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RESTORING SOIL FUNCTIONALITY IN DEGRADED AREAS WITHIN VINEYARDS BY ORGANIC TREATMENTS: THE EXPERIMENTAL LAYOUT OF THE RESOLVE CORE-ORGANIC+ PROJECT

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Abstract

In vineyards, degraded areas characterized by a reduction in quantity or quality of grape production are frequent, even if managed under organic farming. Degradation is mainly caused by soil truncation, soil erosion, or salts enrichment. Recovering strategies implemented in 19 degraded vineyards in 5 countries concerned: (i) composted organic amendments, or seeding of cover crops for (ii) green manure or (iii) dry mulch. This study aims to minutely detail areas involved in experimental designs in relation to vineyard management and pedo-climatic conditions. This survey is useful to better understand other contributions dealing with RESOLVE project reported in the present special issue. The potential soil erosion by water was estimated for the 38 degraded and non-degraded plots, confirming that is a common agent of land degradation in vineyards. The results suggested that compost is the more expensive treatment, but involves greater certainty of success. Indeed, the nature of degradation requires optimum seedbed preparation to grow green manure crops. Dry mulching plants needs less tillage operations, helping the recovery of soil functionality.

Keywords: *organic agriculture, viticulture, cover crops, organic amendment, compost, USLE*

Introduction

Vineyards are normally subjected to strong land transformation to adapt fields to mechanization and they are also sensitive to high soil erosion. As described in Costantini et al. (this issue), the most common effects of land transformation are mixing of soil horizons and soil truncation, which results in reduction of soil depth and available water, organic matter depletion, and enrichment of calcium carbonate

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content in the topsoil. Figure 1 outlines the Driver–Pressure–State–Impact–Response (DPSIR) framework (Carr et al., 2007) applied to RESOLVE project.
Once the spatial distribution of degraded areas within vineyards are identified, several approaches can be used to attempt soil functionality improvement, recovering both chemical and biological topsoil fertility. Nevertheless, a complete recovering of soil functionality is difficult to achieve in situations related to strong soil truncation and decreased rooting depth and water availability.
The strategies proposed for the RESOLVE project, were the following: (i) strong adding of composted organic amendments (COMP); (ii) cover crops used as green manure (GM); (iii) cover crops used as dry mulching (DM).
Composted organic material, consisting of manure, pruning and other plant residues, is an important material used in agriculture and horticulture, in many areas, and more recently also in viticulture (Pinamonti, 1998; Powell et al., 2007; Özdemir et al., 2008). Compost increases the water holding capacity of soil (Curtis and Claassen, 2005) and improves the physical properties of the soil, namely the total porosity and aggregate stability (Jamroz and Drozd, 1999).

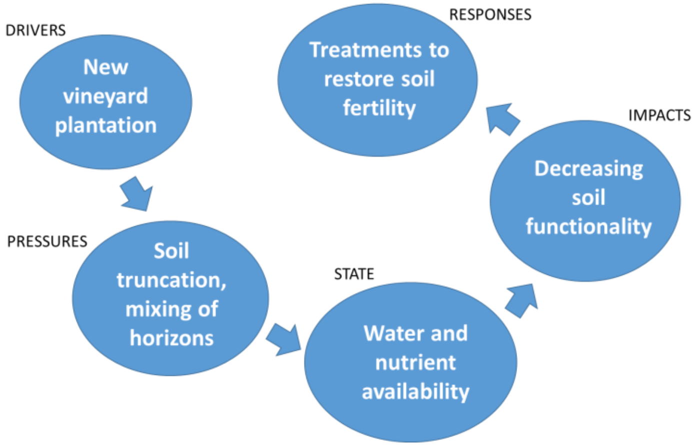

Figure 1
The DPSIR approach implemented by the Resolve project.

