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Physical properties of soil after change of use from native forest to vineyard

Propiedades físicas de suelo posterior al cambio de uso de bosque nativo a viña

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ABSTRACT

In Chile, as the soils located in valleys are cultivated, the hillsides with natural vegetation have been used by agriculture. In the Apalta valley, Santa Cruz, VI^th^ Region of Chile, some soil properties both inter-row (IR) and row planting (R) were measured in cultivated sloping vineyard (7-year establishment, 8% slope hillside), comparing the results with soil properties from a natural vegetation site (N). With this purpose, the surface hydraulic conductivity was measured, and some soil physical properties (bulk density, pore size distribution, aggregate stability, aggregate strength and air flux) and organic matter content were measured at three depths (0-10, 10-30, 30-50 cm). In the surface horizon, soil use change caused significant differences with respect to N, decreasing the organic carbon content, the very coarse porosity (>50 μm) and the aggregate stability, and increasing the bulk density and soil strength. The soil physical disturbance promoted a detriment in soil functioning, decreasing the water and air flux capacity. The higher differences were found in the IR surface, while in deep (50 cm) the changes were not significant between locations, leading to conclusion that in depth still persist soil conditions before cultivation.

RESUMEN

En Chile, debido a que los suelos ubicados en los valles se encuentran cultivados, las laderas con vegetación nativa han sido utilizadas por la agricultura. En el Valle de Apalta, Santa Cruz, VI Región de Chile, se midieron algunas propiedades físicas de suelo tanto en la entre hilera (IR) como en la hilera de plantación (R) en una viña cultivada en una ladera (7 años desde su establecimiento, 8% de pendiente), comparando los resultados con las propiedades de suelo de un sitio con vegetación nativa (N). Con este propósito, se midió la conductividad hidráulica en superficie y algunas propiedades físicas (densidad aparente, distribución de tamaño de poros, resistencia tensil, estabilidad de agregados y flujo de aire) y materia orgánica en tres profundidades (0-10, 10-30, 30-50 cm). En el horizonte superficial, el cambio de uso de suelo generó diferencias significativas con respecto al sitio N, disminuyendo el contenido de carbono orgánico, la porosidad gruesa (>50 μm) y la estabilidad de agregados, e incrementando la densidad aparente y la resistencia tensil. La perturbación física del suelo promovió un deterioro en la funcionalidad de este, disminuyendo la capacidad de flujo de agua y aire. Las mayores diferencias fueron encontradas en la superficie del sitio IR, mientras que en profundidad (50 cm) los cambios no fueron significativos entre los sitios, por lo que se concluye que aún persisten las condiciones de suelo previo a su cultivo.

Palabras clave: Cambio de uso de suelo, estabilidad de agregados, resistencia tensil, funcionalidad porosa.

INTRODUCTION

Normally, agricultural activities modify the soil structure. These modifications depend on the kind of management and time of utilization after land-use change from native vegetation (Ellies *et al*., 1993).

When a natural or non disturbed area is modified by change in use, the soil tends to show structure degradation, related to an increase of bulk density (Db) and changes in pore size distribution, affecting water/gas fluxes. Those changes can occur also as the result of natural processes, like surface water impact by rain and internal decrease of soil volume by wetting and drying cycles. Nevertheless, the highest impact has an anthropogenic origin, which promotes soil compaction and structure disruption by machinery traffic, animal traffic, and excessive ploughing (Ellies *et al*., 1993; Dörner *et al*., 2009).

With high intense soil use, total porosity and, especially, coarse porosity, tends to diminish (Ellies, 1995). In soils with native forests, initially with high amount of coarse pores, the change of use promote a decrease of macro-pores and an increase of micro-pores, and the change depends on the type of stress (Peng *et al*., 2012). As a consequence, soil structure is degraded (Broquen *et al*., 2000) and the soil functioning (related to water and air fluxes) is negatively affected (Horn and Fleige, 2009).

In a soil with a normal consolidation, without significative changes in materials through the profile, the Db increases and the coarse porosity decreases in depth (Ellies and Hartge, 1992). This tendency changes depending on the soil use; for example, by intensive farming, a high soil strength, related to soil densification, can be found at a 20 cm depth, as a result of plough pan generated by tools used at the same depth during successive seasons, while in a prairie with direct animal trampling the highest soil strength can be concentrated at 5-10 cm depth (Ellies *et al*., 2000; Kayser *et al*., 2012). The same authors have shown than in deeper horizons (below 50 cm) the soil properties are similar to the parent material, being not possible to detect differences among soil managements.

