Abstract. The physical characteristics of soil aggregates influence soil tilth, surface sealing, water infiltration and root growth. Soil management and compaction significantly affect these characteristics. The aim of this work was to determine the effects of tractor traffic across the slope on bulk density, water stability, tensile strength and sorptivity of aggregates from grass covered and cultivated sloping (18%) vineyard soils. The grass covered (G) treatment included periodical mowing and cutting back of herbage and cultivation (C) treatment consisting of autumn ploughing (18 cm) and spring and summer rotary hoeing in the vineyard inter-row zones (2.7 m). A crawler tractor (2.82 Mg) was used in the inter-row zones, moving across the slope for all tillage and chemical operations. Soil aggregates were taken from the inter-rut and the upper and lower rut areas (0-10 and 20-30 cm) in the inter-row zones and then air-dried. Bulk density and tensile strength were lowest in the inter-rut areas and highest in the lower crawler rut. Aggregate water stability was greater under the lower rut and sorptivity in the inter-rut area in comparison to the remaining inter-row areas. In comparable inter-row areas, water stability and sorptivity of soil aggregates were greater and lower under G than C, respectively. The differences in bulk density and tensile strength between G and C were not consistent and varied depending on the inter-row zone and depth.

The stability of soil aggregates is an important factor controlling soil erosion through surface seal formation, infiltration rate and associated transport of surface-applied agricultural chemicals. The strength of soil aggregates influences the resistance of soil to compaction by farm implements [10] and rainfall [2] as well as the effects of soil friability [4, 14] and root growth [6]. Moreover, pore structure of soil aggregates affects the storage of water and its availability for plants [19]. The sorptivity of soil aggregates influences water flow and helps to split the flow through the less mobile intra-aggregate pores and the very conductive inter-aggregate pores in the soil [11].
These characteristics are largely influenced by management systems and soil compaction [9, 12]. Soil in vineyards is subject to compaction by the intensive machinery traffic associated with tillage, chemical operations and grape harvesting. In sloping vineyards with rows across the slope, the compactive effort can be greater beneath the lower than the upper portions of the slope owing to the tilt of the tractor. The differences can be enhanced by uneven soil water content along the slope.

Therefore, the aim of this study was to determine the effects of tractor traffic across the slope on bulk density, water stability, tensile strength and sorptivity of soil aggregates under grass covered soil and under cultivated soil in the inter-row zones of sloping vineyards.

MATERIALS AND METHODS

The experiment was undertaken at a hillside viticulture farm in Piedmont (NW Italy), at an elevation of 450 m and a climate that included cold winters with snow, dry summers, and a yearly rainfall average of 841 mm. The soil was a silt loam (typical Eutrocrept) overlying marls and containing, on average, 33% of sand, 58% of loam and 9% of clay. Selected soil characteristics are shown in Table 1.

In a vineyard with rows perpendicular to the slope (average slope of 18%), two plots of total area of 0.58 ha were managed for seven years: one with grass cover on the inter-row zones with mowing and chopping of the herbage three times per year (G), the other conventionally tilled with autumn ploughing (18 cm depth), with two tillings in spring and late summer (C). In both treatments, a crawler tractor of 2.82

<table>
<thead>
<tr>
<th>Parameters</th>
<th>G</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth (cm)</td>
<td>0-10</td>
<td>20-30</td>
</tr>
<tr>
<td>Organic matter content (g kg(^{-1}))</td>
<td>55.2**</td>
<td>24.1</td>
</tr>
<tr>
<td>Bulk density (g cm(^{-3}))</td>
<td>1.20*</td>
<td>1.23*</td>
</tr>
<tr>
<td>Saturated moisture content (%v/v)</td>
<td>53.0</td>
<td>50.1</td>
</tr>
<tr>
<td>Field capacity (%v/v)</td>
<td>38.1*</td>
<td>37.1*</td>
</tr>
<tr>
<td>Penetration resistance (MPa)</td>
<td>2.2</td>
<td>3.1</td>
</tr>
</tbody>
</table>

Means with * and ** at the same depth are significantly different at p = 0.05 level and p = 0.01 by Student-t test.
Mg weight and 1.31 m width was used between the rows, moving across the slope for both locations. Ground contact pressure for the upper and the lower tracks were 27.4 and 38.0 kPa, respectively. These treatments were used in the vineyard for 10 years. The measurements of aggregate bulk density, water stability, tensile strength and sorptivity were made in places corresponding to the upper rut, inter-rut and lower rut areas at depths of 0-10 and 20-30 cm. The measurements were made in two locations for each treatment and performed across four transects of each plot.

