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Soil physical quality in a Sicilian agricultural area

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Abstract. The objective of this study was to determine the soil physical quality for two contiguous agricultural areas under annual crops (A) and vineyard (V), respectively, located at the *Riserva Naturale Integrale Grotta di Santa Ninfa* site, in Sicily. The A and V areas had different textural fractions and organic matter content. Soil water holding parameters did not vary substantially between the two areas whereas field saturated hydraulic conductivity changed appreciably with the area and also with the sampling date, especially in the A soil. Horizontal anisotropy of laboratory determined saturated soil hydraulic conductivity was noticeable especially at the greatest depths. A better quality was detected for the A soil than the V one. However, conditions denoting a generally poor physical quality of the sampled soils were not detected in this investigation. Therefore, agricultural practices were not responsible of substantial soil degradation processes in the sampled areas.

Keywords. Soil physical quality – Agricultural soils – Land use – Soil hydraulic properties.

La qualité physique du sol dans une zone agricole Sicilienne

Résumé. *La qualité physique du sol est un sujet très important, recevant une attention particulière ces dernières années. L'objectif de cette étude est de déterminer la qualité physique du sol dans deux zones agricoles cultivées respectivement en cultures annuelles (A) et en vigne (V) et situées dans la Riserva Naturale Integrale Grotta di Santa Ninfa, en Sicile. Les zones A et V sont caractérisées par des textures et des contenus en matière organique différents. Les paramètres de retention hydrique n'ont pas présenté une variabilité significative entre les deux zones, alors que la conductivité hydraulique a changé remarquablement d'une zone à l'autre et selon la période d'échantillonnage, surtout dans la zone A. La conductivité hydraulique du sol saturé déterminée au laboratoire, a détecté une anisotropie horizontale notable surtout en profondeur. Une meilleure qualité a été détectée pour le sol A en comparaison avec le sol V. Cependant, au cours de l'expérimentation, des conditions dénonçant une mauvaise qualité physique du sol n'ont pas été détectées. Par conséquence, pour les zones étudiées, les pratiques agricoles ne peuvent pas être considérées responsables d'importants processus de dégradation du sol.*

Mots-clés. *Qualité physique du sol – Sols agricoles – Occupation du sol – Propriétés hydraulique du sol.*

I – Introduction

Soil quality, which is a subject receiving increasing attention in recent years, is usually considered to have three main aspects: physical, chemical, and biological (Dexter, 2004). Soil physical quality affects chemical and biological processes in the soil and, therefore, it plays a central role in studies on soil quality (Dexter, 2004). The physical quality of an agricultural soil refers primarily to the soil-strength and fluid transmission and storage characteristics in the crop root zone (Topp *et al.*, 1997; Reynolds *et al.*, 2002). An agricultural soil with a good physical quality maintains a good structure, holds crops upright, resists erosion and compaction, allows unrestricted root growth and proliferation of soil flora and fauna, and permits the correct proportions of water, dissolved nutrients and air for both maximum crop performance and minimum environmental degradation (Topp *et al.*, 1997; Reynolds *et al.*, 2002). Intensive field crop production can cause the physical quality of agricultural soils to decline (Reynolds *et al.*, 2002). Optimal soil physical quality parameter values for maximum field crop production with minimum environmental degradation are still largely unknown, notwithstanding that various empirical guideline parameter values have been proposed (Topp *et al.*, 1997; Reynolds *et al.*, 2002, 2003; Dexter, 2004; Dexter and Czyż, 2007).

Saturated soil hydraulic conductivity, which influences soil physical quality (Reynolds *et al.*, 2003), may vary with both time (Ciollaro and Lamaddalena, 1998) and the considered flow direction (Bagarello and Sgroi, 2008). Therefore, determination of temporal variability and anisotropy of this property should be included in soil physical quality studies.

