

Relationship among soil management, organic matter content and root development along the explorable soil profile in the vineyard

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Abstract. In the most ancient wine area of the Controlled Denomination of Origin (DOC) “*Oltrepò Pavese*” in North-West Italy, foothills of the Apennine mountains, the soils of 14 representative vineyards managed for about 10 years with tillage (T) or natural grass-cover (G) or the alternation of the two methods between the rows (GT), were compared for their contents of organic matter, main soil parameters and extent of root development, in the first meter of depth. The soils are fine textured, sometimes calcareous, with low levels of organic matter. G and GT soil treatments showed higher organic matter content (on average 1.4%) than T (0.88%). Better root development (number and area) was observed in G and GT, in comparison with T; the number and size of roots showed a positive correlation with the soil organic matter.

1 Introduction

The sustainability of viticulture is also based also on maintenance over time of the chemical and physical fertility of the soil. Under this point of view, organic matter, mineral elements and water availability in the soil play a fundamental role [1, 2]. Good root development is also crucial to improve the sustainability of the vineyard, especially when established on hilly areas [3]. Soil management is known to strongly modify the soil physical and chemical characteristics of the vineyard and to affect vine roots development [4, 5, 6]; soil management practices leading to even small increases in soil organic matter can be worthwhile from the viewpoint of soil physical properties, while even small decreases resulting from soil management may cause greater negative effects [7].

The effects of the different cultural techniques on the balance of organic matter and root development change, according to different agroecosystems (scion and rootstocks genotype, type and depth of soil, climate and productivity required) and, for these reasons, it is important to improve the studies of the relationships between vine growth, soil management and organic matter content.

The zone under study in the present research is *Oltrepò Pavese* (Fig. 1), boasting about 13.000 ha of vineyards, where *Croatina* (ab. 3,900 ha), *Pinot nero* (ab. 2,500 ha) and *Riesling italico* (ab. 1,800 ha) are the most cultivated varieties for red and white wine production, respectively (ISTAT 2010, last agriculture

census). For wine production, the area is among the top ten in Italy. Under the objective of studying this ancient viticulture, the soil organic matter content, and the development of grapevine roots in relation to some different management practices, this research was carried out within the project “*Oltrepò bio-diverso ATTIV- AREE*” (CARIPLO Foundation).

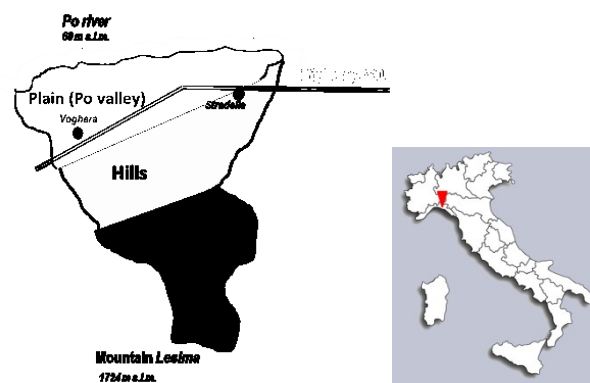


Fig. 1. The *Oltrepò Pavese* on the north-western Apennines, facing to the Po Valley (Stradella town: Latitude 45°04'N, Longitude 9°18'E with about 720 mm of annual rainfall) [8].

2 Material and methods

Within the *Oltrepò Pavese* district, seven representative sites of local viticulture were taken into

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consideration from 2015 to 2017, identifying 14 vineyards in which, for at least 10 years, management of the soil was developed with: tillage (T), or natural grass cover (G) or the alternation of these two methods between the rows (GT) (Tab. 1).

Table 1. Sample vineyards selected, with the type of soil management used (T = total tillage, G = natural Grass, GT = alternation of the two methods between inter-rows), the location (P. = Pavese) and the altitude (meters above sea level). The geological substrate were: CP and SD marls (*Marne di S. Agata fossili*), SMV alternation of sandstone and marls (*Formazione Val Luretta*), MP cc, ct silty and calcareous marls (*Formazione di Contignaco*), and MPcg calcareous marls (*Marne di Monte Piano*).