Soil aggregates were taken using rigid containers from the inter-rut and upper and lower rut areas (0-10 and 20-30 cm) in the inter-row zones and then air-dried. The bulk density of the soil aggregates (40 replicates) was determined using the standard wax method [1]. The strength of single air-dried aggregates of 9-10 mm diameter (12 replicates) was determined using a strength-testing device [15]. The diameter of any individual aggregate was estimated as the mean of the measurements taken along three axes of the aggregate: the longest, the intermediate position, and the smallest [3]. Each piece of aggregate was put in its most stable position on a metal plate and crushed with another plate fixed to a stable tensometric head. The value of tensile strength was calculated from the equation:

\[ q = 0.576 \frac{F}{d^2} \]  

where: \( F \) – polar force at failure (N), \( d \) – mean diameter of the aggregate (m).

Water stability (7 replicates) of the aggregates was measured using a drop-impact method [17] with water drops (0.05 g) falling through a height of 1 m and hitting the aggregate with an energy of \( 4.905 \times 10^{-4} \) J. The number of falling drops to cause the beginning of total breakdown, half breakdown and then total breakdown of the soil aggregates was counted to obtain a measure of aggregate stability.

The sorptivity (40 replicates) of the initially air-dried aggregates was determined using the device described by Leeds-Harrison et al. [11]. This device functions well for aggregates of sizes greater than 20 mm. Therefore, similar sizes of aggregates (20-25 mm) were used in the form of natural clods. In this method, water infiltrates into the aggregate through a circular surface area created from a sponge connected to a horizontal capillary tube. The sorptivity (\( S \)) (mm s\(^{-1/2}\)) was derived from a modified Wooding formula (quoted by Leeds-Harrison et al. [11]):

\[ S = \frac{\sqrt{Qf}}{4bR} \]  

where: \( Q \) - steady-state rate of flow (mm\(^3\) s\(^{-1}\)) through a circular pond of a radius \( R = 1.45 \) mm, \( f \) - fillable porosity (%) obtained using the standard wax method (the aggregates were weighed and then covered by water-resistant lacquer to determine
the volume of a single aggregate needed to calculate the bulk density; fillable porosity was then calculated using the aggregate’s bulk density and the density of soil material), \( b \) - parameter dependent on the shape diffusivity function (usually assumed as 0.55).

**RESULTS AND DISCUSSION**

The bulk density of the soil aggregates collected from the 0-10 and 20-30 cm layers under both management systems was generally the lowest in the inter-rut area and generally increased consecutively in the upper and lower rut areas (Fig. 1). The increments were most pronounced at depths of 20-30 cm where the minimum values in the inter-rut zone was 1.43 g cm\(^{-3}\) under G and 1.33 g cm\(^{-3}\) under C and increased in the lower rut area by 16.1 and 26.3%, respectively. At depths of 0-10 cm, the corresponding increases were 5.7 and 10.9%. The largest of the bulk densities under the lower ruts may result from the greater loading associated with the tractor tilt and the usually higher water content in the lower part of the slope enhancing soil compaction from traffic. Earlier studies at the same site gave ground contact pressures of 27.4 and 38.0 kPa for the upper and lower tracks, respectively [5]. Irrespective of depth, the values of bulk density were greater under G compared to C in the inter-rut zones and upper rut areas while being similar for the lower rut.

The tensile strength, similarly to the bulk densities, was lowest in the inter-rut zone under both depths in G (0.12-0.19 MPa) and C (0.16-0.20 MPa) (Fig. 2). In the upper and the lower rut areas they increased at depths of 0-10 cm by 100 and 175% under G and by 20 and 25% under C. At depths of 20-30 cm, the corresponding increases were 37-47 and 6-113%, respectively. The greatest aggregate tensile strengths under the lower rut in both management systems may be largely a result of their high bulk density and thereby a greater number of contact points or forces.
at each single contact point and the internal aggregate strength [7-9]. The differences in aggregate tensile strength between the management treatments were mostly pronounced in the inter-rut zone at depths of 0-10 cm and under rut areas at depths of 20-30 cm.

