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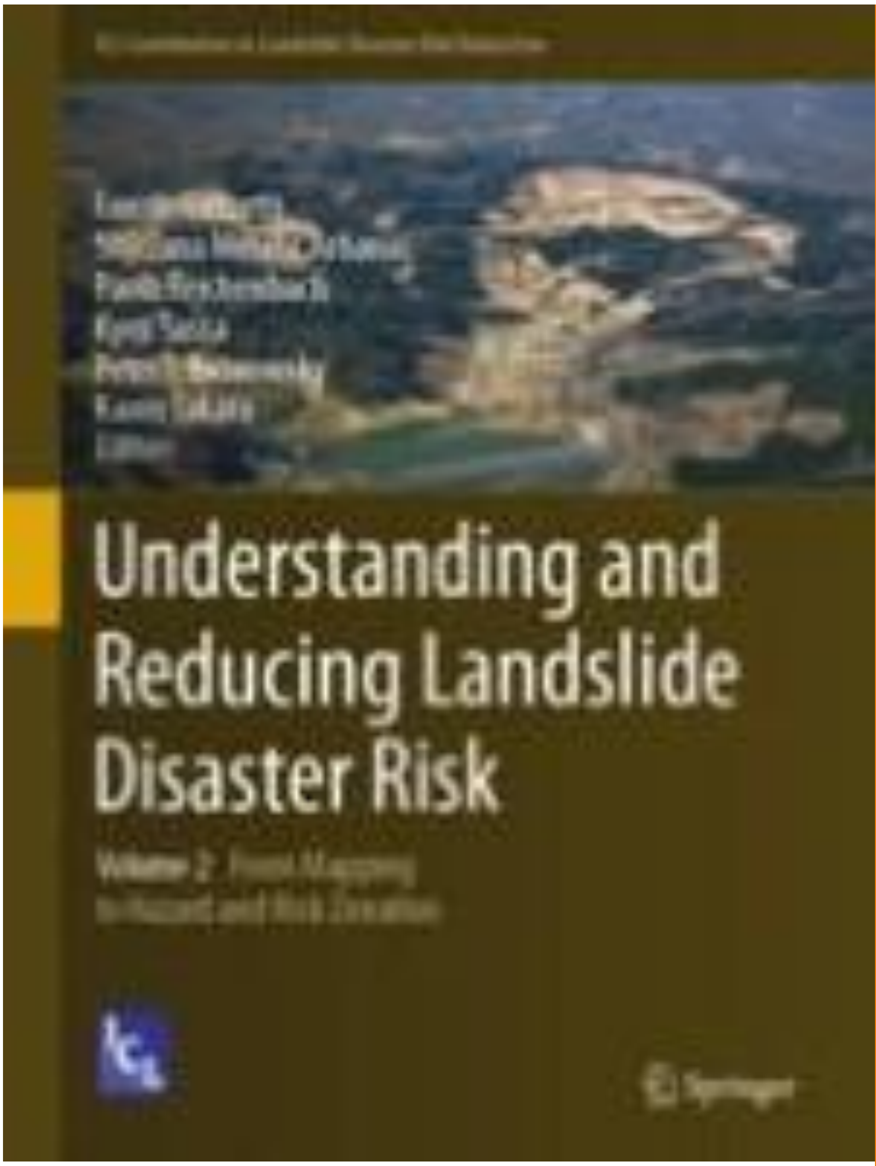
Impact of Agricultural Management in Vineyards to Landslides Susceptibility in Italian Apennines



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Authors: Massimiliano Bordoni, Alberto Vercesi, Michael Maerker, Valerio Vivaldi, Claudia Meisina

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Abstract

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Impact of Agricultural Management in Vineyards to Landslides Susceptibility in Italian Apennines

Massimiliano Bordoni 1, Alberto Vercesi 2, Michael Maerker 1, Valerio Vivaldi 1, Claudia Meisina 1

1. 1.Department of Earth and Environmental SciencesUniversity of PaviaPaviaItaly
2. 2.Department of Sustainable Crop ProductionUniversità Cattolica del Sacro CuorePiacenzaItaly

