	No	No	No	Yes	Yes	No	No	
LOG3 vs LOG4	No	No	No	No	Yes	No	No	No	
LOG5 vs LOG6	Yes	Yes	No	Yes	No	Yes	Yes	Yes	K unbalance Mg excess, Low CEC
Slovenia farm 1: Bonini (VS), Koper									
SL1 vs SL4	Yes	Yes	No	No	No	Yes	Yes	No	
Slovenia farm 2: Prade (VL), Koper									
SL5 vs SL7	Yes	Yes	No	No	No	No	No	No	
Turkey farm 1: Çelebi (Dokuzetkne)									
CRC3 vs CRC1	Yes	Yes	No	No	No	Yes	Yes	Yes	
Turkey farm 2: Evran, Sariveli in Tarsus (Mersin)									
EV4 vs EV13	Yes	Yes	No	No	No	Yes	Yes	Yes	
Frequency									
n.19	12	15	6	13	6	12	12	10	3

* Available Water Capacity = difference between water content at conventional field capacity and wilting point

The qualitative evaluation (yes or no) points to the presence or not of a stronger limitation in the degraded plot, when compared to the non-degraded one.

The evaluation clearly shows that the contrast between degraded and non-degraded soils is much more evident in some farms, for instance in San Disdagio and Bonini,

than in others, like in Bodegas Puelles. Within each farm, the comparison did not provide homogeneous results, that is, the soil profiles of degraded and non-degraded plots did not contrast for exactly the same set of limitations.

As a whole, limitations related to a larger potential water stress, namely lower AWC, higher soil compaction, and shallower rooting depth, resulted the most important soil properties differentiating degraded from non-degraded plots. The second most frequent kind of limitation was associated to the lower total nitrogen content, which went parallel to organic carbon in almost all cases. Actually degraded areas showed very low values of organic carbon, which was the unique form of nitrogen input, because of the organic farming management. Besides nutrient deficiency, in more than half of cases we observed a very low C/N ratio in more than half of cases, stressing the difficulties encountered by microbiota in humifying organic matter in degraded soils, also under permanent grass cover.

Limiting conditions for lime content or poorer internal drainage were also present, localized in one third of cases. In only few cases there were analytical values indicating possible limiting conditions related to Mg or Na excess, K unbalance, or low cation exchange capacity.

Conclusions

The study, carried out in nineteen vineyards of five countries, well representative of premium viticultural districts, indicated that, in vineyards showing fertility problems, there was a marked variability in terms of limitation, also within the same farm and vineyard.

The comparison between the degraded and non-degraded soils highlighted that the limitations related to water nutrition and potential water stress for grapevine (rooting depth, AWC, and compaction) were the most frequent discriminant of soil fertility. Insufficient element nutrition, in particular low nitrogen availability, was the second most important cause of soil malfunctioning. Total nitrogen went along with organic matter content, since this is the main source of nutrients in organic farming. The degradation was also reflected in the very low values of the C/N ratio, pointing to a difficulty of microbiota in synthesizing humus, because of the extremely low organic matter content. Other limiting factor were excessive lime content and poor drainage, while nutrient unbalance or toxicity, as well as low cation exchange capacity, occurred sporadically. The fact that physical and hydrological limitations, which are hardly modifiable, especially in depth, were the soil features most responsible of the low productiveness of degraded areas, underlines the difficulties to restore the fertility of these soils, and suggests caution in planning soil management in new vineyards. In particular, pre-planting interventions should be properly dimensioned, according to a detailed survey of the original soil characteristics and in the light of the desired soil features of the resulting vineyard.

Future research issues shall develop and test additional organic strategies, such as combining the cultivation of deeper soil horizons with green manure, improved soil addition, biostimulants spreading, to restore soil fertility both on surface and in depth.

Acknowledgements

The research work was carried out in the framework of the EU project RESOLVE (Restoring optimal Soil functionality in degraded areas within organic vineyards), supported by transnational funding bodies, being partners of the FP7 ERA-net project, CORE Organic Plus, and the cofound from the European Commission. Authors express their gratitude to the farms that hosted the field trials and thank all the RESOLVE people who helped during field-work and laboratory analysis.

