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THE EFFECT OF COMPACTION ON WATER RETENTION IN THE VINEYARD'S ROOT ZONE

Markela KOZAITI, Sofia KOSTOPOULOU*

AUTH, Faculty of Agriculture, Soil Science Lab., Thessaloniki, Greece
*Corresponding author: skostop@agro.auth.gr

ABSTRACT

In vineyards, frequent machinery traffic between the vine rows results in spatial and temporal changes in soil structure that affect the water retention properties in the root zone. Compaction effects on the soil water characteristic curve in the root zone were evaluated in three vineyards of different soil types (a Cl, a ClL, and a SiL with increased sand percentage). Soil cores were collected from a) the tilled soil on the vine-row and b) the compacted soil of ruts produced by machinery traffic within the inter-row distance. Sampling was carried out at two depths (0-15cm and 15-30cm) and at two time intervals, the first in spring when agricultural vehicles had accomplished 6-8 passes and the second in autumn, after ca 20 passes. The results of the first sampling in the beginning of the cultivation period revealed that compaction increased soil bulk density of the three vineyards in both depths. Drainage pores collapsed to smaller ones while plant available water and textural porosity increased. The effect of compaction was more pronounced on the surface (0-15 cm) of the more fine textured soils. In autumn, at the end of the cultivation period, it was found that the soil water retention characteristics in the vineyards root zone were not substantially further affected by machinery traffic. We concluded that machinery traffic impact on the studied properties was intense in spring when the soil in vineyards was loose from tillage before the cultivation period and had temporally increased moisture content which results in decreased strength.

Keywords: *pore size distribution, bulk density, available water, textural porosity.*

INTRODUCTION

Soil compaction in cultivated soil is mainly caused by the overuse of machinery (Saffih-Hdadi et al., 2009). In vineyards, soil tillage, chemical applications and grape harvesting lead to frequent tractor traffic. Traditional cultivation may require up to 22 passes per year, in highly mechanized viticulture (Ferrero et al., 2005). Tractors circulate in the same inter-row, which can be either between neighboring inter-rows or use all the inter-rows of the parcel (Lagacherie et al., 2006). According to Ferrero et al. (2005), the circulation of vehicles is in permanent transit corridors (ruts) located within the inter-row distance, which is usually varying from 2.0 to 2.7m. Tractor size and slope determine the pressure exerted on the contact surface of soil. Because of the width of tractors it is often that ruts are located close to the vine row and consequently may affect soil conditions within the root zone. Soil deformation induced by mechanical stress leads to alterations in soil structure and thus modification in availability and storage of water, changes in pore continuity, tortuosity and finally in soil functions (Siczek et al., 2015). There are several soil properties that can be studied in order to determine soil compaction. For example, Saffih-Hdadi et al. (2009) suggest texture, structure and hydric state of soil. Soil compaction induced by tractor traffic increased bulk density (BD) in tilled vineyards and particularly in the portion of soil affected by the passage of tractor wheels as wheel tracks in vineyards have fixed locations (Biddoccu et al., 2016; Van Dijck and Van Asch, 2002). Moreover, significant increase in BD after traffic operations may be due to degradation of macro-aggregates into micro-aggregates, preferential loss of larger pores, and rearrangement of the micro-aggregates and primary soil particles. These changes that are more pronounced at the top soil and decrease with depth can also lead to a decrease in total porosity (TP) (Barik et al., 2014). Soil compaction reduces macro-porosity and restricts aeration and the gaseous movement system in soil–plant–air continuum. This preferential loss of larger pores is probable to change important soil hydrological functions related to water infiltration and water holding capacity and drainage. TP decreases with traffic operation and with depth. Significantly, lower TP after traffic operation is possibly due to the weight and stress effects of heavy traffic vehicles and machinery, which resulted in soil structural deterioration (Barik et al., 2014).

Soil compaction alters pore size distribution (PSD) and affects adversely soil physical fertility by impending the storage and supply of water and nutrients (Saffih-Hdadi et al., 2009). According to Głąb (2014), soil compaction influenced the soil water retention characteristics in the high matric potential range, which decreased the volume of large pores and led to an increase in volume of some fractions of smaller pores, resulting in a higher plant available water capacity. Moreover, Otalvaro et al. (2016) showed that there was a reduction of the large pores, whereas the small pores remained constant, in compacted soils. Finally, De Lima et al. (2017) suggest that reduction in soil porosity due to compaction can cause variation in pore size and in the degree of saturation, changing water retention energy. The aim of this work was to evaluate compaction effects of the circulation of machinery in two times within a cultivation period (vine blossom – May and post-harvest – October) on the soil water characteristic curve in the root zone in three vineyards of different soil texture, a Cl, a ClL and a SiL with increased sand percentage.