The site named *Riserva Naturale Integrale Grotta di Santa Ninfa* (GSN), in Sicily, has an important environmental interest due to the presence of a karstic stream. The site includes both agricultural and non-agricultural areas. In particular, two contiguous agricultural areas are under annual crops and vineyard, respectively, that are widely diffused crops at the GSN site. Determining the soil physical quality for these two areas is important to detect a possible occurrence of environmental degradation processes at the GSN site and to evaluate land use effects on soil physical quality parameters.

The objectives of this investigation were to i) compare selected properties of near-surface soil measured in the annual crops and vineyard areas on two sampling dates; ii) determine the near-surface soil physical quality for the two treatments using the existing criteria; and iii) compare the anisotropy of the saturated soil hydraulic conductivity measured in the two experimental areas.

II – Soil physical parameters

The dry soil bulk density, ρ_b (M L^{-3}), i.e. the mass of dry soil solids per unit bulk soil volume, is an index of the soil's mechanical resistance to root growth (Topp *et al.*, 1997). Jones (1983) developed the following empirical relationships to distinguish a lower critical bulk density, ρ_{bL} (g cm^{-3}), below which root growth is effectively unimpeded, and an upper critical bulk density, ρ_{bU} (g cm^{-3}), above which root growth is severely impeded (i.e., ≤ 20% of the root growth at ρ_{bL}) (Reynolds *et al.*, 2002):

$$\rho_{bL} = 1.60 - 0.00468\left(cl + si\right) \tag{1a}$$

$$\rho_{bU} = 1.83 - 0.00429\left(cl + si\right) \tag{1b}$$

where *cl* (%) and *si* (%) are the clay and the silt content of the soil, respectively. Crop root growth becomes progressively more impeded as ρ_b increases above this range due to increasing soil strength, while bulk densities below this range may not provide sufficient root-soil contact and soil water retention for adequate seed germination and seedling growth, nor adequate anchoring to maintain field crops upright when subjected to wind and rain (Reynolds *et al.*, 2003).

The saturated soil hydraulic conductivity, K_s (L T^{-1}), characterizes the ability of soil to imbibe needed water and drain excess water (Topp *et al.*, 1997). Although acceptable K_s for agricultural field soils ranges from about 0.36 to 360 mm h^{-1} (Topp *et al.*, 1997), the narrower range of 18-180 mm h^{-1} is considered to be ideal with respect to promoting rapid infiltration and redistribution of needed crop-available water, reducing surface runoff and soil erosion, and encouraging relatively rapid drainage of excess soil water (Reynolds *et al.*, 2003).

Air capacity of total soil, *AC* (L^{3}L^{-3}), is defined as *SWC-FC*, being *SWC* (L^{3}L^{-3}) the saturated volumetric soil water content and *FC* (L^{3}L^{-3}) the field capacity water content, i.e. the soil water content corresponding to a soil water pressure head, h = -1 m (Reynolds *et al.*, 2002). The *AC* index represents the ability of soil to store and provide essential soil air (Topp *et al.*, 1997). According to Reynolds *et al.* (2002), the near-surface *AC* should be at least 0.10-0.15 m^{3}m^{-3}.

The plant available water capacity, *PAWC* (L^{3}L^{-3}), is equal to *FC-PWP*, being *PWP* (L^{3}L^{-3}) the permanent wilting point water content, i.e. the soil water content corresponding to h = -150 m. The *PAWC* index is used since it is a measure of the ability of the soil to store and provide soil water that is available to crop roots. Reynolds *et al.* (2002) reported that *PAWC* should be > 0.20 m^{3}m^{-3}

or within the range 0.15-0.25 m^3m^{-3}. According to Verdonck *et al.* (1983) and Cockroft and Olsson (1997), 0.20 ≤ *PAWC* ≤ 0.30 m^3m^{-3} is required for optimum root growth/function and minimum droughtiness in fine-textured soils and horticultural substrates.