Label and soil management	Places	Alt. (m)	
CP ro	T	Canneto P. - roncole	170
CP cb	G	Canneto P. - casa bazzini	178
SD br	G	S. Damiano - braccio	156
SMV cn1 cn2 cn3 cn4 cn5	T G GT GT GT	S. Maria Versa - case nuove	270
MP cc1 cc2	G G	Montalto P. - casa cuneo	330
MP ct1 ct2	T T	Montalto P. - casa tacconi	320
MP cg1 cg2	G G	Montalto P. - costa gallotti	344

All vineyards were grafted on the same rootstock (SO4) but different varieties were featured: *Croatina* (CPro, CPcb, SMVcn1), *Pinot nero* (SMVcn2, MPcc), *Riesling italico* (MPct, MPcg) and *Merlot* (SMVcn3, SMVcn4, SMVcn5). In each of these vineyards, a profile excavation was opened and, for each 10-30 cm soil layer down to the depth of about 100-120 cm, soil samples were collected for the determination of texture (USDA method) as % of gravel, sands, silt and clay; organic matter %, pH, CEC cation exchange capacity meq/100g, potassium exchangeable (K, mg/kg) and magnesium exchangeable and (Mg, mg/kg), phosphorous (P, "Olsen") calcium exchangeable (Ca mg/kg). At the same time, the number of vine roots and their section were determined to produce an estimate of the vine root systems along the soil profile (total number of roots, number of roots with diameter >2mm, area of roots) on the basis of the data collected with photographic methodology used in the slope geology [10]. Analysis of variance was used to study the soil variables measured and to evaluate the effects of geological formation, as well as depth and type of soil management on the soil chemical main compounds and on the parameters related to root evaluation. The Levene statistic (L) was applied to test the homogeneity of the variances and when L reached significant levels (p<0,05) and variances were judged to be not homogenous, the Brown-Forsythe (bf) statistic was applied to test data variability [11]. When the results of the test (F or bf) were significant, the differences among the means were

verified with the Student-Newman-Keuls test (SNK, p<0,05).

3 Results and discussion

3.1 Soils characteristics

The soils of the examined vineyards belong to four different geological formations [9]: *Marne di S. Agata Fossili* (Msaf), *Marne di Monte Piano* (Mmp), *Formazione di Contignaco* (FC) and *Val Luretta* (VL); more (Mmp) or less (Msaf) calcareous marl and alternation of marl and sandstone (FC and VL). Results from soil analysis (Tab. 2 and 3) highlight several significant differences among the different geological formations for: texture, carbonate content, and cation nutrient richness (sand, clay, limestone total and active, K and Mg exchangeable and CEC); the parameters found which varied significantly along the depths of soil were: organic matter and pH.

Tab. 2. Soil textures. Geological formations (Geo.); Depths of soil (D.) range in cm; Soil management (M.) T = Tillage, G=Green natural cover, GT= alternating of green natural cover and tillage, between the inter-rows. L=Levene test; F=Fisher test; bf=Brown Forsythe test; ns = not significant; * and ** = significant per p<0.05 and p<0.01, respectively. Within each column, medium values with different letters are significantly different at SNK test (p<0.05).

Var.	Gravel	Sand	Silt	Clay
Geo. L	4,46*	17,7**	1,54ns	11,7**
F	-	-	-	-
bf	1,43ns	8,62**	1,47ns	3,11ns
	%	%	%	%
Msaf	1.88 a	18.48 b	50.24	29.40a
Mmp	4.87 c	18.51 b	43.30	33.31a
FC	2.54 ab	5.79 a	46,57	45.10b
VL	3.32 b	5.18 a	40.98	50.53b
D. L	0.31ns	1.39ns	0.45ns	0.56ns
F	0.01ns	0.16ns	0.60ns	1.47ns
bf	-	-	-	-
	%	%	%	%
0-40	3.01	9.08	46.39	41.51
41-80	2.87	7.89	43.56	45.68
81-120	3.02	10.23	43.08	43.67
M. L	3.47*	2.57ns	4.04*	4.75*
F	-	-	-	5.07**
bf	0.20ns	-	2.37ns	-
	%	%	%	%
T	2.65	11.85	44.49	40.99a
G	3.31	9.67	47.46	39.55a
GT	2.77	5.35	41.25	51.64b

Soil texture varied between the geological formations, but it was quite uniform along the first meter of soil depth.