Different authors have found a decrease of soil organic matter content (OM) when a native forest is subjected to agriculture use (Six *et al*., 1998; Denef *et al*., 2004), affecting soil aggregate dynamic, decreasing the aggregate stability and increasing the risks of erosion (Ellies *et al*., 1995; Pietola, 2005). Nevertheless, Degryze *et al*. (2004), pointed out that change in soil OM content by change of soil use is important in surface horizon (0-7 cm) being non significant in depth (50 cm). By other hand, the increase of soil OM content by organic amendments improves the structural stability, total porosity, water infiltration, and water storage (Barzegar *et al*., 2002; Seguel *et al*., 2013).

Considering pore functioning, there is a close relation between saturated hydraulic conductivity (Ks) and coarse porosity (Ellies *et al*., 1997), being relevant the amount, size, continuity and stability of porous system as indicators of soil structure condition (Pagliai and Vignozzi, 2002; Horn and Fleige, 2009). Ellies *et al*. (1997) showed that Ks is more dependent on soil structure than soil texture, and coarse pores can explain a similar behavior between well-structured clay soil and sandy soil. In such a way, Ks is a good property to characterize soil structure, evaluate water aggregate stability (Ellies *et al*., 1997) and analyze compaction by the loss of coarse porosity (Dexter, 2002; Lipiec, 2004). In general terms, the higher the amount of coarse pores, the higher Ks, and the lower the aggregate stability is, the higher the variation and decrease of Ks after a prolonged water flux.

Wine is one of the most important development axes in Chile, reaching a total of 120,000 hectares planted with vines (INE, 2008). Currently, the pressure to expand arable land has led the wine industry to expand into areas with an increasing gradient slope, creating a potential risk of soil degradation. In particular, the Libertador Bernardo O'Higgins Region in Chile presents severe and very severe erosion on 90,348 ha, representing 13.8% of coastal dryland (CIREN, 2006). This is precisely the case of Apalta Valley, where the main agricultural activity relates to the production of grapevine (*Vitis vinifera* L.) in soil slopes position.

Considering the precedent background, the objective of this research was to study some soil physical properties, in order to evaluate the impact of soil use change on soil structure and functioning. A hillside with a vineyard was selected and compared with natural (original) conditions, analyzing the magnitude in change of soil properties, with special attention in porosity, soil functionality, and physical-mechanical aggregate stability.

MATERIALS AND METHODS

The study was conducted in the Apalta Valley, VI Region of Chile (34° 37' 11" S; 71° 13' 20" W), a typical agricultural production area. Because of alluvial soils are cultivated with annual crops, vineyards increase the grapevine (*V. vinifera*) surface using the hillsides, with slopes ranging between 3 to 35%. For this purpose, natural vegetation (sclerophillous forest) is removed and the new vineyard is planted (Figure 1a). The study was conducted in a seven-year-old vineyard planted on a piedmont with south west exposition (8% slope). The typical management includes about ten passes of agricultural machinery (1.8 Mg) during each season and organic amendments applied on the row planting (10 Mg of compost per year). Next to the upper position of the vineyard, a natural forest (Figure 1b) with dominance of *Peumus boldo* Mol., *Quillaja saponaria* Mol. and *Cryptocaria alba* (Mol.) Looser, among other natural species is located.

Soil Association is La Lajuela (Loamy fine, mixed, thermic, Ultic Haploxeralfs) derived from colluvial deposits on granitic materials of Chilean coastal range. The textural classes range from sandy clay loam in surface to clay in depth; the structure is characterized by subangular blocky till 50 cm and a massive condition in depth (CIREN, 1996). The climate is classified as warm-temperate, with 6 dry months, precipitation ranging between 750 – 900 mm, concentrated during win-