As can be seen from Fig. 3, the differences in water stability between the inter-row zones were most pronounced at the third disintegration stage, corresponding to a total breakdown of the aggregates. The number of water drops causing aggregate breakdown was much greater under the lower rut than under the upper rut and of the inter-rut zone, with similar stability under both management systems and depths. Greater stability under the lower rut may be associated with closer packing of the primary soil particles, as indicated by a greater aggregate bulk density (Fig. 1) and thus lower porosity resulting in reduced disruptive action of air entrapped in the aggregates during wetting [13].

The differences in water stability between the management systems were most pronounced under the lower rut area where total breakdown of aggregates under G occurred after 1320 and 510 drops at the depths of 0-10 and 20-30 cm. Under C, the corresponding numbers of drops were 83 and 33% lower. In the inter-row and upper rut zones, the resistance was generally greater under G than C at both depths, but the relative differences were smaller than in the lower rut area. The results indicate that the aggregate water stability for soil was generally higher with a grass covering than with cultivated soil. This improved stability of the aggregates under G may be due to abundant roots producing mucilages that form bridges between the primary soil particles [6]. The data agree with earlier results, indicating a negative effect of tillage on aggregate water stability [2, 12]. The results imply that the lower water stability of the aggregate structure and associated surface sealing in C than G can reduce infiltration and increase the hazard of soil erosion and runoff in a sloping vineyard.
Aggregate sorptivity was generally highest in the inter-rut zones and lower in lower rut areas, irrespective of the management system and depth (Fig. 4). For all comparable inter-row zones the sorptivity was greater under C than G. Comparison of Figs 1, 2 and 3 indicates that the lowest water sorptivity and thus wetting rate under the lower rut was accompanied by both the greatest water stability of the soil aggregates (possibly due to reduced slaking during wetting) and bulk density. These data support earlier results indicating that the rate of wetting is indicative of soil structure stability [16, 18].
CONCLUSIONS

1. Soil management of sloping vineyard results in spatial variability of the soil structure in the inter-row zone.

2. Aggregate bulk density and tensile strength were the lowest in the inter-rut zone and consecutively increased under the upper and lower crawler ruts within the inter-row zone for both grass covered (G) and cultivated (C) sloping vineyard soils. The differences in the bulk density, tensile strength of aggregates between the inter-row zones were more pronounced under G than under C.

3. The maximum aggregate water stability occurred under the lower rut and sorptivity in the inter-rut zones. Irrespective of the inter-row aggregate, water stability was greater and sorptivity was lower under G than under C.

REFERENCES


Fig. 4. Sorptivity of soil aggregates under grass covered and tilled in the vineyard inter-row soil. Bars represent standard error. Strips for grass covered and tilled soil as in Fig. 1.
TRWAŁOŚĆ I SORPCYJNOŚĆ AGREGATÓW GLEBOWYCH WINNICY NA ZBOCZU POD MURAWĄ I UGOREM

Właściwości fizyczne agregatów glebowych mają istotny wpływ na podatność gleby na erozję, zagęszczenię i wzrost korzeni roślin. Są one w znacznym stopniu kształtowane przez stan zagęszczenia i sposób użytkowania gleby. Celem niniejszych badań było określenie wpływu przejazdów ciągnika w poprzek zbocza na gęstość, wodoodporność, wytrzymałość na zgniatanie i sorpcyjność agregatów glebowych w międzyrzędach winnicy na zboczu pokrytym murawą (G) i utrzymywanym w ugorze czarnym (C). Badano agregaty pobrane z miejsc pod ślada mi ciągnika i między ślada z głębokości 0-10 i 20-30 cm. Gęstość i wytrzymałość na zgniatanie były najmniejsze między ślada, a największe – pod śladem dolnym. Wodoodporność agregatów była większa pod śladem dolnym, a sorpcyjność między ślada w porównaniu do pozostałych miejsc w międzyrzędzie. Wodoodporność agregatów glebowych w porównywalnych miejscach międzyrzędzia była większa w obiekcie G niż C i odwrotnie w przypadku sorpcyjności. Kierunek zróżnicowania gęstości i wytrzymałości na zgniatanie pomiędzy obiektami G i C był odmienny w zależności od miejsca w międzyrzędzie i w warstwie.