The *FC/POR* ratio, being *POR* (L^3L^{-3}) the soil porosity, is an index of the balance between soil water holding capacity and aeration. Olness *et al.* (1998) suggested that the optimal value of *FC/POR* is 0.66. The rationale for this criterion is that, in rain-fed agriculture, soils with this ratio are likely to have desirable water and air contents for good microbial production of nitrogen more frequently and for longer time periods than soils that have larger or smaller ratios (Reynolds *et al.*, 2002).

Dexter (2004) proposed the so-called *S* index to evaluate the soil physical quality. This index is defined as the slope value of the soil water retention curve at its inflection point. Dexter and Czyż (2007) provided the following descriptive categories of soil physical quality in terms of the corresponding values of *S*: $S \geq 0.050$, very good; $0.050 > S \geq 0.035$, good; $0.035 > S \geq 0.020$, poor; and $0.020 > S$, very poor.

III – Materials and methods

The study was carried out at the GSN site. The boundaries of this site coincide approximately with the limits of a watershed of 140 ha. Mean annual rainfall is 610 mm and mean annual air temperature is 17 °C. The areas supporting the annual crops (A) and the vineyard (V) are located on the same field at a distance of a few dozen meters. This field has an elevation of approximately 440 m a.s.l., a slope of 15% and a S-E aspect. Information on land use and recent cultivation practices for the A and V areas was summarized in Table 1.

Table 1. Information on land use and recent cultivation practices for the two sampling areas

Area	History	Year 2004/2005	Year 2005/2006
Annual crops (A)	Vineyard until 1998. Temporary grass-land from 1999 to 2004.	Autumn 2004: deep ploughing (depth = 0.8 - 0.9 m) followed by harrowing. December 2004: sowing of Italianrye-grass.	Autumn 2005: ploughing (depth = 0.25 m) followed by sowing of vetch. February 2006: green manure of vetch and harrowing of the surface to prepare the seedbed for wheat.
Vineyard (V)	Vineyard since the 1980s.	No tilling in the months before the sampling date. Harrowing on June.	No tilling in the months before the experiments.

A 100-m^2 sampling area was selected in each area. On May 2005, undisturbed soil cores were collected at nine randomly chosen locations within each sampling area by gently hand-hammering stainless steel cylinders (inside diameter = 0.08 m, height = 0.05 m) into the surface horizon of the soil, after removing the first few centimeters (< 5 cm). A disturbed soil sample was also collected at each sampling point.

The particle size distribution of each soil sample was determined by the hydrometer method for particles having diameters < 74 μm and by sieving for particles between 74 and 2000 μm. The clay (*cl*), silt (*si*) and sand (*sa*) percentages were determined according to the USDA classification scheme (Gee and Bauder, 1986). The organic matter content (*OM*) was estimated to be equal to 1.724 times the organic carbon content determined by the Walkley-Black method. For each soil sample, the soil erodibility factor, K_U (t ha h ha^{-1} MJ^{-1} mm^{-1}), of the Universal Soil Loss Equation (Wischmeier and Smith, 1978) was determined.

Desorption water retention data were determined in the laboratory on each undisturbed soil core using a hanging water column apparatus (Burke *et al.*, 1986) for pressure head values of -0.05, -0.1, -0.2, -0.4, -0.7, and -1.2 m. For each sampling point, sieved soil was packed to the bulk density value of the undisturbed core in rings having an inside diameter of 0.05 m and a height of 0.01 m. These soil samples were used to determine the soil water content corresponding to pressure head values of -3.37, -10.2, -30.6, and -153.0 m by a pressure plate apparatus. For each sampling point, water retention data were described by the van Genuchten (1980) model. The RETC code (van Genuchten *et al.*, 1991) was used to determine the unknown parameters of this model.