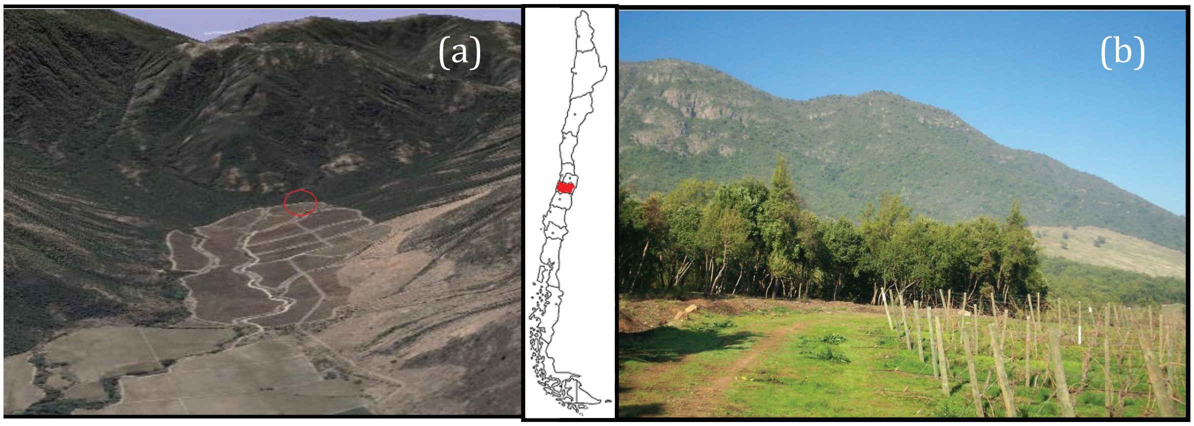

Figure 1. Location of the study site (in red circle, 1a) and detail of the vineyard and native forest (1b).

Figura 1. Ubicación del estudio (en círculo rojo, 1a) y detalle de la viña y el bosque nativo (1b).

ter time, 943 mm of potential evapotranspiration and mean annual temperature of 14.5 °C (Uribe *et al*., 2012).

Treatments and experimental design

In both: vineyard and native forest, soil morphological properties were characterized with three replicates randomly located. Based on pedogenic characterization and root abundance, three depths were selected (0-10; 10-30; 30-50 cm) to collect soil samples. In the case of the vineyard, measurements were performed in both: row (R, planting row) and inter-row (IR, under wheel track), comparing properties with a natural place (N) used as a control, where the organic horizon was removed previous to sampling. In this sense, three treatments are defined (R, IR, N) being the soil profile in an area of 1m^2 and 50 cm depth the experimental unit, considering three replicates for all measurements.

Soil properties measurements

Under laboratory conditions, disturbed soil samples (2 mm sieved, 27 samples in total) were used to determine particle density (Dr) and particle size distribution, both according to methodologies detailed in Sandoval *et al*. (2012). The organic carbon content was measured according to Nelson and Sommers (1982).

To quantify the porous system, bulk density (Db) was measured by clod method (Sandoval *et al*., 2012), and total porosity (S) was calculated with the relation S=1-(Db/Dr). Water retention curve (Sandoval *et al*., 2012) was measured in non disturbed samples collected in cylinders (6 cm diameter and 5 cm high, three replicates, 27 total cylinders). With this purpose, soil cores were subjected to 0, -6 and -30 kPa of water tension, and at -1500 kPa in disturbed samples; the last one suitably transformed to volumetric water content. Pore size distribution was derived from water retention curve according to Hartge and Horn (2009), calculating the very coarse pores (>50 µm) as the difference between the total porosity (water retention at 0 kPa) and the equilibrium at -6 kPa; the coarse pores (10-50µm) as the difference between water content at -6 and -33 kPa, and the water available pores (0.2-10µm) as the difference between water retention at -33 and -1500 kPa.

With the object of evaluating the functionality of the porous system, the unsaturated hydraulic conductivity with a tension disc infiltrometer (Perroux and White, 1988) was measured on the field at -1, -2, -4 and -6 hPa water suction. Air flux was measured with an air forced permeameter according to Peth (2004) in non disturbed samples equilibrated at -30 kPa water tension.

Finally, to evaluate the aggregate condition, water aggregate stability was measured by dry and wet sieving (Hartge and Horn, 2009) and aggregate strength was measured by direct compression test (Blazejczak *et al*., 1995) on aggregates equilibrated at -33 and -1500 kPa water tension and at air dried condition. Measurements were done in a controlled room temperature.

Statistical analysis

For each measured property, descriptive statistical analysis was used, considering average and standar deviation, the last one because reflect better the variability of the replicates. To compare soil properties between natural and disturbed areas and asses the impact of soil management, an ANOVA (α≤0.05) was performed comparing soil properties at the same depths. A Tukey test was performed when necessary with the object to determine the treatments that showed statistical differences.

RESULTS

General soil properties and porosity

The particle size distribution test defined a loam surface horizon, grading to clay loam and clay in depth (data not shown), with clay content ranging between 23 and 31% at 0-30 cm and increasing above 36% at 30-50 cm. The loam content was very stable in depth, with values between 27-35% in the entire profile. Finally, the sand content decreased from 38-42% (0-30 cm) to 27-33% (30-50 cm).