MATERIALS AND METHODS

Three conventionally cultivated vineyards, from the region of Amyntaion, Greece (40°41′20"N, 21°40′39"E), which varied in terms of texture, were selected to be studied. In all three vineyards similar cultivation practices were followed. The first vineyard was clayey (Cl) and planted with Syrah, the second clayey loam (ClL) with Chardonnay the third silty loam (SiL) with an increased percentage of sand and had the cultivar Montepulcianno. Some soil properties are presented in Table 1. The three vineyards are named after their soil texture.

Table 1. Soil properties of the three vineyards.

Soil type	**Cl**		**ClL**		**SiL**	
Depth (cm)	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**
Sand (%)[1]	18.25	22.80	25.25	24.20	41.20	34.30
Silt (%)[1]	45.95	32.70	45.95	46.15	38.60	47.30
Clay (%)[1]	31.45	40.20	26.50	28.10	12.55	12.60
Organic Matter (%)[2]	1.75	1.01	1.11	1.19	1.26	0.81
pH[3]	8.13	8.03	8.16	8.12	7.01	7.44
EC (μS/cm)[4]	747	554	733	461	403	370
$CaCO_3$ (%)[5]	6.14	9.65	42.28	41.91	0.00	0.00

[1] Pipet Method (Day, 1965), [2] Liquid Oxidation (Nelson and Sommers, 1982) [3] Soil-water suspension of 1: 2.5 (McLean, 1982) [4] Saturation Paste, [5] Electronic Limestone Calculator

The vines were planted in rows in a distance of 1.20m between them. The distance between the rows ranged from 2.30 to 2.50m and was used as the tractor's passage corridors (ruts). The first sampling took place in May 2016, when the vine was blossomed and after the vehicles had carried out 5-8 passages per rut from the beginning of the growing season. The second sampling was performed after the harvest, in October 2016 and when the vehicles had passed 15-20 times from each rut. Three undisturbed and disturbed soil samples a) uncompressed (U), between the stumps on the planting line and b) compressed (C) were obtained from each vineyard in the runway between the rows. The sampling was carried out at two depths: surface (0-15cm, depth 1) and sub-surface (15-30cm, depth 2). In all, the study comprised 24 treatments (3 vineyards*2 compression levels*2 depths*2 time intervals) with three repetitions.

The characteristic curve for soil water retention (WRC) was constructed from pairs of humidity values (h) and soil moisture (θ). Undisturbed soil cores of 4 cm in height and 5.5 cm in diameter were wetted by suction to saturation and then equilibrated in a series of suctions hj = 0, 2, 4, 10, 30, 100, 300, 600 and 1500KPa using the sand table and the high pressure ceramic plate (Klute, 1986). Total porosity was determined from the saturated water content. Pore size distribution of soil samples was determined from the WRC using the capillary rise equation for the following classes of pores with equivalent diameter >150, 150-75, 75-30, 30-10, 10-3, 3-1, 1-0.5, 0.5-0.2, 0.2-0.02 and <0.02μm and expressed as a percentage (%) of the total porosity. The same samples were used to determine BD from dry soil volume and weight. For the quantification of compression effects on the structural characteristics of pores, total porosity was divided in two major classes: the structural or inter-aggregate pores with equivalent diameter >10 μm, which are defined by the position, orientation, and shape of aggregates, and drain at matric potentials between saturation and 30 KPa; and the textural or intra-aggregate pores, which are defined by the spatial distribution of primary soil particles and correspond to the remaining porosity when structural pores are excluded (Leij et al. 2002; Aschonitis et al., 2012). To assess the compression effects on the soil hydraulic characteristics, we evaluated the alterations of drainage pores (or air-filled porosity) with equivalent diameter >30μm and of the available water to the plants (AW) which is the water retained at matric potentials between 10 and 1500 KPa. Statistical analysis was done by ANOVA with a single factor at a significance level of 0.05.

RESULTS AND DISCUSSION

In Table 2 are shown the changes of the studied properties of the different treatments in the two time periods (blooming and post-harvest). In May, in the two fine textured vineyards (Cl and ClL) vehicle circulation increased significantly the BD, at both depths in comparison to the corresponding uncompressed samples while in the (SiL soil) compression significantly increased the bulk density only at the first depth (Table 2). Van Dijck and van Asch (2002) report that the circulation of vehicles in vineyards results in increased values of BD of both the surface soil and the subsoil due to the load exerted by the wheel. The same results between compressed and uncompressed soil samples were obtained, in October.