Field saturated hydraulic conductivity, K_{fs} (L T^{-1}), was measured by the SFH technique (Bagarello *et al.*, 2004) in 15 randomly selected points within each sampling area, using stainless steel rings (inner diameter of 0.15 m) that were inserted after removing the first few centimeters of soil. Two undisturbed soil cores (0.05-m diameter by 0.05-m high) were collected near the ring at a depth of 0 to 0.05 m and 0.05 to 0.10 m, respectively, two days before the SFH experiment. These cores were used to determine the bulk density, ρ_b, and the initial volumetric soil water content, θ_i (L^3L^{-3}), that were averaged over the two depths. An α*-parameter equal to 12 m^{-1} was used to calculate K_{fs} by the SFH equation.

Measurement of K_{fs} was repeated on April 2006 in 15 newly selected points within each sampling area. The second sampling date was characterized by wetter soil conditions (mean of θ_i = 0.270 m^3m^{-3}, sample size, N = 56) than the first one (mean = 0.235 m^3m^{-3}, N = 90). The ρ_b and K_{fs} values obtained on the first and the second sampling dates were denoted by the symbols ρ_{bI} and ρ_{bII}, and K_{fsI} and K_{fsII}, respectively.

On April 2006, undisturbed soil cores (inside diameter = 0.085 m, height = 0.114 m) were also collected in the A and V areas at three depths below the soil surface (0.1, 0.3, and 0.5 m) to evaluate the anisotropy of the laboratory saturated soil hydraulic conductivity, K_s (L T^{-1}). For a given area and depth combination, two vertically oriented soil cores and two horizontally oriented soil cores were collected at a distance of a few centimeters between replicated cores by gently hand-hammering stainless steel cylinders into the soil (total sample size, N = 24). In the laboratory, the soil cores were saturated from the bottom for 2-4 days, depending on the core, and then K_s was measured by the constant-head permeameter method (Klute and Dirksen, 1986).

For each soil sample, *AC*, *PAWC* and *FC/POR* were calculated using the fitted water retention function, and a value of *S* was obtained according to Dexter (2004). For a given area, the mean and the associated coefficient variation, *CV*, of each considered variable (*cl*, *si*, *sa*, *OM*, K_U, ρ_{bI}, ρ_{bII}, K_{fsI}, K_{fsII}, *AC*, *PAWC*, *FC/POR* and *S*) were calculated. The K_{fs} data were assumed to be ln-distributed, as is common for this variable, and the geometric mean and the associated *CV* were determined (Lee *et al.*, 1985). The other data were assumed to be normally distributed and the arithmetic mean and the associated *CV* value were calculated. For each variable, a comparison between the two areas was carried out using a two-tailed *t* test. A similar comparison was carried out within a given area between the two sampling dates for both ρ_b and K_{fs}. A probability level, P = 0.05, was used for all statistical tests. For each considered soil physical quality parameter (ρ_b, K_{fs}, *AC*, *PAWC*, *FC/POR*, *S*), the values measured in the two areas were then compared with the ones suggested to discriminate between various categories of soil physical quality. A comparison between the A and V areas in terms of the anisotropic characteristics of K_s was also carried out. In this case, the geometric mean of the two K_s measurements obtained for given sampling area, depth and orientation was calculated.

IV – Results and discussion

According to the USDA classification scheme, the soil texture of the individual soil samples was silt or silt-loam, and silt was the prevailing textural fraction in both the A and V areas (Table

2). The V area had a significantly higher *si* and *OM* content and a significantly lower *cl* and *sa* content as compared with the A area. The two areas differed by *AC*, with the A area yielding a significantly higher *AC* result than the V one, but not in terms of K_U, *PAWC*, *FC/POR*, and *S*. For ρ_b, significantly higher values were measured in the V area than in the A one on the first sampling date (ρ_{bI}), whereas the results were not significantly different on the second date (ρ_{bII}). The differences between the K_{fs} values measured in the two areas were statistically significant on both sampling dates but the sign of the difference varied with the date. In particular, the K_{fs} values were significantly higher in the A area than in the V one on the first sampling date (K_{fsI}) whereas the opposite result was obtained on the second date (K_{fsII}). However, large or very large *CV* results were obtained for K_{fs}, suggesting that an improved characterization of the sampled areas could be desiderable. For both K_{fs} and ρ_b, the variability between the two sampling dates was more noticeable for the A area (mean values of K_{fs} and ρ_b differing by a factor of 17.0 and 1.14, respectively) than for the V one (K_{fs} and ρ_b differing by a factor of 1.9 and 1.04, respectively), and the differences between the two dates were statistically significant in the A area for both variables and in the V area only for K_{fs}.