The clay content increased in depth in all sites. Nevertheless, both R and IR under 10 cm showed a higher clay content than native place (N), probably due to soil loss by erosion in the disturbed place (Ellies, 2000) or by soil compaction, decreasing the thickness of the soil (Horn and Lebert, 1994; Ellies, 1995; Ellies *et al*., 1996; Ellies, 1999). On the other hand, particle density (Dr) did not show important differences between sites, with values ranging from 2.55 to 2.66 Mg m^{-3}, expected for mineral soils (Sandoval *et al*., 2012). Only the superficial horizon (0-10 cm) of native area (N) showed a low Dr value (2.47 Mg m^{-3}) due to the high OM content. Table 1 shows the organic matter (OM) content of soil at different depths.

The N site shows high OM content in superficial horizon (10.48 %) due to falling leaves provided by native forest and their slow decomposition; among 10-30 cm the effect persists, showing a significant higher amount of OM compared with the vineyard site. As it was expected, there was an important difference between row (R) and inter row (IR) as the result of organic amendment addition on the row planting. Among 30-50 cm there is a slight increase of OM content in the disturbed site (R and IR), being slightly higher than N site. In agricultural systems, there are important losses and changes of the OM distribution into the profile, owing that tillage incorporates organic residues into the soil, favouring the microbial activity (Six *et al*., 2004). In our case, there is higher clay content in the vineyard at 30-50 cm, promoting the protection of OM in micro aggregates (Puget *et al*., 2000; Dexter, 2002) compared to the surface horizon, resulting in lower stratification ratio (SR) according to Franzluebbers (2002).

A simple and sensitive properties to asses the effect of soil use change is the bulk density (Db) because it is directly related to the total porosity. Table 2 shows the distribution in depth of both properties in the soil profile for the different treatments.

The vineyard site showed high Db values in surface horizon as a result of machinery loading. In this sense, the native site (N) represents the original condition of the soil before the change of use, with low Db in agree-

Table 2. Bulk density (Mg m^{-3}) and total porosity (%) in native site (N) and the vineyard (R, row; IR, inter-row) at three depths. Average (±SD).

Cuadro 2. Densidad aparente (Mg m^{-3}) y porosidad total (%) en el sitio nativo (N) y en la viña (R, sobre hilera; IR, entre hilera) en tres profundidades. Promedio (±SD).

Site	Depth (cm)		
	0-10	10-30	30-50
		Bulk density (Mg m^{-3})	
N	1.13 (±0.03) a	1.38 (±0.08) a	1.56 (±0.04) a
R	1.53 (±0.06) b	1.59 (±0.23) a	1.59 (±0.03) a
IR	1.67 (±0.07) c	1.60 (±0.18) a	1.56 (±0.12) a
		Porosity (%)	
N	54 (±1.1) a	47 (±3.1) a	40 (±1.7) a
R	40 (±2.6) b	39 (±8.6) a	39 (±1.5) a
IR	35 (±2.3) c	38 (±7.0) a	42 (±4.7) a

At the same depth, values followed by a different letter are significantly different (P≤0.05).

Table 1. Soil organic matter contents (%) and stratification ratio (SR) in native site (N), in the row (R), and inter-row (IR) of the vineyard at three depths. Average (±SD).

Cuadro 1. Contenido de materia orgánica del suelo (%) y razón de estratificación (SR) en el sitio nativo (N), en la hilera (R) y en la entre hilera (IR) de la viña en tres profundidades. Promedio (±SD).

Site	Depth (cm)			SR
	0-10	10-30	30-50	(OM_{0-10}/OM_{30-50})
		Organic matter content (%)		
N	10.48 (±0.20) a	5.68 (±0.09) a	5.18 (±0.04) a	2.02
R	4.75 (±0.09) b	4.62 (±0.10) b	5.44 (±0.04) b	0.87
IR	4.23 (±0.07) c	4.64 (±0.07) b	5.69 (±0.04) c	0.74

At the same depth, values followed by a different letter are significantly different (P≤0.05).

ment with high OM content. This condition is kept among 10-30 cm, but without statistical differences. Between 30-50 cm there were no differences between treatments, establishing that the impact of soil use at such depths is negligible, and the original conditions are maintained.