In the Cl vineyard, the plant available water increased after compression in most cases but the difference was significant, only in October, in both depths (Table 2). On the contrary, in the other two vineyards compaction has positively influenced available water in May and statistically significant difference is only observed between compressed and uncompressed samples in the second depth. This must be due to the collapse of bigger pores to smaller ones, after compression (Fig. 1). In all treatments, AW had a tendency to increase with depth only in the uncompressed samples. Contradictory results about the effect of compression on AW have been found by others as Barik et al. (2014), which report an increase in the volume of soil moisture after compression or Lipiec et al. (2012) who observed a decrease in available water after compaction.

Total porosity of the soil is distinguished in structural (pores> 9μm, between the aggregates) and textural (pores <9μm, within the aggregates) (Leij et al., 2002). Compression increased significantly textural porosity in all soil types at both depths and sampling times but the change was more pronounced in the surface soil (Table 2). Also, vehicle circulation decreased significantly drainage pores (>30μm) in all cases but the effect was dramatically negative in the SiL soil in May (Table 2). Moreover, the largest percentage of larger drainage pores is found in the first depth of uncompressed soil, while a statistically significant reduction of these pores was detected in second depth.

Table 2. Bulk density (BD), available water (AW) and percentage of a) drainage (>30μm) and b) textural (<10μm) pores of the first (May) and second sampling (October) for compressed (C) and uncompressed (U) soil samples of the first (1) and second (2) depth

Soil Type/ Treatment		**BD (g cm^{-3})**		**AW (m^3 m^{-3})**		**Drainage Pores >30μm**		**Textural Pores <10μm**	
		May	**Oct**	**May**	**Oct**	**May**	**Oct**	**May**	**Oct**
Cl	**C1**	1.34b A	1.24b A	0.321ab A	0.359c A	11.27a A	12.62b A	84.13b A	82.56c A
	U1	1.03a A	1.08a A	0.297a A	0.292a A	37.17b A	38.06d A	58.32a A	55.70a A
	C2	1.33b A	1.40b A	0.344bc B	0.317b A	12.70a B	3.69a A	82.12b A	91.62d A
	U2	1.15a A	1.10a A	0.374c B	0.299a A	28.36ab A	29.47c A	67.53ab A	63.86b A
ClL	**C1**	1.39b A	1.44b A	0.308a A	0.324a A	15.19a A	12.87a A	78.15c A	78.51d A
	U1	1.08a A	1.18a A	0.326ab A	0.329ab A	42.70c A	35.39d A	50.89a A	56.87a A
	C2	1.33b A	1.43b A	0.386c A	0.337ab A	10.11a A	21.18b B	83.05c B	71.73c A
	U2	1.18a A	1.25a A	0.347b A	0.354b A	24.05b A	28.54c A	70.06b A	64.86b A
SiL	**C1**	1.60b A	1.44b B	0.397ab B	0.317a A	3.92a A	21.27a B	78.83c B	58.13b A
	U1	1.21a A	1.03a A	0.375a A	0.381b A	32.88c A	38.25b A	48.34a A	46.60a A
	C2	1.46b A	1.44b A	0.428b A	0.381b A	6.16a A	12.28a A	68.05bc A	68.24c A
	U2	1.49b A	1.38b A	0.370a A	0.399b A	23.16b A	16.67a A	65.01b A	62.13bc A

*Significant differences between treatments (lowercase letters) and between the two time periods (capital letters).

No significant differences were found between the first and second sampling for the BD of all treatments in the two vineyards with fine texture. Only in the surface compressed soil of SiL vineyard there was a statistically important difference in the two time periods studied. The AW changed (increased) significantly only in the second depth of compressed treatment of the clayey soil and in the first depth of compressed treatment in the coarsest vineyard. In this treatment also changed the percentage of larger pores (>30μm), which increased post-harvest. This could be happening because the soil had reached the highest level of compaction, related to the weight of the tractors, during the cultivation period. According to Barik et al. (2014), the impact of traffic on compaction is greater under loose soil conditions.

Figure 1 presents the PSD of soil of the three vineyards between the deferent treatments for the two periods. We observe generally that the circulation of vehicles ends up in the reduction of macro-porosity and an increase of pores of smaller diameter. Liepig et al. (2012) also note the reduction of volume of larger pores, > 1–3 μm in surface and subsoil with increasing soil compaction. The reduction of the percentage of larger pores is more pronounced in May, probably due to the looser conditions mentioned above.