Long-term application of compost in vineyards increased soil organic matter and nitrogen content, as much as grape yield, but had limited effects on grape quality (Mugnai et al., 2012). Following Chan et al. (2010), in vineyards characterized by low production, grape yield increased after the use of composted mulch, as well as pH and potassium content of berries. The strategies promoted by circular economy policies suggest the use of high-quality compost to mitigate greenhouse gas emissions (Razza et al, 2018 and references therein).
Intercrops in vineyards, notably grass cover (natural or seeded) in the inter-rows, were recently introduced to increase the ecosystem services (Garcia et al., 2018). Intercrops have the potential to: (i) increase water infiltration and decrease runoff (Novara et al., 2011), (ii) mitigate soil erosion (Battany and Grismer, 2000), (iii)

increase biodiversity and minimize risk of N leaching (Montanaro et al., 2017), (iv) improve water utilization by grapevine roots (Celette et al., 2005), and in some cases (v) reduce of weed vegetative development (Valdés Gomez et al., 2008).

However, many authors agree that cover crops in Mediterranean vineyards can have negative outcomes, due to water and nutrient competition (Pardini et al., 2002 and references). In fact, the risk of severe drought during spring and/or summer and the need to allow the tractor access for treatments has hampered the adoption of intercrops in Mediterranean vineyards. Nevertheless several farmers, in particular organic ones, have been starting to apply cover crops for green manure and for mulches also in Central Italy and southern France. A recent paper (Garcia et al., 2018) reported that about 30% of vineyards in southern France (Provence, Languedoc) are cover cropped and that N-fixing species are increasingly used to improve soil fertility. It is known that the amount of nitrogen available for secondary, or successive crop, will depend on the C/N ratio of the cover crop and on the amount of biomass produced (Finney et al., 2016). Therefore, the use of legumes for intercropping can increase soil fertility in vineyard areas with nutritional deficiencies and nitrogen needs (Bair et al., 2008).

One of the land degradation threats is erosion by water, which can be estimated at field scale through the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). It is an empirical model widely known, tested and used. Since 1978 the USLE model and its factors have been widely revised by many authors (i.e. Ferro et al., 1999; McCool et al. 1987 and 1989; Stone and Hilborn, 2012), therefore it is reported also as Revised Universal Soil Loss Equation (RUSLE). Measuring soil erosion is not a trivial task, and it is also subject to considerable levels of error, therefore, USLE estimations can be a valuable mean of comparing soil erosion rates in-between vineyards and in-between plots of the same vineyards (Novara et al., 2011).

The aim of this paper is to describe: (i) the strategies used in all farms involved in RESOLVE project (ii) the climatic and pedoclimatic conditions in relation to local agronomic issues, (iii) encountered practical difficulties to implement the strategies (iv) soil erosion estimation to establish if it could be a key factor of degradation in different vineyards. In addition, the detailed description of the RESOLVE vineyards and applied restoring strategies reported in this paper is useful as a reference to better contextualize the results discussed in the next manuscripts of this journal issue.

Materials and methods

In important viticultural areas in Spain, France, Italy and Slovenia (used for wine production), and Turkey (for table grapes) nine commercial organic farms were selected to participate in the project. The geographical distribution of these farms were pointed out in Figure 2.

The trials were carried out in vineyards representative of each wine district selected for the project: namely, referring to farm codes outlined in Fig.2, "La Rioja" (Spain, LOG), "Montagne Saint-Emilion, Bordeaux" and "La Clape, Languedoc" (France, MB and PR), "Maremma, Tuscany" and "Chianti, Tuscany" (Italy, SD and FON), "Primorska" (Slovenia, VS and VL) and of the two Turkish areas famous for table grape, namely "Adana" and "Mersin" (Turkey, ET and CC).

The wine grape cultivars were Sangiovese (SD and FON), Tempranillo (LOG), Cabernet Franc and Syrah (MB and PR, respectively), Refošk (VS and VL) and table grapes, namely Early Cardinal (ET) and Yalova Incisi (CC). The ages of the vineyards ranged between 10 to 20 years in LOG, SD, FON, VS, ET and CC, 30 to 40 years for PR and VL and 70 years in MB. Climate was temperate oceanic in LOG, MB, VL, VS and warm Mediterranean in the others sites.

Figure 2. *Localization of experimental farms in RESOLVE project. Satellite photo source: wikimedia.org*

All selected farms adopted organic farming prescription since several years with the exception of SD, in conversion to organic agriculture from 2014. Irrigation was absent in the experimental vineyards, except for the Turkish farms and SD, which used on a regular base and only during summer 2017 as emergency irrigation, respectively.

