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# Soil management effect on soil properties in traditional and mechanized vineyards under a semiarid Mediterranean environment

Sakine Ozpinar*, Ali Ozpinar, Anıl Cay

*Canakkale Onsekiz Mart University, Agriculture Faculty, 17020 Canakkale, Turkey*

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ABSTRACT

The aim of this study was to investigate the effects of short-term tillage on soil bulk density (BD), penetration resistance (PR), soil temperature (ST), electrical conductivity (EC), pH and oxygen diffusion rate (ODR) in both the topsoil and subsoil of vineyards in an area with the same soil type in Bozcaada. Mechanized tillage practices consisting of using tractor-driven rotary tiller (TDR) and field cultivator (TDC) were tested against hand driven rotary tiller (HDR) in two vineyards (wired-wide row spacing) for two growing periods. These practices involved mechanical weeding by frequent tilling and cultivating in late winter and early spring, and rotary-tilling in early summer in rainfed vineyard soils. The BD was sampled six times in two years of growing period for each tillage at 20 cm intervals between 0–60 cm in two row positions (between and in-row) while PR, ST and ODR were at the same depths of BD in the second growing period. BD in both TDR and HDR showed similarity in terms of soil depths and row positions in two growing periods, but it is lower in TDC. The highest values of the PR (1.65–2.61 MPa) were found below the depth of tilling (20 cm) regardless of tillage systems. PR was higher under HDR at subsoil in between-row than in in-row compared to TDR and TDC. However, TDC had the lowest PR in both between and in-row, especially at the subsoil, compared to HDR and TDR. The differences in BD and PR with respect to row position and soil depth were more pronounced in both TDR and HDR than in TDC. ODR was higher at topsoil than subsoil in both row positions for three tillage systems, but the highest ODR was in TDC throughout the soil profile.

## 1. Introduction

There are over 7.5 million hectare of vineyards worldwide according to the International Organisation of Vine and Wine (OIV, 2017). Most of the vineyards are located in the semiarid Mediterranean regions, where vineyard cultivation is an important economic activity (Zdruli et al., 2014). The quality of the grapes grown in these vineyards depends on climate, crop management, soil properties and cultural practices such as tillage, protection and others. Soil temperature is one of the most important environmental regulations of numerous physical and chemical processes in soil which affects plant roots and shoots growth (Abu-Hamdeh, 2000). Soil temperature is considerably modified by soil tillage practices, which may change penetration resistance, bulk density and associated porosity and water content affecting soil thermal properties or surface roughness influencing the reflection of solar energy (Abu-Hamdeh and Reeder, 2000). Soil aeration is another important physical property of the soil which is very dynamic and varies substantially with a range of factors, in particular, with water content and bulk density (Bhandral et al., 2007). Several authors have reported that insufficient soil air (oxygen) may limit the development of plant root system and growth on compacted soils (e.g., Letey et al., 1962; McArtney and Ferree, 1999; Czyź, 2004; Watson and Kelsey, 2006). The availability of oxygen to plant roots depends not only on its concentration in soil air, but also on soil physical properties and conditions around the roots that are strongly influenced by tillage practices. The ability of the soil to transmit oxygen to plant roots can be measured by the oxygen diffusion rate (ODR) (Gliński and Stępniewski, 1985; Czyź, 2004). The ODR of soils has been proposed by several studies as a good index of soil aeration (Letey et al., 1964; Stolzy and Letey, 1964; Gliński and Stępniewski, 1985; Flowers and Lal, 1998; McArtney and Ferree, 1999; Khan et al., 2000; Czyź, 2004; Watson and Kelsey, 2006).

In vineyards, the cultural practices such as tillage can be performed more efficiently by machine than by hand, using machines not only complete practices at the appropriate time, but also often reduces production costs, particularly in labour. In order for the cultural practices to be carried out by machinery, the vineyards must be designed in accordance with the operations of the machinery. However, in

* Corresponding author.
*E-mail address:* sozpinar@comu.edu.tr (S. Ozpinar).

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Bozcaada Island, which is under semiarid Mediterranean climate, it is not possible to cultivate mechanically the current traditional narrow rows of vineyards and these traditional vineyards must be designed appropriately for mechanization. Therefore, the traditional vineyard practices such as planting in narrow-row and using goble-type vineyards have been abandoned and replaced by wide-rows with wired-frame support. In most vine-growing areas, herbicide application in vineyard rows is used due to its high degree of efficiency and relative low cost of weed control. Tillage is another popular method to control weed without using herbicide, but is more labour intensive (Ferrero et al., 2005). Compared to herbicide weed control, tillage has been shown to decrease the presence of grapevine roots in the topsoil (Smart et al., 2006). In contrast, Centinari et al. (2016) reported that tillage did not reduce root growth at the same soil depth. The tillage and herbicide applications under wet soil conditions are very frequent for vineyards (Coulouma et al., 2006; Lagacherie et al., 2006). Growers mainly apply shallow tillage to avoid weed competition for water at 15–20 cm depth where rotary tiller is one of the most commonly used machinery. Tillage application is also repeated after each significant rainfall to break down the surface crusts. However, under mechanized vineyards, the soil is compacted by the load of the tractor and the coupled machinery in both tillage and herbicide applications. The load produced by wheel tractor in vineyards have permanent locations within the between-row distance varying usually from 2.0 to 2.7 m (Van Dijck and Van Asch, 2002). Under semiarid Mediterranean vineyards, equipment such as field cultivator, rotary tiller and disc harrow are often used to till the topsoil and to lose this soil depth without inversion. Many studies have reported its effect on crop yield (e.g., Jorajuria et al., 1997) and cultivation costs (Bailey et al., 1995), but few studies are available on the effect of vineyard cultivation on soil properties (Van Dijck and Van Asch, 2002; Ferrero et al., 2005; Coulouma et al., 2006), particularly the effect of soil compaction on aeration after changing from traditional to mechanized vineyard systems. Furthermore, limited information is available on the effects of shallow tillage system versus to traditional tillage on different soil properties.