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Abstract

Cultivation of grapevines in sloping soils is very widespread all over the world, representing also a fundamental branch of the local economy of several hilly zones. Vineyards can be managed in different ways especially in the inter-rows. These management practices may influence deeply soil properties and grapevine root development. Therefore, this work aims to analyze the effects of different agronomical practices of inter-rows on soil properties, grapevine root systems and proneness towards shallow landslides. We focused on traditional agricultural techniques of tillage and permanent grass cover as well as the alternation of these two practices between adjacent inter-rows. The research was conducted in several test-sites of the Oltrepò Pavese, one of the most important Italian zones for wine production in northern Italian Apennines. Among the examined soil properties, soil hydraulic conductivity was the most influenced one by different soil management practices. Regarding the features of the grapevine root system, vineyards with alternation management of inter-rows had the highest root density and the strongest root reinforcement. As a consequence, slopes with medium steepness were unstable if inter-rows of vineyards were tilled, while vineyards with permanent grass cover or alternation in the inter rows promoted the stability of slopes with higher steepness. The results of this study yielded

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Keywords
Vineyard Soil Root Shallow landslides Failure probability Land management

Introduction

Vineyards cover currently 7.5 million ha corresponding to about 0.5% of the entire agricultural areas in the world (OIV 2017). As other human activities, viticulture has strong impacts on the environment Moreover, vineyard cultivation causes important effects in different parts of the soil system, influencing its physical, hydrological, chemical and biological properties through different management techniques, in particular of the inter-row management (Prosdocimi et al. 2016; Rodrigo-Comino 2018).

The management practices of inter-rows have also an important impact on the distribution of grapevine roots in the soil, in terms of rooting depth and, especially, of root density (Smart et al. 2006). The density of roots within the soil, together with their mechanical behavior related to shear and/or tensile forces, increases soil stability (Bischetti et al. 2009; Cohen and Schwarz 2017). Root reinforcement may have beneficial effects in preventing slope instabilities and is often used as an effective tool to decrease landslide susceptibility, in particular for shallow landslides affecting the first 2.0 m of soil (Wu 2012). Shallow landslides triggered by intense rainfall events frequently affect vineyards located in sloping terrains, causing the partial or complete destruction of the vineyards, of local structures and infrastructure and thus, creating severe economic damages. Shallow landslides in vineyards are widespread in different European contexts characterized by traditional viticulture, especially, in Italy (Fonte and Masciocco 2009; Blahut et al. 2014; Bordoni et al. 2019). For this reason, a quantification of root reinforcement of grapevines in vineyards with different inter-row management is fundamental to understand the practices that might promote the stability of sloping vineyards and the ones that cause slope instability.

Root reinforcement can be also implemented in models to estimate the slope stability towards shallow failures (Chiaradia et al. 2016; Zhang et al. 2018). In the case of vineyards, different agricultural managements could determine differences in root reinforcement and, consequently, differences in modelled proneness to shallow failures.

The main aim of this paper is to analyze the effects of different inter-row management techniques on soil properties, grapevine root systems and proneness towards shallow landslides. The research was conducted in one of the most important Italian wine production areas, the Oltrepò Pavese, in Lombardy region, in north-western Italy. This area is also representative of the main geological, geomorphological and agronomical features of northern Italian Apennines (Bordoni et al. 2019).

Materials and Methods

Study Area

Oltrepò Pavese (265 km^2, Fig. 1) is characterized by a traditional viticulture, conducted on hillslopes and based on different grapevine cultivars, as Croatina, Pinot noir, Barbera, Riesling italico, Chardonnay and Moscato bianco. In the northern part of the area, bedrock materials are characterized by a Mio-Pliocenic succession consisting of sandstones, conglomerates, marls and evaporitic deposits. In this area, slopes are steep, with slope angles generally steeper than 20°. Shallow soils derived from bedrock weathering consists in sandy silts or clayey sandy silts with thickness ranging between few centimeters and 2.5 m. In the southern part of the area, bedrock is composed of Cretaceous flysch deposits and other Eocenic-Miocenic bedrocks, consisting of marls, calcareous-marls, sandstones and scaly shales. In this sector, slopes are less steep with slope angles generally between 10° and 20°. Vineyards are mainly cultivated at elevations ranging between 60 and 500 m a.s.l. and on slopes between 5° and 37°.