The experimental layout involved three vineyards for each farm, with the exception of the farms in Slovenia and Turkey, which have one vineyard each. In each vineyard, a degraded area (DEG), showing reduced soil functionality due to various factors (Costantini et al, this issue), was delimited as study area to test restoring treatments. Each DEG area was compared with a non-degraded area (ND) without soil functionality degradation, located in the same vineyard. In each area, a soil profile was described and soil type classified according to the world reference base (IUSS WORKING GROUP, 2014). In addition, the slope of the degraded areas was estimated by means of on-site inspections and interpretation of satellite photos. The features of all areas are detailed in Table 1.

The degraded areas within vineyards were subdivided into 4 plots up to 250 m^2 each (Fig. 3), leaving a distance of few meters between adjacent treatments, as buffer zone.

The different restoring treatments were: (i) organic amendment (COMP; composted manure with or without pruning residues, applied in November 2015 and 2016); (ii) green manure of winter legumes and cereal (GM; incorporated into the soil in April, or May-June 2016 and 2017); (iii) dry mulching of legumes mowed and leaved on the surface (DM; mowed in May-June 2016 and 2017); (iv) tillage with no fertilization, used as control treatment (CONTR).

Table 1. *Description of all the sites studied in the project. Each degraded area (DEG) were compared with a non-degraded area (ND) located in the same vineyard.*

Country	Farm (CODE)	Mean annual temp. (°C)	Rainfall (mm)	Vineyard	Lat	Long	Altitude asl (m)	Slope (%)	Row orientation to slope gradient	Stonines s v/v (%)	Soil classification (IUSS, 2014)
					WGS84						
Spain	Bodegas Puelles (LOG)	13,9	405	DEG-A	42,582942	-2,706442	664	1	parallel	1	Cambic Calcisols (Loamic, Hypercalcic)
				ND-A	42,583122	-2,706906	669	1	parallel	3	Calcaric Cambisol (Siltic)
				DEG-B	42,582817	-2,705484	663	1	parallel	1	Cambic Calcisols (Siltic, Hypercalcic)
				ND-B	42,582499	-2,705348	660	2	parallel	2	Cambic Calcisols (Loamic, Hypercalcic, Ruptic)
				DEG-C	42,579928	-2,707798	642	3	diagonal	5	Cambic Calcisols (Siltic, Hypercalcic)
				ND-C	42,580581	-2,706972	641	1	parallel	3	Cambic Calcisols (Loamic, Hypercalcic, Ruptic)
France	Château Maison Blanche (MB)	12,8	944	DEG-A	44,931410	-0,156981	38	4	parallel	0	Stagnic Luvisols (Loamic, Hypereutric)
				ND-A	44,932015	-0,157319	34	4	parallel	0	Eutric Cambisols (Loamic)
				DEG-B	44,936830	-0,157354	41	5	parallel	0	Stagnic Luvisols (Arenic, Hypereutric)
				ND-B	44,938028	-0,157509	44	5	parallel	0	Abruptic Gleyic Luvisols (Arenic, Hypereutric)
				DEG-C	44,934370	-0,154907	40	3	parallel	0	Haplic Luvisols (Loamic, Hypereutric)
				ND-C	44,934362	-0,155400	39	3	parallel	3	Cambic Calcisols (Loamic, Hypocalcic)
	Château Pech Redon (PR)	15,4	558	DEG-A	43,159107	3,097357	161	5	parallel	25	Haplic Calcisols (Arenic)
				ND-A	43,158966	3,097324	159	5	parallel	6,5	Haplic Calcisol (Arenic, Hypercalcic)
				DEG-B	43,156992	3,099902	154	8	perpendicular	5	Haplic Calcisols (Loamic, Hypercalcic)
				ND-B	43,156826	3,100884	154	7	perpendicular	2	Haplic Calcisols (Siltic, Hypercalcic)
				DEG-C	43,157305	3,102021	156	4	perpendicular	3	Haplic Calcisols (Siltic, Hypercalcic)
				ND-C	43,157165	3,102307	154	2	perpendicular	1,5	Haplic Calcisols (Loamic)
Italy	San Disdagio (SD)	14,1	792	DEG-A	43,004919	11,223919	149	6	parallel	11	Cambic Calcisols (Loamic, Hypercalcic, Sodic, Stagnic)
				ND-A	43,004980	11,225325	161	1	parallel	7	Cambic Calcisols (Clayic, Sodic)
				DEG-B	43,007373	11,224737	158	6	parallel	17	Cambic Calcisols (Loamic, Stagnic)
				ND-B	43,006784	11,224456	153	3	parallel	5	Stagnic Eutric Cambisol (Loamic)
				DEG-C	43,007913	11,225577	166	7	parallel	16	Cambic Calcisols (Loamic, Hypercalcic, Ruptic)
				ND-C	43,007556	11,225779	164	6	parallel	4	Sodic Calcic Vertisols (Loamic, Stagnic)
	Fontodi (FON)	13,9	817	DEG-A	43,540469	11,307796	369	15	parallel	30	Cambic Calcisols (Clayic, Hypercalcic)
				ND-A	43,540941	11,307519	370	15	parallel	7,5	Cambic Calcisols (Clayic)
				DEG-B	43,533552	11,303838	385	15	parallel	25	Cambic Skeletic Calcisols (Clayic)
				ND-B	43,533135	11,304739	388	13	parallel	40	Calcaric Skeletic Cambisols (Clayic)
				DEG-C	43,534816	11,302028	342	25	diagonal	28	Cambic Skeletic Calcisols (Clayic)
				ND-C	43,534798	11,302917	349	22	diagonal	29	Calcaric Skeletic Cambisols (Clayic)
Slovenia	Brajniki, Bonini (VS)	8,7	938	DEG-A	45,524520	13,776644	44	12	perpendicular	40	Leptic Skeletic Calcaric Cambisol (Loamic)
				ND-A	45,524545	13,776370	41	12	perpendicular	7	Calcaric Cambisol (Clayic)
	Brajniki Prade (VL)			DEG-B	45,536895	13,784775	80	5	parallel	15	Leptic Skeletic Calcaric Cambisol (Loamic)
				ND-B	45,536703	13,785852	82	5	parallel	30	Stagnic Calcaric Cambisol (Loamic, Ruptic)
Turkey	Evran (ET)	20,0	581	DEG-A	36,957540	34,743040	177	6	diagonal	0	Petric Calcisols (Loamic)
				ND-A	36,957626	34,743255	175	6	diagonal	0	Petric Calcisols (Loamic)
	Çelebi (CC)	18,3	724	DEG-B	36,997888	36,019658	134	5	diagonal	2	Leptic Calcisols (Loamic)
				ND-B	36,997836	36,019352	133	5	diagonal	3	Cambic Calcisol (Loamic)