As a consequence of densification in the vineyard, total soil porosity decreased, especially in surface horizon, with original values of 54% to 40 and 35% in R and IR, respectively. Among 10 and 30 cm, total porosity in N site continued to being higher than the disturbed site, but without significant differences. Although the Db and the total porosity are properties easy to measure, they are not enough to characterize structure disruptions as the result of soil management. This make necessary to analyze the pore size distribution, since it relates the soil phases (air-water), as it is shown in Table 3.

In surface (0-10 cm) the R site showed a high drainage porosity (>50 µm), owing probably to the addition of organic amendments as regular management practice in the vineyard. Nonetheless, this effect is only superficial, showing a discontinuity at 10-30 cm. Above 30 cm the N site maintained a stable very coarse porosity, showing values in a moderately porous level according to Pagliai and Vignozzi (2002), and addequate to vineyard production, according to Oliver *et al*. (2013). On the other hand, the IR site showed low values of this porosity, probably affecting the soil functioning. The coarse pores (10-50 µm) ranged between 1.8 and 3.8% in the vineyard sites (R and IR) and 2.1 and 6.6% in N site, but without significant statistical differences (data not shown).

The highest amount of available water pores was found in N site (Table 3), in agreement with the expected results, owing a good structural quality. According to Yoon *et al*. (2007), at low matric tension, the water retention depends on soil structure. At higher matric tension (permanent wilting point, data not shown) water retention depend on their texture, which explain no statistical differences for this pore size. Nevertheless, disturbed sites (R and IR) showed the highest water content at -1500 kPa according to adsorption promoted by clay particles (Yoon *et al*., 2007).

Porosity function

Figure 2 shows the results of non saturated hydraulic conductivity (Kns) of soil.

The Kns (Figure 2) depends on pore water pressure, being a good indicator of porous system quality (Horn

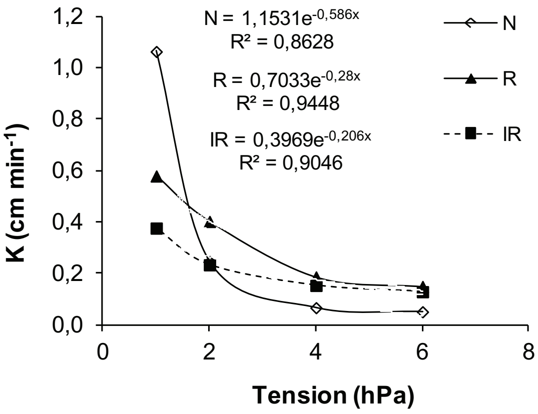

Figure 2. Non saturated hydraulic conductivity (K, cm min^{-1}) at different water tensions in native site (N) and vineyard in the row (R) and inter-row (IR). Equations showed significant adjusts (P<0.05).

Figura 2. Conductividad hidráulica no saturada (K, cm min^{-1}) a diferentes tensiones mátricas en el sitio nativo (N) y la viña, en la hilera (R) y la entre hilera (IR). Ecuaciones mostraron ajustes significativos (P<0,05).

Table 3. Pore size distribution (%) in native site (N), in the row (R), and inter-row (IR) of the vineyard at three depths. Average (±SD).

Cuadro 3. Distribución de tamaño de poros (%) en el sitio nativo (N), en la hilera (R) y en la entre hilera (IR) de la viña en tres profundidades. Promedio (±SD).

Pore size	Site	Depth (cm)		
		0-10	10-30	30-50
Very coarse	N	16.4 (±1.2) a	16.2 (±1.6) a	6.9 (±0.5) a
(>50 µm, %)	R	20.4 (±4.2) a	8.8 (±1.9) b	1.1 (±1.2) b
	IR	6.5 (±1.3) b	5.6 (±2.6) b	4.2 (±1.2) a
Available water	N	19.3 (±2.5) a	16.9 (±3.0) a	13.3 (±1.0) a
(10 – 0.2 µm, %)	R	16.6 (±2.1) a	15.5 (±3.9) a	8.5 (±2.2) b
	IR	15.6 (±2.6) a	10.9 (±5.1) a	8.7 (±2.0) b

At the same depth, values followed by a different letter are significantly different (P≤0.05).

et al., 1994). At low water tension (-1 hPa) the non disturbed site (N) showed a high capacity to conduct water through the soil, as the result of highest amount of coarse porosity and good pore continuity (Ellies *et al*., 1997; Pagliai and Vignozzi, 2002).