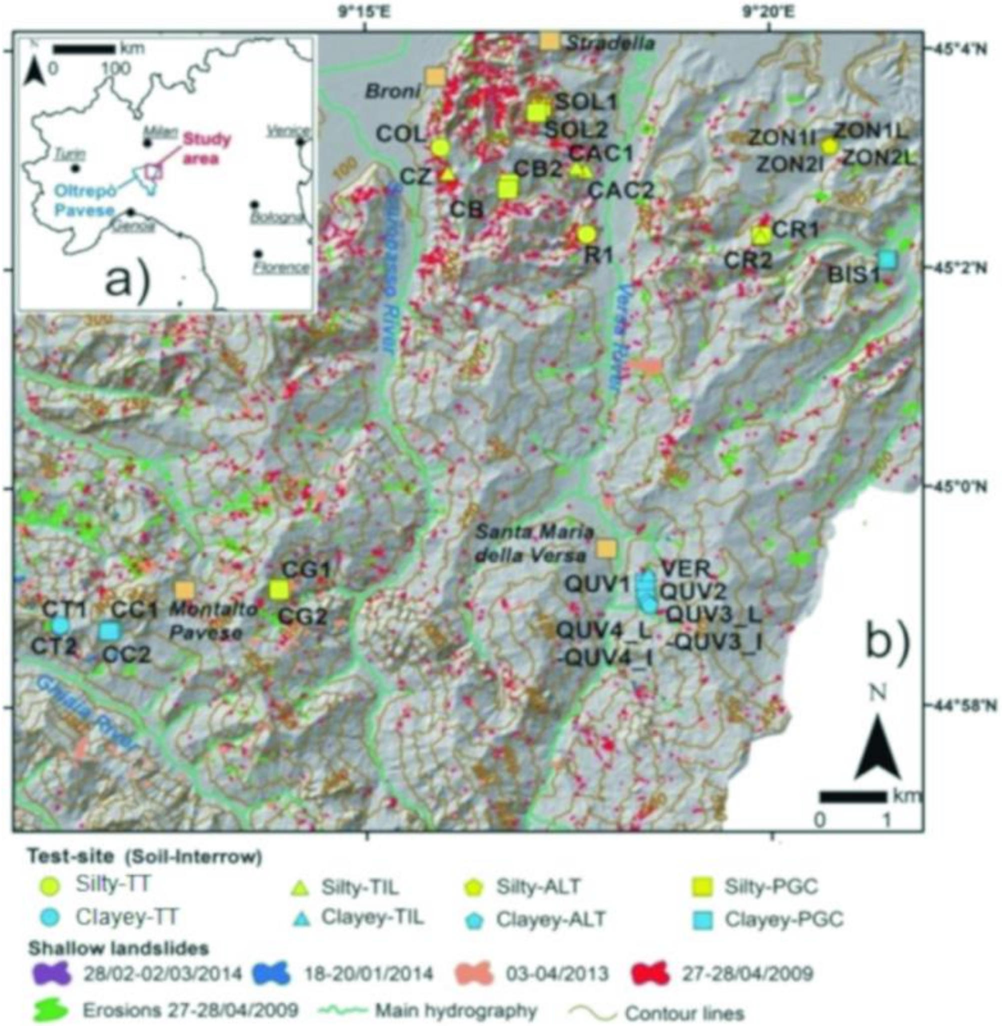

Fig. 1

Oltrepò Pavese hilly zone: **a** location of the study area; **b** location of the selected test-sites and of the shallow slope instabilities

The entire study area is very susceptible to slope instabilities, as testified by several rainfall-induced shallow landslides occurred since 2009 (Bordoni et al. 2019). The mean density of these phenomena is of about 6 shallow landslides per km^2 (2105 phenomena since 2009). Shallow landslides are very common in cultivated vineyards of the study area (Fig. 2). In fact, 424 failures affected vineyards, occupying an area of 3.2 km^2 (2.1% of the area cultivated with vineyards). These phenomena caused the partial or the total destruction of the rows, severe damages to the roads and loss of fertile soil.