In addition, a reference plot in a non-degraded area of the same vineyard (ND) was also monitored.

All the sampling and monitoring activities of soil and grapevines were made in the central part of each plot. The plots were sampled at the beginning of the experiments (2015), and then after one or two years of application of the organic strategies.

Figure 3.
An example of experimental layout, in the San Disdagio farm (Italy). Red dots outlined the location of 6 excavation holes for soil profiles analyses in the 3 vineyards (in degraded and non-degraded area for each vineyards). Red lines delimited the 4 treatment plots (control, compost, dry mulching and green manure) in which degraded areas has been subdivided.

The rate of potential soil erosion by water, (Ep, Mg ha^{-1} yr^{-1}), was estimated by applying the USLE, multiplying the factors: rainfall erosivity (R, MJ mm ha^{-1} hour^{-1} yr^{-1}), soil erodibility (K, Mg hour MJ^{-1} mm^{-1}), slope length (L, adimensional) and steepness (S, adimensional). The R factor was estimated using the formula proposed for Sicily and other Mediterranean territories by Ferro et al. (1999). Monthly rainfall data for the years 2015-17 were measured on field. The K factor was obtained starting from soil texture and soil organic carbon content of the topsoil applying the coefficients according with Stone and Hilborn (2012). The L and S factors were obtained using the formulas proposed by McCool et al. (1987, 1989). Each USLE factor, and the resulting Ep, have been calculated separately for all the 38 plots and then means and standard errors (SE) calculated for DEG and ND areas, except for Turkey and Slovenia where only a DEG and ND area per farm was carried out. Post-hoc LSD test (by STATISTICA 7.0, Statsoft, Inc. 1984-2004) was performed to estimate the differences between Ep values within farm areas.