In general, the soil texture (Tab. 2) shows higher values of silt (about, 41 – 50 %) and clay (29 – 50 %), associated with lower levels of sand (5.3 – 16.0 %) and, above all, of gravel (1.6 – 4.9 %). According to the significant texture differences observed (Tab. 2), it is

therefore possible to identify two main types of soil, the first (VL and FC) with higher level of clay (>45%) and a very low sand content (<5%), and a second soil (Msaf and Mmp) where the silt is equal or higher than clay and the sand (≈ 18%). Therefore, the first soil (VL and FC) is a Clay-Silt-Sand and the second (marls) is a Silt-Clay-Sand. Each texture fraction did not change significantly according to soil depth or the type of soil management adopted.

Table 3. Soil general parameters. O.M.=organic matter; C=carbon; N=Nitrogen; Limes.=Limestone; T.=total; A.=active (see also the caption of Tab. 2).

Var.	pH	O.M.	Limes. T.	Limes. A.	CEC
Geo. L	3.04ns	2.93ns	17.2**	10.7**	4.68**
F	2.68ns	3.87*	-	-	-
bf	-	-	22.3**	22.2**	31.1**
Msaf	8.32	1.44	20.75b	10.04ab	16.31a
Mmp	8.18	1.87	23.25b	11.25b	18.54a
FC	8.25	1.04	27.20b	13.18b	20.10a
VL	8.21	1.23	12.89a	6.91a	33.07b
D. L	0.11ns	2.21ns	4.97**	0.22ns	0.93ns
F	9.22**	10.3**	-	3.77*	0.31ns
bf	-	-	1.87ns	-	-
0-40	8.11a	1.75b	22.23	11.39b	22.62
41-80	8.30b	1.05a	19.31	9.69ab	25.75
81-120	8.36b	0.88a	15.83	7.41a	26.96
M. L	3.04ns	3.04ns	17.18**	10.7**	4.68**
F	2.68ns	3.87*	-	-	-
bf	-	-	22.3**	22.2**	31.0**
T	8.34	0.88a	44.49	40.99	19.63a
G	8.18	1.53b	46.23	41.41	21.62a
GT	8.23	1.26ab	41.29	50.30	34.46b

Regarding the main general chemical characteristics of the soil (Tab. 3), only limestone and CEC changed significantly among the different geological formations. Limestone is lower in VL and higher in FC, with about 13% and 27%, respectively; the marls soils (Msaf and Mmp) have intermediate calcareous values compared to the first two. The variations of O.M. and pH was not significant among different geological formations. With the depth of soil, O.M. decreases and pH increases. Limestone, pH, CEC and O.M. were affected by the type of soil management used, with significantly higher pH and limestone in the case of Tillage, whilst the soils managed for years with green cover alternated with tillage showed a lower level of limestone. Regarding availability of mineral ions in soils (Tab. 4), the geological formations caused significant differences for Potassium, Magnesium and Calcium-, N and P contents did not change substantially according to the geology variation of the substrates. All the elements appeared to vary significantly with the depth of soil, with the exception of Mg; in fact N, P, K and Ca decreased significantly with the depth of soil.

According to the texture observed, it is possible identify two main agronomic types of soil: Marls (Msaf and Mmp) and Clays (FC and VL) with a low variability

in the first meter of depth; among the different types of soil management methods studied, the differences were mainly not significant, with the exception of N, O.M., LsA%, MgO and CaO.

Table 4. Main mineral macronutrients. N=nitrogen, K=potassium, Mg=magnesium, exc.=exchangeable (see also the caption of Tab. 2).