Fig. 2 - Examples of rainfall-induced shallow landslides affecting cultivated vineyards of Oltrepò Pavese

Test-Sites

29 test-sites (Fig. 1) were selected, representing the main geological, geomorphological and agronomical features of the area. 17 sites had soils with a predominantly clayey silt or clayey sandy silt texture, classified as low plastic soils (CL) according to the Unified Soil Classification System (USCS).

The other 12 sites were characterized by silt with clays or silty clays and could be considered as high plastic soils (CH), according to USCS. As regards the geomorphological features, all the test-sites were located on slopes, at elevations ranging between 115.0 and 344.1 m a.s.l. Moreover, slope angle changed between 5.0 and 37.0°, while all slope aspects apart of north directions occurred.

Most of the analyzed vineyards (25 test-sites) were characterized by a row orientation parallel to the maximum slope gradient (Par VN). Row orientation perpendicular to the maximum slope gradient (Perp VN) was less widespread (4 test-sites). The studied grapevine plants had ages between 5 and 30 years. Four different types of inter-row management, corresponding to the techniques usually adopted by the local wine-growers, were tested: (1) Total tillage (TT), which does not allow to grow grasses in the inter-rows during the entire year; (2) Tillage (TIL), where mechanical operations are conducted to limit the grow of grasses; (3) Alternating tillage-grass (ALT), in which a row is tilled while the next one is left with permanent grass cover, with alternation every 3–5 years; (4) Permanent grass cover (PGC), where grass cover is maintained in the inter-rows.

Evaluation of the Soil Properties

Soil samplings were performed in each test-site, in correspondence of a soil pit of 1.0 m × 2.0 m excavated in the inter-row. Disturbed and undisturbed soil samples were collected in the identified horizons of the soil profile for laboratory analysis. The following soil attributes, considered the most affected by inter-rows management, were analyzed (l. 2017): soil texture (especially the amount of gravel, sand, silt, and clay in the soil), dry density and porosity, soil water content, water retention curve and soil saturated hydraulic conductivity. Moreover, Atterberg limits and oedometric properties of the soils were determined to complete the characterization and to evaluate potential differences according to different inter-row management techniques. All the laboratory tests were performed according to American Society for Testing and Materials (ASTM) procedures. Instead, saturated hydraulic conductivity (K_s) was measured in field through a constant head permeameter device. Ks was measured in at least 3 points of each test site in the first 0.2 m of soil profile and in the horizons below 0.2 m, generally between 0.5 and 1.0 m depth.

Evaluation of Root Density and Reinforcement

In most of the test-sites, root density was evaluated at three distances from the rootstock, to analyze potential variation on this parameter at different distances from the trunk: (i) one measure close to the plant, between 0.0 and 0.5 m from the stem; (ii) one measure at 0.5 and 1.0 m from the trunk; (iii) one measure between 1.0 and 1.5 m from the trunk (the middle between two adjacent rows). Root density was then quantified by counting the number of roots per root diameter class by means of the root-wall technique (Bischetti et al. 2009). The measured root amount and root density was estimated through the Root Area Ratio (RAR), which is the ratio between the cross sectional area of the roots and the soil area in the frame of known size (0.3 × 0.3 m). Data of root mechanical properties of grapevine plants of different test-sites were obtained from Bordoni et al. (2019). For calculating root reinforcement (c_r), Root Bundle Model—Weibull (RBMw) (Schwarz et al. 2013) was used, integrating the data related to root density and root mechanical properties.