With higher water tensions (-4 and -6 hPa), Kns decreased in each studied site, according to decrease of water content in macropores, showing similar values of Kns. The exponential adjust in each site allowed to estimate the saturated hydraulic conductivity of 69.2, 42.2 and 23.8 cm h^{-1} for N, R and IR, respectively. To evaluate the pore continuity at higher tension, Figure 3 presents the results of air flux through the soil in samples equilibrated at water tension of -33 kPa.

The native site (N) showed the highest air flux at surface, maintaining a good condition of soil aeration until 30 cm (Figure 3). This is the result of high macroporosity and a stable soil structure, because of the soil capacity to conduct fluids, which is not only dependent of total pore volume, but more on the pore size distribution and the continuity of porous system (Ellies *et al*., 1997; Dexter, 2002).

Compared with N, the air flux in IR is low and homogeneous in the entire soil profile, according to high bulk density and low macroporosity values, as a consequence of machinery traffic. The traffic in non adequate soil water condition promotes formation of fine porosity by collapse of coarse porosity, resulting in low stable aggregates and high pore tortuosity (Hillel, 1980; Horn, 2003).

All treatments showed low values of air flux at 30-50 cm, because of the dominance of fine porosity as a consequence of clay texture and low pedological development of investigated soil.

Aggregate stability

The variation of aggregate diameter (VD) between dry and wet sieving is a good index of aggregate stability when soil is submitted to wetting and drying processes by irrigation or rain. The higher the dispersion by water, the higher the VD as instability index. Table 4 resumes the result of this property.

In a well structured soil, the pore system into the individual aggregate is complex, while in a degraded soil there is a homogenization of components by compaction, resulting in a reduction of amount and stability of individual aggregates when natural ecosystems are converted to agriculture (Six *et al*., 2000).

At the soil surface in the disturbed area (R and IR) the impact of intensive agriculture is demonstrated by a low water stability of aggregates (higher VD values). As OM decreases by agricultural activity, the humectability increases in the contact points of soil particles (Ellies *et al*., 2005). As a consequence, aggregates are dispersed by water during wetting events and the VD is higher.

At 10-30 cm, both R and IR show lower values of VD (higher stability) compared to surface horizons. This could be due to the alteration by land use change which is not intense at deeper horizons, and the OM that is protected by soil. Nevertheless, N place continued showing the highest stability, but without statistical difference with disturbed area.

At deeper horizons (30-50 cm), the VD is high in all treatments, characterized by weak aggregates, as a consequence of low pedological development and the absence of biological activity. Finally, Table 5 shows the results of tensile aggregate strength at three matric tension.

As was expected, there is an increase of aggregate strength when the soil is drying. Because of the plowing being performed in wet soil conditions, it was important to measure the mechanical strength at high water contents (Munkholm *et al*., 2002b). In this condition (33 kPa water tension) aggregates are weaker than in

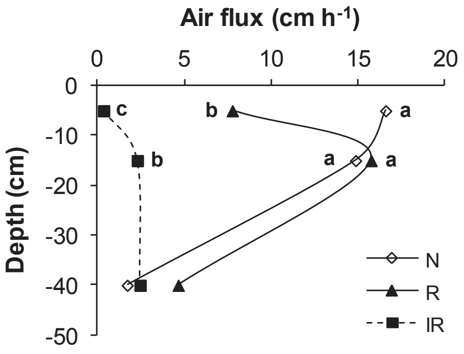

Figure 3. Air flux in native site (N) and vineyard in the row (R) and inter-row (IR) at three depths.

Figura 3. Flujo de aire en el sitio nativo (N) y la viña en la hilera (R) y entre hilera (IR) en tres profundidades.

Table 4. Aggregate stability (VD, %) in native place (N) and disturbed place in the row (R) and inter-row (IR) evaluated at three depths. Average (±SD).

Cuadro 4. Estabilidad de agregados (VD, %) en el sitio nativo (N) y el sitio disturbado en la hilera (R) y la entre hilera (IR) evaluada en tres profundidades. Promedio (±SD).

Place	Depth (cm)		
	0-10	10-30	30-50
	VD value (%)		
N	3 (± 5) a	25 (± 9) a	93 (±4) a
R	78 (±15) b	59 (±37) a	100 (±1) b
IR	86 (± 7) b	54 (±41) a	98 (±3) ab

At the same depth, values followed by a different letter are significantly different (P≤0.05).

Table 5. Aggregate strength (kPa) in native place (N) and disturbed place in the row (R) and inter-row (IR) at three matric tension and three depths. Average (±SD).