Var.	N	C/N	K exc.	P	Mg exc.
Geo. L	1.44ns	1.19ns	2.71*	3.61*	2.37ns
F	1.30ns	2.10ns	5.34**	8.42**	27.5**
bf	-	-	6.58**	4.08ns	-
Msaf	%		mg/kg	mg/kg	mg/kg
Mmp	1.01	8.33	141a	6.75	182a
FC	1.25	8.68	335c	23.24	160a
VL	0.79	7.79	192ab	5.61	522a
	0.86	8.40	273bc	6.42	1196b
D. L	0.44ns	3.13ns	1.59ns	7.85**	0.21ns
F	11.0**	1.21ns	3.56*	-	5.95**
bf	-	-	-	7.22**	-
0-40	%		mg/kg	mg/kg	mg/kg
41-80	1.22b	8.24	285b	12.52b	444a
81-120	0.77a	8.01	205ab	5.46a	765ab
	0.61a	8.50	187a	3.91a	1049b
M. L	2.15ns	1.99ns	2.18ns	2.40ns	0.94ns
F	4.25**	1.73ns	1.92ns	1.55ns	33.9**
bf	-	-	-	-	-
T	%		mg/kg	mg/kg	mg/kg
G	0.65a	8.08	196	5.08	517a
GT	1.09b	8.09	220	10.05	405a
	0.85b	8.60	280	6.92	1363b

3.2 Root development

In general, the study showed roots exploring soils at a depth of about 1.0 – 1.2 m, the limit reached without excessive effort by the excavator blade and that corresponded to the depth where the roots became sporadic. In two cases of vineyard managed with total tillage of the soil, the roots became sporadic starting from 80 cm. The majority of the roots (by number) were confined in the first 60 cm of depth (on average 68,4% of the roots), at about 80 cm the limit of 90,0% of the total roots was exceeded. The number and the area of roots measured in the different geological formations showed high variability (Tab. 5), but without a clear trend in the differences among the averages; number and area of roots significantly decreased with depth; while there were no significant differences among grapevine varieties, the type of soil management used by the vine-grower in the years had a significant effect on root development. The higher values of root number and area were found in the vineyard managed with cover grass and especially in the case of the alternation of cover grass with tillage between the rows. Conversely, total tillage of the vineyard soil decreased root development. The number of roots with diameters more than 2 mm and the area of these same roots tended to be higher in the case of the grass cover of the soil, but it is, of course, higher in the case of the method of alternate management in the rows, with values significantly higher also than total green cover.

Table 5. Number (N r) and area (A r) of roots (see also the caption of Tab. 2).

Var.	N r	Area r	N r >2mm	Area r >2mm
Geo. L	3.68*	10.97**	9.42**	9.45**
	F -	-	-	-
bf	0.96ns	3.99**	3.09*	3.83*
	n./m ²	cm ² /m ²	n./m ²	cm ² /m ²
Msaf	183	11.24	70.37	9.28
Mmp	234	12.35	84.26	10.25
FC	188	8.08	62.50	6.56
VL	206	14.07	133.33	16.87
D. L	10.31**	14.6**	4.97**	0.22ns
	F -	-	-	3.77*
bf	96.0**	41.4**	1.87ns	-
	n./m ²	cm ² /m ²	n./m ²	cm ² /m ²
0-40	302c	18.52c	22.23	11.39b
41-80	225b	13.34b	19.31	9.69ab
81-120	74a	3.63a	18.83	7.41a
cv L	3.41*	8.55**	6.89**	6.71**
	F -	-	-	-
bf	0.70ns	3.10*	3.11ns	3.09ns
	n./m ²	cm ² /m ²	n./m ²	cm ² /m ²
PN	179	9.20	73.84	8.62
CR	209	14.18	80.99	10.81
RI	204	9.94	67.13	7.99
ME	217	15.12	198.15	24.63
M. L	5.79**	9.61**	15.40**	15.76**
	F -	-	-	-
bf	5.14**	5.06**	3.78*	5.06**
	n./m ²	cm ² /m ²	n./m ²	cm ² /m ²
T	146a	7.59a	36.8a	7.69a
G	204b	12.33b	95.7ab	9.86ab
GT	229b	14.51b	148.5b	19.71b

Calculating the correlation coefficients between the soil parameters evaluated and the measures of the roots, it is observed that the most significant positive correlations were, above all, with organic matter and N, P, and K whilst the correlations were negative with pH and Mg (Tab. 5, Fig. 2).