References

- BAZZOFFI P, ABBATTISTA F, VANINO S, PELLEGRINI S. (2006) Impact of land levelling for vineyard plantation on soil degradation in Italy. *Bollettino della Società Geologica Italiana*, 6:191–199.
- BIGNAL E.M., McCracken D.I. (2000). The nature conservation value of European traditional farming systems. *Environmental reviews*, 8:149–171.
- BUCELLI P., COSTANTINI E.A.C. (2009) Wine Grape and Vine zoning. Manual of methods for soil and land evaluation. Costantini, E.A.C. (Ed.), Science Publishers, Enfield (NH), (USA), 353-400.
- BURT, R. editor (2004). Soil survey laboratory methods manual. Soil Survey Investigations Report., n.42, version 4.0, USDA-NRCS, Lincoln, Nebraska.
- COSTANTINI E.A.C. (1992) Study of the relationships between soil suitability for vine cultivation, wine quality and soil erosion through a territorial approach. *Geoöko-Verlag, Geoökoplus III*:1–14.
- COSTANTINI E. A.C., PELLEGRINI S., VIGNOZZI N., BARBETTI R. (2006) Micro-morphological characterization and monitoring of internal drainage in soils of vineyards and Olive Groves in Central Italy. *Geoderma*, 131(3-4):388-403.
- COSTANTINI E.A.C. (ed.). (2007) Linee Guida dei Metodi di Rilevamento e Informatizzazione dei Dati Pedologici. CRA_ABP, Firenze, Italia, 296 p. (In Italian, with English summary) [On-line at <http://abp.entecra.it/soilmaps/ita/downloads.html>].
- COSTANTINI E.A.C., BARBETTI R. (2008) Environmental and Visual Impact Analysis of Viticulture and Olive Tree Cultivation in the Province of Siena (Italy). *European Journal of Agronomy*, 28:412–426.
- COSTANTINI E.A.C., AGNELLI A.E., FABIANI A, GAGNARLI E, MOCALI S, PRIORI S, SIMONI S., VALBOA G. (2015) Short-term recovery of soil physical, chemical, micro-and mesobiological functions in a new vineyard under organic farming. *Soil*, 1:443-457.
- GOBIN A., JONES R., KIRKBY M., CAMPLING P., GOVERS G., KOSMAS C., GENTILE A. R. (2004) Indicators for pan-European assessment and monitoring of soil erosion by water. *Environmental Science & Policy*, 7(1):25-38.
- IUSS, WORKING GROUP WRB (2015) World Reference Base for Soil Resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome..
- JAHN R., BLUME H. P., ASIO V. B., SPAARGAREN O., SCHAD P. (2006) Guidelines for soil description. FAO, Rome, 97 pp.
- LE BISSONNAIS Y, MONTIER C, JAMAGNE M, DAROUSSIN J, KING D. (2002) Mapping erosion risk for cultivated soil in France. *Catena*, 46:207–220.

- MARTÍNEZ-CASASNOVAS J.A., RAMOS M.C. (2006) The cost of soil erosion in vineyard fields in the Penedès–Anoia Region (NE Spain). *Catena*, 68:194–199.
- MARTÍNEZ-CASASNOVAS J. A., CONCEPCIÓN RAMOS M. (2009) Soil alteration due to erosion, ploughing and levelling of vineyards in north east Spain. *Soil use and management*, 25(2):183-192.
- PEE, M. C., FINLAYSON B. L., McMAHON T. A. (2007) Updated world map of the Köppen-Geiger climate classification. *Hydrology and earth system sciences discussions*, 4(2): 439-473.
- PRIORI S., MARTINI E., ANDRENELLI M.C., MAGINI S., AGNELLI A.E., BUCELLI P., BIAGI M., PELLEGRINI S., COSTANTINI E.A.C. (2013) Improving wine quality through harvest zoning and combined use of remote and soil proximal sensing. *Soil Science Society of American Journal*, 77(4):1338-1348.
- PROSDOCIMI M, CERDÀ A, TAROLLI P. (2016) Soil water erosion on Mediterranean vineyards, a review. *Catena*, 141:1–21.
- VAUDOUR E., COSTANTINI E.A.C., JONES G. V., MOCALI S. (2015) An overview of the recent approaches to terroir functional modelling, footprinting and zoning. *Soil*, 1:287–312.
- VAN REEUWIJK L.P. (2002). *Procedures for soil analysis*. Sixth edition. International Soil Reference and Information Centre, Wageningen, The Netherlands.