Results and discussions

The vineyards were situated at different altitudes (from 34 and 669 m a.s.l.) with absent to relatively abundant coarse material. Slope in DEG areas was either equal or steeper than in ND areas, soil erosion was increased according to the orientation of the rows, that in the majority of vineyards was parallel to slope. Table 2 shows the treatments actually carried out in the test areas: the initial protocol was gauged on local practices and pedoclimatic conditions.

Table 2. *Summary of the organic treatments tested in the experimental vineyards. The amount of composted organic amendment (COMP) was around 30-50* $Mg\cdot ha^{-1}$*, correspondent to about 2.5-3 kg* m^{-2} *of dry organic matter. In Slovenian vineyards, about 2 kg* m^{-2} *of sheep manure based compost (moist weight) were supplied*

Country	**Farm code**	**Vineyard**	**COMP**	**GM**	**DM**	**CONTR**
SPAIN	LOG	A B C	Composted sheep manure	Mix of barley and faba bean, mown and tilled in May-June	Mix of oats and alfa-alfa, mown in May-June	Spontaneous grass
FRANCE	MB	A B C	Locally sources compost	Mix of barley and vetch, mown and tilled in May-June	Mix of ryegrass and alfa-alfa, mown in May-June	Spontaneous grass
	PR	A B C	Locally sources compost			Mechanical tillage
ITALY	SD	A B C	Composted prunings (2015) and composted cow manure (2016)	Mix of barley and faba bean, mown and tilled in May-June	Squarrose clover, mown in May-June	Mechanical tillage
	FON	A B C	Compost on farm (cow manure and prunings)			Spontaneous grass
SLOVENIA	VS	A	Composted sheep manure	Mix of ryegrass and hairy vetch, mown and tilled in May-June	Mix of ryegrass and alfa-alfa, mown in May-June	Spontaneous grass
	VL	B				
TURKEY	ET	A	Compost on farm (manure and prunings).	Vetch, mown and tilled in April	Mix of vetch and triticale, mown and left on soil surface in April	Mechanical tillage
	CC	B				

Site descriptions reported in Table 1, especially if related to treatments reported in Table 2, are useful to better investigate the results reported in the various project related contributions (this issue).

Some examples of strategies applied during RESOLVE project are shown in Figure 4. The cover crops used for both GM and DM treatments did not show the same growth and cover everywhere and in both of the years 2016 and 2017.

In particular, the winter between 2016 and 2017 was very dry in most of the countries. Therefore, a general lower germination of seeds was observed. Moreover, low cover crops growth characterized the plots with the most severe conditions of soil fertility and with seeding difficulties due to the high stoniness.

1) COMP 2) GM 3) DM 4) CONTR

Figure 4. *Pictures illustrating applied restoration strategies: COMP, composted organic amendment; GM, green manure; DM, dry mulching and the degraded control (CONTR).*

The farms where cover crops had a good growth were: SD (Italy), CC and ET (Turkey). These farms had in common emergency or regular base irrigation and seedbed preparation by rotary tiller. In some cases, as FON (Italy), VS and VL (Slovenia), good cover of natural grass was observable instead of seeded cover crops.

In the others, although secondary seeding was tried in February-March, the growth of cover crops was modest and not satisfactory. Tillage was not expected for at least two years in DM. Accordingly, DM was the treatment with the lowest impact on soil cultivation, especially if cover crops are self-reseeding, i.e. clover in Italy.

The high quality compost application (Razza et al., 2018) confirms to be the best strategy for soil recovery (Priori et al., this issue). Indeed, since the plots were situated in areas of the vineyards characterized by low or very low fertility, the use of cover crops should probably be used after a strong organic fertilization in most of the cases. The preparation of a fine seedbed seems also to be a key-point of the success of cover crops.

The mean DEG and ND values for R, K, L and S are reported in the Table 3.