Tab. 5. Most significant correlation coefficients between Number (N r), area (A r) of roots and the soil characteristics.

	pH	O.M.	N	P	K	Mg
Nr	0.55	0.63	0.69	0.37	0.34	-0.45
Ar	0.50	0.68	0.68	0.42	0.42	-0.25

3 Conclusion

The soils of the *Oltrepò Pavese* area studied innortheastern Italy were found to be alkaline (pH 8.2-8,3), fine textured, sometime calcareous, with a low level of organic matter (<2.0%), but with high or too high level of K and Mg, respectively. The use of grass mulching (G) or its alternation with tillage between the adjacent rows (GT), has increased, over the years, the soil organic matter in comparison with tillage (T) that frequently is associated with too low soil organic content (<1.0%); however, the tillage of the vineyard rows after

some years of green cover, has produced an increase of organic matter in the superficial layers of soil, in comparison with the total annual tillage. The size of the roots (number and area of their sections) is higher where green cover was permanently used (G) or in alternation with tillage (GT). The roots showed significant positive correlations with the soil organic matter content and negative correlations with high pH and very high levels of Mg.

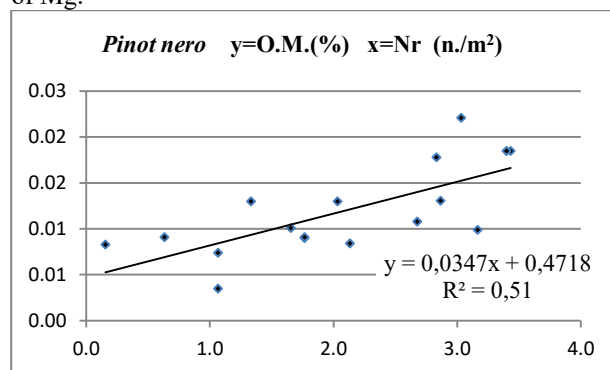


Fig. 2. Graphic representation of the linear regression between Nr (number of roots) and the soil organic matter content evaluated for the vines of *Pinot nero*.

References

1. E.W. Russell. *Soil Conditions and Plant Growth* (Longman, London, 1973)
2. L. Tombesi, *Elementi di scienza del suolo e di biologia vegetale. Guida all'interpretazione delle analisi dei terreni.* (Edagricole, Bologna, 1977)
3. M. Bordoni, C. Meisina, A. Vercesi, G.B. Bischetti, E.A. Chiaradia, C. Vergani, *Soil and Tillage Research*, **163** (2016)
4. Saayman D.S. *Afr. J. Enol. Vitic.*, **3** (1982)
5. Morlat R., Jacquet A., *Vitis*, **32** (1993)
6. R. Linares, M. de la Fuente, P. Junquera, J.R. Lissarrague, P. Baeza, *Bio Web of Conferences*, **3** (2014)
7. D. Powlson 1, P. Smith, M. De Nobili in *Soil Conditions and Plant Growth*, Peter J. Gregory and Stephen Nortcliff (Eds.) (Wiley-Blackwell, 2013)
8. A. Vercesi *Proceedings VIII International Congress Terroir, Soave (VR) Italy*, **1**, (2010)
9. L. Pellegrini, P.L. Vercesi, *I geositi della Provincia di Pavia* (Ponzio and son, Pavia, 2005)
10. G.B. Bischetti, E.A. Chiaradia, T. Simonato, B. Speziali, B. Vitali, P. Vullo, A. Zocco, *Plant Soil*, **278** (2005)
11. M.B. Brown, A.B. Forsythe, Alan B., *Journal of the American Statistical Association*, **69** (1974).