Probabilistic Assessment of Failure Probability

Failure probability (P_r) was calculated for different inter-row managements by means of a probabilistic method, based on Lu and Godt's (2008) model, for the assessment of slope safety factor (FS) also under partially conditions (Eq. 1):

$FS=(\tan\phi'\tan\theta)+(2(c'+cr)\gamma z\sin 2\theta)-\sigma s\gamma z[(\tan\theta+\cot an\theta)\tan\phi']$

(1)

where: φ' is the soil friction angle; θ is the slope angle; c' is the soil effective cohesion; c_r is the root reinforcement, γ is the soil unit weight, z is the depth below ground level in which a potential sliding surface could develop; σ^s is the suction stress.

Because most of the involved geotechnical and root mechanical parameters are affected by natural variability, this model was applied within a probabilistic approach based on a Monte Carlo procedure (Chiaradia et al. 2016). Considering a defined range of values of the required soil and root parameters involved in Eq. 1 (φ', c', c_r, γ, σ^s), Monte Carlo was run for a total of 1000 repetitions, each considering randomly selected values of each variable parameters. The number of times in which FS was less than 1 (unstable conditions) was divided for the 1000 times that FS was calculated. In this way, the failure probability P_r was obtained as (Eq. 2):

$Pr=P(FS<1)$

(2)

Results

Soil Properties

Dry density and porosity were similar in vineyards characterized by different inter-row management, both for sites with low plastic (CL) clayey or clayey sandy silts and high plastic (CH) clays with silts or silty clays. The average differences in dry density and porosity was, in fact, of less than 0.6 kN/m^3 and 0.05 between vineyards with different inter-row management, for both the soil. Saturation degree of dry period of the soil levels till 0.2 m from ground of test sites with different inter-row management ranged between 32 ± 3 and 37 ± 3%. In wet periods, saturation degree of the most superficial horizons were very similar concerning different inter-row management and very close to complete saturation (between 95 ± 4 and 99 ± 1%). Only K_s parameter showed an evident difference between different inter-rows management. K_s of topsoil horizons in PGC was about 4–5 times higher than TT and TIL and about 2 times higher than ALT. Instead, for the soil levels below 0.2 m from ground, K_s decreased passing from tilled vineyards to ALT and PGC ones of about 2–3 times (Fig. 3).

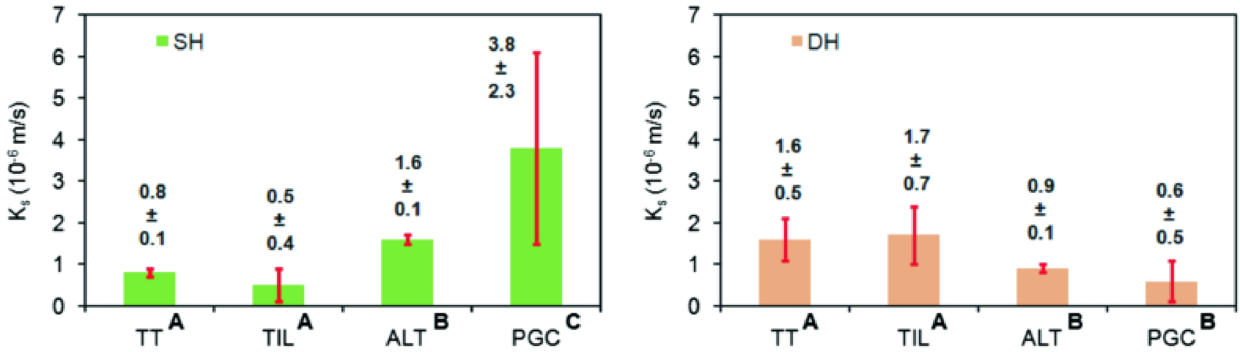

Fig. 3

Saturated hydraulic conductivity (K_s) values measured in vineyards with different management, in the first 0.2 m from the ground level (SH) and below this soil horizon (DH)

Root Density and Reinforcement

Grapevine root density did not show significant differences considering different distances from plant trunk, since the RAR values kept in a range of less than 0.05%. Besides the different management of the inter-row, in all the test site the highest amounts of roots were found between 0.3 and 0.6 m below ground level. Root density changed significantly according to different inter-row management (Fig. 4). ALT sites had the highest root density all along the soil profile. PGC had a root density on average 10–15% lower than ALT. While, for TT and TIL sites, the decrease of root density in respect to ALT was more evident, on average of about 51–66%.