Therefore, the objective of this study was to experimentally evaluate the short-term impact of tractor-driven rotary tiller and field cultivator tillage versus to traditional hand-driven rotary tiller on properties of vineyard soils in semiarid Mediterranean conditions.

## 2. Materials and methods

### 2.1. Study area

The study area is located in the Bozcaada (*Tenedos*) island (coordinates 39°49′19″N, 26°1′59″E at 18 m above sea level with a gentle slope and south/southwest-facing aspect) in the North Aegean Sea (northwest Turkey) where 20 km southwest of Dardanelles (*Canakkale Bogazi*). Bozcaada is the third biggest island of Turkey with an area of 42 $km^2$. Vineyards are the main land use in the island with a long tradition for vineyard cultivation. Island vineyards were not irrigated and were traditionally grown in narrow-row cultivated manually by men or by horse power, without using tractor, due to narrow passage for tractor traffic. Since the last decade, the traditional narrow-row systems were abandoned and vineyards planted in wide rows with wire frame were generally preferred. The climate in the area is typical semiarid Mediterranean with dry, hot summers and moist winters. Mean annual temperature is 15 °C with the mean maximum in July (25.1 °C) and minimum in January (6.2 °C). Mean annual rainfall is 526 mm with a principal maximum occurring in winter (from December to March): 42% of the annual total precipitation) and a secondary maximum in spring (from April to June: 22% of the annual total precipitation) (Fig. 1). The total amount of rainfall from October to April was 469 mm. Summers are dry, especially July (0 mm) and August (1.6 mm) over mean of two experimental years (Fig. 1). Table 1 shows main characteristics (organic matter (OM), pH, calcium carbonate ($CaCO_3$), electric conductivity (EC) and texture) of the topsoil and subsoil layer, collected before the experiment was performed. The most notable characteristics are low organic matter content, 0.60% and 0.47% in both topsoil and subsoil, respectively. There is relatively high sand (50–2000 μm) content, averaging about 56% in all experimental vineyards, while the content of clay (< 2 μm) and silt (2–50 μm) are around 22% (Table 2). The pH and electrical conductivity are 7.9 and 0.64 mS $m^{-1}$ at the 0–30 cm, respectively, which represents the tillage depth. The calcium carbonate ($CaCO_3$) content is 7.8%.

### 2.2. Experimental design

The study was carried out in a 3-year-old mechanized vineyard (new) in wide row system, where land levelling practices were carried out before vineyard establishment and two 30-year-old vineyards, as documented by the owner. One of them cultivated by hand with narrow-row, and the other was modified to adapt it to facilitate mechanization operations removing one vineyard row. The experimental vineyards were close to each other on neighbouring fields (within 2 km) located on the southwest of island. The main variety of grape is Cavusuzumu which is grown with a density of 2269 and 4538 plants $ha^{-1}$ in both mechanized and hand-cultivated vineyard, respectively. Alternative management practices in a mechanized vineyard (vine spacing is 1.3 m in rows and 3.4 m between rows) were tested during 2 years (2014–2015 and 2015–2016) against the traditional tillage. Traditional tillage, known as goble-type narrow row spacing, commonly used in the island (vine spacing is 1.3 m in rows, 1.7 m between rows) which implies frequent hand-driven rotary at 8–10 cm depth 2–3 times during the growing cycle to maintain the soil free of weeds. This system also had horse-driven ploughing to a depth of 10–12 cm for 20 years, and then was converted to hand-driven rotary tiller for the last 11 years. No disease and pest was recorded in the island vineyards (Özpınar et al., 2010). Herbicides and chemical fertilizers have never been used for the first 20-year, which is the usual soil management in the island, whereas manure was applied at intervals of 3–4 years and a rate of 500 kg $ha^{-1}$ in autumn. The last application was in November 2006 and no further manure was applied during this study. However, N-P-K inorganic fertilizer was used for the last 10-year at intervals of 1–2 years as 250 kg $ha^{-1}$. HDR received on average three tillage operations in spring (March-April/May and early summer (June) in two experimental years. Cultural practices were performed by hand operations such as tillage and mechanical weed control. Alternative soil tillage systems consisted of using tractor-driven rotary tiller (TDR) (or shallow tillage) and tractor-driven field cultivator (TDC). Vineyard under TDR had been planted the same year as HDR in 1986, and cultural practices were the same as HDR for the first 20-year. In 2006, one row was removed leaving a wide spacing (1.3 m × 3.4 m). The cultural practices for TDR were mechanical weeding by frequent rotary tiller in early spring and summer. TDC was carried out on abandoned vineyard which was re-designed in 2013 to wide spacing. TDC was cultivated with a ripper to loosen the soil up to 1 m depth and to enhance vine rooting before plantation in 2012. During the experiment, the new vineyard was cultivated entirely by periodic tillage, according to the farm strategy of keeping the soil surface free of weeds until the start of a commercial level of grape production. The mechanized vineyard treatment included field cultivator from late winter/early spring to the beginning of the dry period (early summer) in between-rows. Tillage and other management practices by tractor are carried out following the position of the vineyard rows and left vegetation cover under and around the vines. Thus, vineyards are maintained with the soils bare for most of the year and during the growing period. Both TDR and TDC were connected to a tractor having a power of 40 kW. The field cultivator had a working width of 1.5 m and was equipped with seven steel shanks. The rotary tiller had a working width of 1.45 m and was equipped with six tools each equipped with two milling cutter blades. The working width of rotary tiller driven manually was 0.75 m and