Cuadro 5. Resistencia tensil de agregados (kPa) en el sitio native (N) y el sitio disturbado en la hilera (R) y la entre hilera (IR) a tres tensiones mátricas y tres profundidades. Promedio (±SD).

Place	Tension (kPa)	Depth (cm)		
		0-10	10-30	30-50
		Aggregate strength (kPa)		
N	33	27,1 (± 5,8) ab	18,7 (± 9,3) a	13,2 (± 4,4) a
R		22,6 (± 9,9) a	14,8 (± 4,8) a	12,7 (± 3,6) a
IR		31,1 (±15,4) b	16,7 (± 8,2) a	20,0 (± 8,1) b
N	1500	36,3 (± 15,7) a	32,6 (± 12,9) a	50,0 (± 22,9) a
R		32,8 (± 12,4) a	70,6 (± 39,5) b	60,8 (± 36,7) a
IR		65,5 (± 34,4) b	53,2 (± 18,4) b	106,0 (± 79,9) b
N	Air dry	115,3 (± 43,6) a	151,4 (± 41,2) a	264,7 (± 77,3) a
R		348,6 (±185,9) b	283,1 (±153,1) b	354,0 (±248,5) a
IR		435,3 (±262,9) b	273,7 (±141,8) b	422,7 (±331,0) a

At the same depth and water tension, values followed by a different letter are significantly different (P≤0.05).

dry conditions, and the higher values are in the surface, confirming the importance of OM on stability when the soil is wet. When the soil is evaluated in driest condition (-1500 kPa and air dried) the strength is the result of internal tension which sort soil particles closer to other ones by water meniscus contraction (Horn *et al*., 1994), process favoured by the increase of clay content in depth. In the case of disturbed place (R and IR) the higher strength in surface at low water tension is favored by high Db (Munkholm *et al*., 2002b). In both cases (high OM or high Db) there are higher contact points that promote the higher strength.

DISCUSSION

The land-use change has diminished the OM at surface, since plowing and deforestation are the main reasons of soil OM loss when natural ecosystems are used in agriculture (Six *et al*., 2000; Degryze *et al*., 2004). The low OM content in the disturbed site could be related also to erosion, because of the carry out of mineral particles associated with organic compounds (Rodríguez *et al*., 2000) and a lower protection of aggregates as a result of structural deterioration (Six *et al*., 2000).

In non disturbed sites, the strength is in equilibrium with the weight of the different horizons, increasing the Db in depth (Ellies and Hartge, 1992). In this sense, the N site showed the expected tendency. Nonetheless, in the disturbed place there is a densification in superficial horizons by agricultural traffic, affecting the normal consolidation (Horn *et al*., 2007), especially under the wheel track (IR site). The lowest values of Db are in the superficial horizon of N place, in view of the absence of anthropogenic activity and high OM content (Dexter, 2002; Barzegar *et al*., 2002). The traffic of agricultural machinery increases the Db to critical values in the IR (Oliver *et al*., 2013), and the organic amendments applied in the R site are not enough to ameliorate the impact of intense soil use. There is a decrease of Db at 10-30 cm in IR, because in compacted soils the external loads are transmitted horizontally, without reaching deeper horizons (Ellies *et al*., 1996; Usowicz and Lipiec, 2009).

Probably the soil compaction in the sites with *V. vinifera* is in equilibrium with the bearing capacity of soil, and new substantial compaction in the soil is not expected (McPhee *et al*., 2015). However, the erosion processes should be relevant, in view of lack of vegetal cover in the inter-row (IR), especially below the tire road (Jordán *et al*., 2010). At 30-50 cm, the Db does not present significant differences between places; the external loads are residuals in depth, and the Db values reflect the original condition before the soil use change (Ellies *et al*., 1996; Ellies, 1999).

The high porosity in the N place is a consequence of macropores produced by biological activity, promoted by foliage fall over, and the mechanical effect of roots and their organic exudates (Traoré *et al*., 2000) which promotes a good structural development. The soil-use change has a negative impact on these factors, and the contribution of machinery traffic promotes a collapse of coarse porosity, decreasing the total porosity (Ellies, 1995; Horn, 2003).

The structure formation by swelling and shrinkage promotes the heterogeneity in pore size distribution (Horn *et al*., 1994). The N site has coarse porosity (>50 μm) enough to drain the excessive water from the soil, reestablishing an adequate air condition to the root system. A good equilibrium between air/water relations in the porous system is observed down until 30 cm in the non disturbed place, contrary to IR, where coarse porosity is very low, especially in superficial horizon, due of external loads by traffic. This situation was observed by several authors in a wide kind of soils as an immediate consequence of soil-use change (Ellies, 1995; Pagliai and Vignozzi, 2002; Lipiec, 2004).