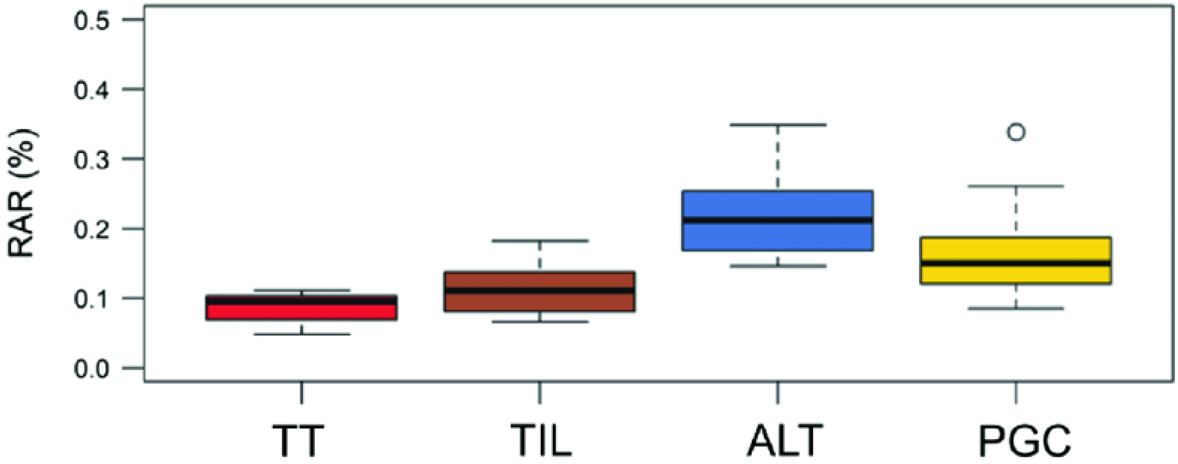

Fig. 4

RAR distribution in vineyards with different management

c_r was, then, estimated at: (i) 0.3 m, in correspondence to the topsoil layer; (ii) 0.5 m, in correspondence to the highest root density; (iii) 1.0 m, where shallow landslide sliding surfaces prevalently occurred in the vineyards of the study area; (iv) 1.5 m, in correspondence to the measured highest rooting depth of all the test sites. c_r trends followed the trend of root density, with an increase at 0.5 m in respect to the topsoil layers and a consequent decrease with depth below 0.5 m (Fig. 5). Moreover, as for the root density, c_r was different in sites with different inter-row management (Fig. 5). ALT sites provided the highest root reinforcement, at all the considered depths (11.73 ± 2.34 kPa at 0.3 m from ground, 14.28 ± 2.59 kPa at 0.5 m from ground, 9.18 ± 1.99 kPa at 1.0 m from ground and 5.56 ± 1.59 kPa at 1.5 m from ground). Generally, PGC had c_r values 40–45% lower than ALT. While, for TT and TIL sites, a decrease of c_r in respect to ALT was on average more than 67–73%, with lowest values documented at TT sites.