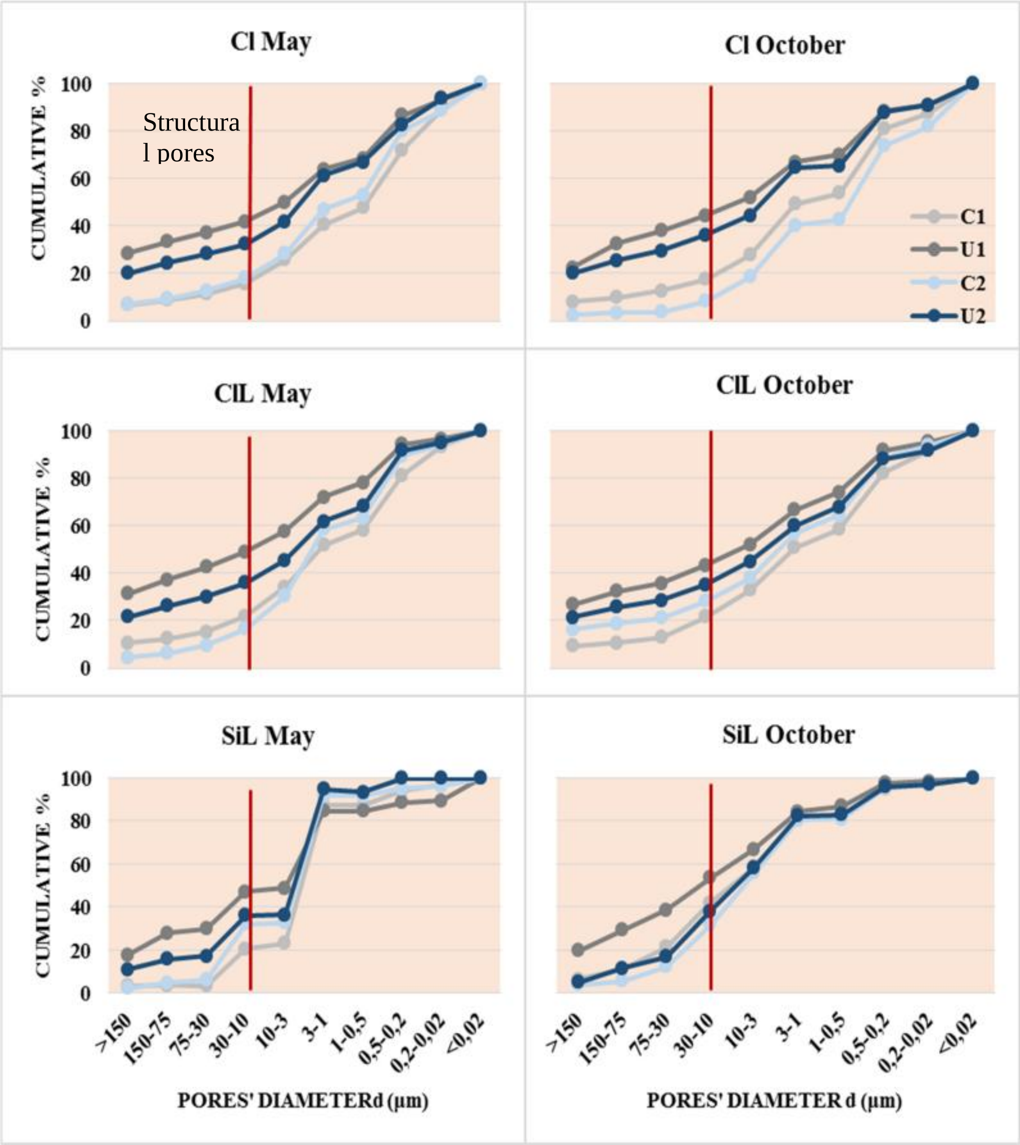

Figure 1. Pore Size Distribution (PSD) for compressed (C) and uncompressed (U) soil samples of the first (1) and second (2) depth.

CONCLUSIONS

Compaction changed the physical properties of the vineyards root zone by increasing the BD in the surface (0-15 cm) and sub-surface (15-30 cm) depth. In addition, it shifted the pore size distribution in both periods towards the predomination of pores of smaller sizes as drainage pores collapsed to smaller ones. This fact resulted in increased textural porosity and water availability. At the end of the cultivation period, the studied properties in the vineyards root zone were not substantially further affected by machinery traffic. Soil texture affected the degree of the impact compression on BD and WRC.

From the above it is concluded, that soil compaction-due to vehicle circulation in vineyards is intense in spring when the soil is loose from tillage before the beginning of the cultivation period and has temporally increased moisture content, which results in decreased strength.

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