Potential soil erosion by water resulted on average higher in DEG plots, although not statically significant due to high variability between areas. By comparing the pairs of DEG versus ND plots, it resulted generally higher erosion in DEG plots, contrariwise in Turkish plots. The main factor affecting these results was K, in some cases also L (i.e. MB and CC) or S (i.e. SD) are determinant.

Actual erosion (E) is given by $E = Ep \times C \times P$, assuming the land cover and management factor (C) value equal to 0.524, as applied in Sicily (Fantappiè et al., 2014), and the soil conservation practices factor (P) value equal to one, as if no protection strategies were applied, only the Spanish plots would have an E tolerable rate (< 2 Mg ha^{-1} yr^{-1}, Jones et al., 2012).

This states that soil conservation measures are suggested to maintain the sustainability of the majority of investigated plots, particularly in DEG ones. The bulk of the results confirmed that soil erosion by water is an agent of land degradation in some of the studied vineyards, especially in the degraded ones. However, pre-planting earth movements were the major driver of the land degradation process. A rough estimation of treatment costs has been carried out taking into account increase of fuel. seeds and compost costs in relation to CONTR.

Table 3. *Mean potential soil erosion by water (Ep, Mg ha^{-1} yr^{-1}) ± standard error (SE) for degraded (DEG) and non-degraded (ND) plots. R stands for rainfall erosivity, K for soil erodibility, L for slope length and S for slope steepness*

Farm code	plot	R	K	L	S	Ep±SE
LOG	DEG	420,7	0,044	1,05	0,21	4.1 ± 1.6 d
	ND		0,039	1,06	0,17	3.0 ± 0.3 d
MB	DEG	699,8	0,035	1,57	0,46	17.8 ± 5.1 c
	ND		0,034	1,21	0,46	13.3 ± 0.9 cd
PR	DEG	459,8	0,038	1,48	0,64	16.5 ± 3.2 cd
	ND		0,028	1,58	0,53	10.9 ± 2.8 cd
SD	DEG	427,8	0,035	1,41	0,71	14.9 ± 5.2 cd
	ND		0,035	1,41	0,39	8.2 ± 5.9 cd
FON	DEG	640,4	0,030	1,18	2,52	56.9 ± 5.7 a
	ND		0,028	1,00	2,26	40.0 ± 7.8 b
VS	DEG	1191,8	0,040	1,00	1,50	70,7
	ND		0,028	1,00	1,50	49,6
VL	DEG	1191,8	0,040	1,88	0,57	50,4
	ND		0,040	1,03	0,57	27,7
ET	DEG	549,8	0,026	1,00	0,68	9,8
	ND		0,034	1,00	0,68	12,7
CC	DEG	761,2	0,034	1,17	0,57	17,4
	ND		0,034	1,53	0,57	22,7
mean	DEG	612,7	0,036	1,32	0,89	26.0 ± 4.9
	ND		0,033	1,24	0,81	20.7 ± 3.6

COMP resulted the more expensive treatment, due to the compost transport and purchase costs, estimated in around 300 €/ha. The compost production at farm or local consortium level, mixing manure and shredded prunings can reduce costs. DM resulted slightly cheaper than GM, because of lack of tillage if perennial plants were sown. The cost increase ranged around 200 €/ha, even dependeding if CONTR interrow is tilled once or twice a year.

Conclusions

Proposed restoring strategies resulted viable in all tested area, remaining within organic agriculture management. However, GM and DM treatments depended on pedoclimatic conditions that could reduce biomass supply, mainly as a result of drought, very low fertility, high calcium carbonate content, and/or high stoniness. During exceptional dry winters and early springs, cover crops might compete with grapevines, in these cases, it is better to anticipate the mowing and green manuring to April. For these reasons exogenous organic matter (i.e. compost) involves greater certainty of success. Nevertheless, the results of cost estimation suggested that COMP is the more expensive treatment.

Finally, is noticeable how strategies proposed directly involves only topsoil horizons; probably, when soil functionality degradation involves even deep soil horizons (> 50-60 cm), they cannot solve the problem (at least in the short term).

Additional organic strategies, such as cultivation of deeper soil horizons and /or improved soil addition shall be developed and tested in the future.

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