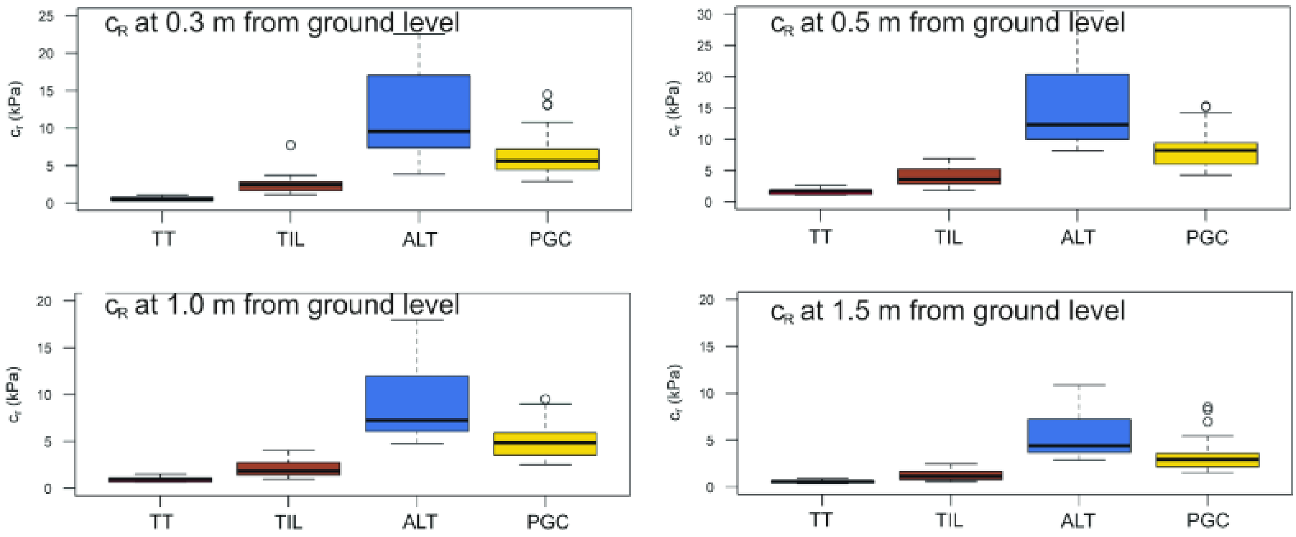

Fig. 5

Root reinforcement (c_r) distribution in vineyards with different management, at 0.3, 0.5, 1.0 and 1.5 m from the ground level

Failure Probability

For the assessment of P_r through the probabilistic approach, c_r and the geotechnical parameters (φ', c', γ) were extracted from a normal distribution (Table 1). Pr was calculated for two soil types, which are the most widespread in Oltrepò Pavese area: (i) clayey silts or clayey-sandy silts; (ii) clays with silts or silty clays.

Table 1 Mean and standard deviation of the geotechnical parameters used for the assessment of the failure probability

Soil type	γ (kN/m^3)	φ' (°)	c' (kPa)
Clayey silts or clayey sandy silts	18.0 ± 0.8	26 ± 4	1.8 ± 1.6
Clays with silts or silty clays	19.4 ± 0.5	12 ± 4	0.0 ± 0.0

As regards σ^s, a uniform distribution between 0 and 10 kPa was considered, consistent with the values measured during past triggering events in the study area (Bordoni et al. 2015). P_r was evaluated considering slope angle ranging between 5 and 45°, which is the typical steepness of the hillslopes in the study area, and for soil depth of 1.0 m from ground, where most of the shallow landslides sliding surfaces developed (Bordoni et al. 2015). P_r obtained for different management in vineyards indicated that the probability of slopes failure for TT and TIL was the highest (Fig. 6). Regardless the type of soil, P_r decreased considering PGC and ALT (Fig. 6). Considering clayey silts or clayey-sandy silts, P_r exceeded 0.5 (50% of the simulations with FS lower than 1.0) for slope angle higher than: (i) 17° for TT; (ii) 18° for TIL; (iii) 25° for PGC; (iv) 33° for ALT. Regarding clays with silts or silty clays, P_r was higher than 0.5 at slope steepness lower for each type of land use, due to the poorer geotechnical properties than the ones of clayey silts or clayey-sandy silts. Thus, the probability of rupture exceeded 0.5 for slope angle higher than: (i) 10° for TT and TIL; (ii) 21° for PGC; (iii) 28° for ALT.