The higher intensity of external loads promoted by agricultural activity explains the lower values of hydraulic conductivity in R and IR sites evaluated at -1 hPa. At very low water tension (-1 hPa) the IR has the lower Kns as result of the collapse of coarse pores by compaction and the increase of pore tortuosity (Horn *et al*., 1994; Lipiec, 2004). In other words, with the deterioration of structure the soil has a lower functionality compared with natural conditions (Ellies *et al*., 1997; Reynolds *et al*., 2009). This remarks the importance of organic amendments (Abiven *et al*., 2009) and the necessity of using inter-row crops to protect the soil (Seguel *et al*., 2013). The relation between infiltration and runoff, like other important processes in the soil, depends on K (Arnaez *et al*., 2007). In this sense, the low saturated K expected in the IR place, and the absence of vegetal cover, could promote the runoff and soil erosion by intense precipitations.

Dörner *et al*. (2009) demonstrated that soil compaction reduces the capability of air to flow in Andisols. The low air flow in the IR is a consequence of pore collapse, promoting discontinuity in the pore system. The reduction of soil functionality in the IR, reflected by low transmission of air and water, is proof of the increment of pore tortuosity (Lipiec, 2004). The change in the air flux capacity in depth was related to bulk density change, with a significant correlation ($R^2 = 0.83$, $\alpha<0.05$) between these variables (data not shown).

The high aggregate stability in superficial horizon of N site denotes a minimal perturbation when the soil is wetted. The large OM content promotes this stability as the effect of slow humectability of aggregates, generating organic-mineral bonds with soil particles and preventing the dispersive effect of water (Ellies *et al*., 1995; Chenu *et al*., 2000; Dexter, 2002).

Dexter (1988) defines the soil structure as the special heterogeneity of their components and properties. In our study, the aggregate deterioration by agriculture has leaded to the homogenization of soil (Horn *et al*., 1994), especially in the IR place. This structural deterioration favors the action of water on soil surface, promoting the dispersion and loss of soil particles and, in some cases, generating superficial crusts (Ellies *et al*., 2005). The gradient and length of the slope and the absence of a cover on IR surface are components that must be considered in this process (Ellies, 2000; Blanco and Lal, 2008).

In agreement with other authors (Munkholm *et al*., 2002a; Seguel and Horn, 2006), there is an increase of aggregate strength when the soil is drying. In the IR, soil compaction caused a high mechanical strength, reflecting aggregate strength on surface horizon at any water tension. In one way, this is a favorable characteristic, considering that IR has to support all the traffic loads by machinery (McPhee *et al*., 2015).

In the non disturbed place (N) the strength in the superficial horizon at -33 kPa water pressure is related to high OM content (10.48%) because of the organic-mineral bonds that obtain stronger particles joints (Horn *et al*., 1994) and prevent a fast wetability (Ellies *et al*., 2005), decreasing the dispersive effect of water on contact points.

In surface, when the soil is in air-dry condition, the mechanical strength in N place increased 4.3 times compared with strength at -33 kPa, while in disturbed place it increased 15.4 and 14.0 times in R and IR respectively. This means that N place shows a good stability in wet conditions and good friability when is dry (Utomo and Dexter, 1981; Dexter, 2002), without falling into an excessive mechanical strength and maintaining good conditions to root development. Stock and Downes (2008) show that the difference of the aggregate strength evaluated in dry and wet conditions is lower as the structure gets better, as in the case of N site in this study, being a good indicator of structural quality and functioning of the strength properties evaluated at different matric tensions (Fuentes *et al*., 2013).

CONCLUSIONS

The soil-use change, from non disturbed natural vegetation to grapevine crop and associated managements, in a hillside 8% slope gradient, modified their properties, decreasing the organic matter content, hydraulic conductivity, air flow, aggregate stability, and macroporosity, and increasing the bulk density and mechanical strength.

The negative consequences of the soil degradation is a direct consequence of a reduced soil functioning when the original favorable characteristics to water flow and storage, air flow, aeration, soil friability, and root exploration are lost.

These unfavorable changes are concentrated mainly on surface horizon, and with higher intensity in the inter row. In depth (50 cm) the disturbed soil maintained the original characteristic of natural place. From a morphological and functional perspective, the cropped soil has suffered a deterioration of properties, loosening important characteristic from the original soil.

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