Table 2. Soil properties for the A (annual crops) and V (vineyard) areas

Variable	A		V	
	Mean	**CV**	**Mean**	**CV**
cl (%)	17.2a	0.309	7.3b	0.897
si (%)	64.8a	0.071	77.1b	0.103
sa (%)	18.0a	0.076	15.6b	0.141
OM (%)	1.56a	0.191	2.71b	0.093
K_{USLE} (t ha h ha^{-1} MJ^{-1} mm^{-1})	0.057a	0.105	0.065a	0.184
AC (m^3 m^{-3})	0.141a	0.233	0.080b	0.518
PAWC (m^3 m^{-3})	0.180a	0.140	0.187a	0.048
FC/POR	0.748a	0.110	0.832a	0.108
S	0.043a	0.126	0.039a	0.083
ρ_{bI} (g cm^{-3})	1.148a,A	0.110	1.368b,A	0.074
K_{fsI} (mm h^{-1})	3084.4a,A	1.870	453.5b,A	1.860
ρ_{bII} (g cm^{-3})	1.313a,B	0.046	1.317a,A	0.049
K_{fsII} (mm h^{-1})	181.5a,B	5.870	848.1b,B	3.730

Values followed by the same lower case letter in a row are not significantly different (P = 0.05)

For a given variable (e.g. Kfs or ρb), values followed by the same capital letter in a column are not significantly different

Silt particles are known to be particularly erodible because they are more easily detached than clay particles and more easily transported than sand particles (Toy *et al.*, 2002). Therefore, a possible interpretation of the observed differences in terms of textural fractions is that higher soil erosion rates occurred in the A area than in the V one in the past years. The mean values of K_U were in the upper half of the K_U range established by Wischmeier *et al.* (1971). Differences between the two areas were particularly noticeable in terms of soil water transport parameters, but soil water holding parameters did not change significantly with the exception of *AC*. The two areas differed in terms of temporal variability of both ρ_b and K_{fs}, that was more noticeable in the A area than in the V one.

Probably, land use was an important factor, and perhaps the most important one, affecting the comparison between the A and V contiguous areas, differing by crops and cropping practices since 1999 (Table 1). According to this interpretation, soil water holding parameters were less affected than transport parameters by land use and management practices. Temporal variability of both ρ_b and K_{fs} was substantially affected by land use since a different temporal variability of these variables was detected in the two sampled areas.

Eqs. (1) yielded ρ_{bL} = 1.216 g cm^{-3} and ρ_{bU} = 1.478 g cm^{-3} for the A area. The mean value of ρ_{bI} (1.148 g cm^{-3}) was lower than ρ_{bL} whereas the mean value of ρ_{bII} (1.313 g cm^{-3}) was in the range between ρ_{bL} and ρ_{bU} (Table 2). For the V area, the ρ_{bL} and ρ_{bU} values were equal to 1.205 and 1.468 g cm^{-3}, respectively. For this area, the mean values of both ρ_{bI} (1.368 g cm^{-3}) and ρ_{bII} (1.317 g cm^{-3}) were higher than ρ_{bL} but lower than ρ_{bU}. Therefore, density-induced impedance to root growth should not be a factor severely affecting crop production in the two sampled areas. However, other types of problems (e.g. root-soil contact or anchoring) may occur in the A area, given that $\rho_{bI} < \rho_{bL}$ was obtained in this area.