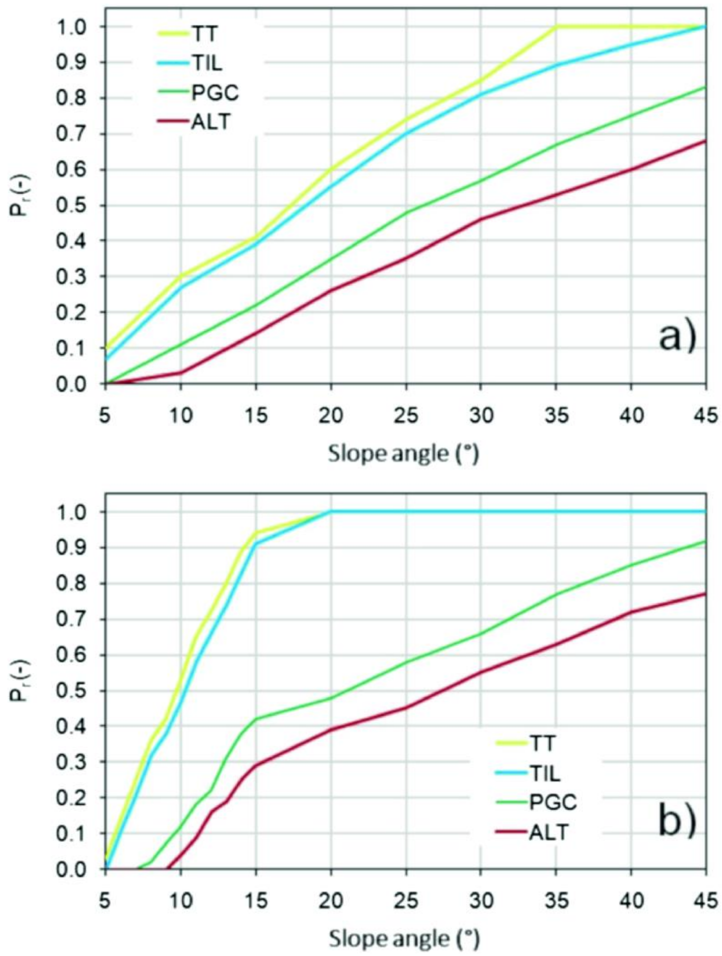

Fig. 6

Failure probability (P_r) as function of steepness for different land uses, considering **a** clayey silts/clayey-sandy silts soils or **b** clays with silts/silty clays

Discussions and Conclusions

The agronomical practices in vineyards, in particular the management of the inter-rows, influence soil properties and grapevine root development. In the context of the Oltrepò Pavese, representing viticulture in sloping landscapes of the northern Italian Apennines, the soil hydraulic conductivity is the most influencing parameter by the inter-row management. The macroporosity allows to increase the superficial (first 0.2 m of soil) hydraulic conductivity of inter-rows without tillage. In the remaining part of the soil, a high density of roots may represent an obstacle for hydraulic conductivity and the related water fluxes, as shown for vineyards with alternating tillage and permanent grass cover. Anthropic factors related to grapevine cultivation and harvesting (e.g. deep ploughing, spread of fertilizers, harvesting, plant pruning activities) during the year tend to standardize the other soil physical, geotechnical and hydrological properties.

Vineyards with alternation management of the inter-rows or with permanent grass cover promote a significant increase in root density and root reinforcement than other types of management. Thus, the failure probability decreases passing from vineyards with tilled inter-rows to the ones with grass covering or alternating inter-rows.

In the typical conditions of shallow landslides triggering, slopes with medium steepness (10° for clayey soils, 17–18° for silty soils) are unstable if inter-rows of vineyards are tilled. In the same conditions, permanent grass cover or alternation in the inter-rows promote the stability of slopes in a wider range of steepness (>21–25° for vineyards with permanent grass cover in the inter rows, 28–33° for vineyards with alternation in the inter rows). The slope stability analyses leading to these results were conducted with a 1D approach, which could be improved through a 2D approach in order to model better the soil fluxes and the variations in root reinforcement across a hillslope.

These results provide important indications for land use planning at catchment and regional scales able to reduce the proneness towards shallow landsliding, maintaining or increasing soil conservation.

Notes

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