The mean K_{fs} results were at the upper limit of the ideal range of K_s values suggested by Reynolds *et al.* (2003) (18-180 mm h^{-1}) for the second sampling date in the A soil. In the other cases, the K_{fs} results were above the upper limit of the wider ideal range suggested by Topp *et al.* (1997) (0.36-360 mm h^{-1}). Thus, the sampled soils may be susceptible to near-surface droughtiness during dry years, particularly in the V area.

Assuming that an air capacity of 0.10-0.15 m^{3}m^{-3} is the minimum for adequate near-surface root aeration, then the A soil, having AC = 0.141 m^{3}m^{-3}, was well aerated. A probably moderate aeration deficit was detected for the V soil, having a mean value of AC equal to 0.08 m^{3}m^{-3}.

The PAWC of both soils was lower than 0.20 m^{3}m^{-3} but it was in the range 0.15-0.25 m^{3}m^{-3}, that is specifically required for sustained plant growth in constructed urban soils (Crauls, 1999; Reynolds *et al.*, 2002). Therefore, plant available water capacity was probably slightly lower than the optimal one for both areas.

The *FC/POR* ratio calculated for the A area (0.75) was closer to the optimal value of 0.66 than the same ratio obtained for the V area (0.83). According to this criterion, the A soil had a better balance among *FC*, *AC* and *POR* for microbial production of crop-available nitrogen as compared with the V soil (Reynolds *et al.*, 2002).

The mean values of the *S* index (0.043 for the A soil and 0.039 for the V soil) were in the range of the *S* values defining a good soil physical quality according to Dexter and Czyż (2007). Therefore, a good soil physical quality in terms of *S* results was associated with bulk density values lower than the ones denoting substantial impedance to root growth, optimal or near-optimal aeration conditions, slightly lower than optimal plant available water capacity, higher *FC/POR* ratios than the optimal one, and high to excessively high saturated soil hydraulic conductivities measured in the field.

The A soil had a better physical quality in the near-surface zone than the V soil in terms of density-induced impedance to root growth, near-surface root aeration, and balance among *FC*, *AC* and *POR*. The two areas had a similar, and probably slightly lower than optimal, quality in terms of ability to store and provide soil water that is available to crop roots. The physical quality in terms of K_{fs} was better for the A soil (near-optimal values on a sampling date) than the V one (excessively high values on both sampling dates). Therefore, the general conclusion was that a better quality was detected in the A soil than in the V one. However, conditions denoting a generally poor physical quality of the sampled soils were not detected in this investigation, although some individual parameters suggested a lower than optimal quality. Therefore, this analysis suggested that agricultural practices were not responsible of substantial soil degradation processes within the field. This result is particularly important given the particular environmental interest of the experimental area.

Both horizontal, K_{sH}, and vertical, K_{sV}, saturated hydraulic conductivity decreased with depth in the V area whereas they increased in the A area (Fig.1). The K_{sH} and K_{sV} values of the surface layer were higher in the V area than in the A one. The A area yielded higher K_{sH} and K_{sV} results than the V area at greater depths. For the V area, a relatively low vertical anisotropy (K_{sV}/K_{sH} =1.5) was detected in the surface layer. At greater depths, a more appreciable horizontal anisotropy was observed, especially at the greatest depth (K_{sH}/K_{sV} equal to 3.3 at 0.3 m and to 10.2 at 0.5 m). For the A area, only horizontal anisotropy was detected with K_{sH}/K_{sV} ratios varying between 1.7 and 3.7. Therefore, horizontal anisotropy prevailed in the sampled field and it was particularly noticeable at the greatest depth in both areas. The soil profile was less disturbed in the V area than in the A one (Table 1). Therefore, this investigation suggested that the quasi-natural tendency was that the soil hydraulic conductivity decreased appreciably with depth, developing a remarkable horizontal anisotropy at the greatest depths. Tillage and earthworm activity, that was observed only in the A area at depths ≥ 0.3 m, homogenized the soil conductivity along the profile and reduced the anisotropic character of this hydraulic property.

The percentage of the individual K_s measurements falling within the ideal range of K_s values was 42% for the narrow ideal range (18-180 mm h^{-1}) and 83% for the wide ideal range (0.36-360 mm h^{-1}). Therefore, comparison between laboratory K_s results and the wide ideal range suggested that the two soils had a near optimal soil physical quality in terms of saturated conductivity. Generally, lower conductivity results were obtained in the laboratory than in the field. This discrepancy may depend on different factors including compaction of undisturbed soil cores or swelling phenomena of laboratory saturated soil. However, the effect of the measurement procedure on the conductivity results should be investigated for the sampled field.

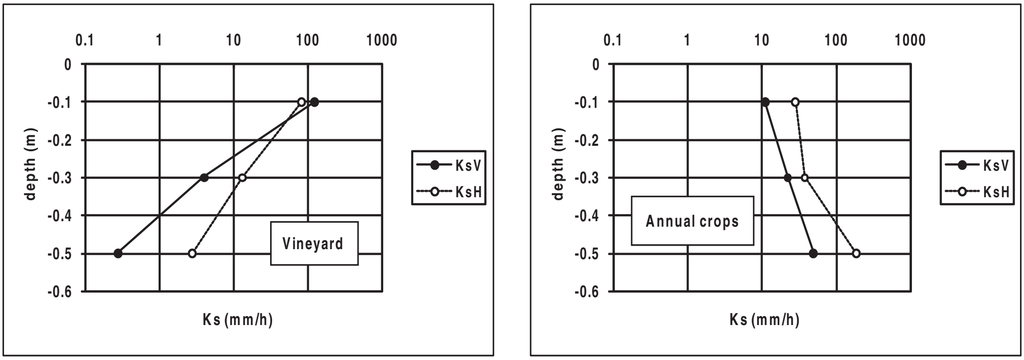

Figure 1. Saturated hydraulic conductivity measured in verticaly (K_{sV}) and horizontaly (K_{sH}) soil cores collected in the annual crops (A) and vineyard (V) areas at three depths below the soil surface.

V – Conclusions

Intensive field crop production can cause the physical quality of agricultural soils to decline. The site named *Riserva Naturale Integrale Grotta di Santa Ninfa* (GSN), in Sicily, has an important environmental interest due to the presence of a karstic stream. The main objective of this investigation was to determine soil physical quality for two contiguous, cropped areas supporting annual crops (A) and a vineyard (V), respectively, located within the GSN boundaries.

Based on available criteria, the A soil was found to have a better physical quality in the near-surface than the V soil in terms of density-induced impedance to root growth, near-surface root aeration, and balance between soil water holding capacity and aeration for microbial production of crop-available nitrogen. The two areas had a similar, and probably slightly lower than optimal, quality in terms of ability to store and provide soil water that is available to crop roots. The physical quality in terms of field saturated soil hydraulic conductivity was better for the A soil than the V one since near-optimal results were obtained in the A soil on one of the two sampling dates whereas excessively high values were obtained for the V soil on both sampling dates. In quasi-natural conditions, saturated soil hydraulic conductivity measured in the laboratory decreased appreciably with depth, developing a remarkable horizontal anisotropy at the greatest depths. Tillage and earthworm activity homogenized the soil conductivity along the profile and reduced the anisotropic character of this hydraulic property.

Conditions denoting a generally poor physical quality of the sampled soils were not detected. Therefore, the conclusion of this investigation was that agricultural practices were not responsible of substantial soil degradation processes within the field.

The ideal ranges established in the literature may not be optimal for any particular soil or field site because they are only guidelines based on broad soil types. Therefore, more relevant estimates of optimal indicator ranges may be required to improve soil physical quality evaluation.

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