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Effect of Standard Disk Plough on Soil Translocation in Sloping Sicilian Vineyards

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Abstract: Tillage is the main force of soil redistribution in agricultural land use and has been seen as more critical than water erosion. This study aims to evaluate the effect of tillage with standard disk in vineyards. A representative study area with grapevines was selected, and 39 inter-rows were selected to test the effect of slope and forward speed. In each inter-row, a strip of soil was collected, and mixed with 2 kg of coloured sand used as a tracer, then replaced in the strip, and shallow soil tillage was performed by means of a standard disk plough. Three soil subsamples were collected along the slope every 0.30 m from the coloured strip and the sand tracer was separated from the soil and weighed. The results show that the mean soil translocation distance ranged from 0.73 to 1.14 m along the upslope direction, and from 0.32 to 0.84 m along the downslope direction. The net translocation was -0.33 ± 0.12 m which indicate an upslope soil movement. Mean translocation distance was not significantly affected by the considered forward speeds. These results demonstrate that tillage can reallocate soil upslope and open new insights into the use of disk plough as sustainable management in vineyards.

Keywords: soil degradation; tillage erosion; tillage implements; soil movement

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1. Introduction

Soil erosion in vineyards is an environmental issue that threatens the sustainability of winemaking in all the wine production world regions. It is not only a Mediterranean issue restricted to the three main producers: Italy [1,2], Spain [3,4], and France [5]. Emerging wine producer regions also face similar problems [6–8]. Vineyards are mainly located in sloping terrains, and this is the key question for the high erosion rates [9] but also the mismanagement for centuries with intensive ploughing and the lack of sustainable management [10–12].

The high erosion rates recorded in vineyards are responsible for a decline of soil fertility with a subsequent higher requirement of nutrients and landscape impact due to sediment translocation [13]. Besides the widely studied water erosion, recent studies in semiarid vineyards have shown the severe effect of tillage on soil translocation [1]. Novara et al. [1] found a yearly soil loss of 4.9 Mg ha^{-1} in a vineyard plot under conventional shallow tillage by means of a tine harrow. Estimating soil translocation in a larger Sicilian vineyard area (2836 ha) demonstrated that the soil erosion caused by tillage exceeded the erosion tolerance limit in 94% of surveyed plots [14]. As the soil erosion caused by tillage is human-induced, the reduction of tillage operations and a proper choice of tillage factors (type of agricultural implement, tillage frequency, forward speed and tillage depth) could control the soil redistribution along a slope [15] and contributes to achieving a sustainable agriculture development. The above factors determine tillage erosivity, defined as the potential for a tillage operation to translocate soil within a landscape [16]. However, the strong interaction between soil physical parameters (e.g., structure and porosity) and tillage factors determine contrasting results on the magnitude of soil translocation.

Among tillage implements, the mouldboard plough has been widely studied, being ploughing the most common tillage practice in conventional agriculture [17–20]. The mouldboard plough causes the detachment and movement of the topsoil layer, and therefore ploughing has been generally considered the most erosive tillage [21]. Despite this evidence, other authors found that tillage erosion results not only from mouldboard and chisel passé operations, but that frequent shallow tillage significantly contributes to soil displacement [22,23]. Similarly, Marques da Silva et al. [24] and Lobb et al. [18] reported very high soil erosivity caused by the tillage carried out using disk implements. They conclude that tillage depth, forward speed, disk characteristic and soil conditions are critical factors affecting the soil translocation distance during tillage with disk harrow or plough.

Two different types of disk plough are available for soil tillage: standard disk plough; vertical disk plough.

A standard disk plough is constituted by 1–6 spherical caps, mounted in neutral on independent pivots. Its maximum working depth is 30 cm ca., as the disk diameter is 60–80 cm. This implement is useful for resistant soils, rich of particles thicker than sand, in order to perform a high crushing. In a standard disk plough, the disk angle, included between the axis of the spherical cap and the direction of travel, is 45° ca., while the tilt angle, included between the plane of the spherical cap and the line perpendicular to the field plane is variable from 15 to 25°.

Instead, a vertical disk plough is constituted by 4–15 spherical caps, mounted in neutral on the same axle. Its maximum working depth is 20 cm ca., as the disk diameter is 45–75 cm.

Both the above types of disk ploughs are equipped with deflectors and a stabilising wheel. Each deflector is constituted by a curved scraper blade, mounted on the implement frame, in front of each disk. Three types of deflectors can be mounted on disk ploughs: like mouldboard; reversible; like hoe. The stabilising wheel is constituted by a ballasted disk equipped with a compression spring and able to keep both the implement alignment and working depth constant [25].

The values of soil erosion (translocation mass) reported in the literature for tillage with disk implements ranged from 9 kg m^{-1} [26] to more than 300 kg m^{-1} [24]. The high variability of reported results demonstrates that soil erosion is site-specific and strongly dependent on the design of the used tillage implement.

Although tillage erosion has been researched, some key questions are to be solved from a scientific perspective. One of them is the impact of tillage erosion in vineyards and orchards, where the crop determines the redistribution of the materials, such as was found using topographical methods in citrus [27]. The distribution of the vines in rows determine the impact of ploughing and the redistribution of the material, which is relevant to understand the connectivity of the flows and then the soil erosion by water [9]. Previous research on tillage erosion was developed on cereal fields where the ploughing is not affected by any crop (rows of trees), and there is no information about how tillage determines the soil erosion process in vineyards and orchards. It is widely studied the impact of water erosion on vineyards, but little is known about the role of tillage.

Although several studies showed a higher soil translocation along the downslope direction rather than the upslope one in arable lands, some winegrowers, through their field observations, hypothesise the ability of the standard disk plough to reduce the soil translocation along the slope. Based on the above state-of-art and considering that the measurements of soil tillage erosion using disk ploughs are limited and never performed in vineyards, this work aims to evaluate the soil translocation during tillage using a standard disk plough, both along the upslope and downslope directions with different slopes and forward speeds. In semiarid ecosystems, farmers do not accept to switch from tillage to no-tillage, and our investigation will contribute to understanding the potential use of disk plough in semiarid vineyards and its sustainability.

2. Materials and Methods

2.1. Vineyard Tillage Experiment

A 5-ha vineyard was located in Santa Margherita Belice (Agrigento), South-West of Sicily (37°41′ N; 13°02′ E, 227 m a.s.l.). The area has a Mediterranean climate, with a mean yearly rainfall of 610 mm, with a summer drought from June to September. The lowest mean daily temperature is in February with 7 °C and the highest in August with 29 °C. The topsoil has a clay texture with an average content of clay of 45%, silt of 25% and sand of 30%. Vines belonging to cv. Viogner were planted in 2014. The vine planting frame is 2.50 (inter-row) × 0.90 m (between plants along each row), North-South oriented and trained using VSP (Vertical Shoot Positioned) Trellis.

In May 2021, in the selected vineyard, 21 inter-rows having different slopes, i.e., 0, 11, 14, and 17%, were chosen. The selected slope sections were straight, in order to avoid concavity and convexity of soil surface, that could interfere with the soil translocation by tillage. For each slope, three inter-rows were selected for downslope tillage and three ones for upslope tillage. Soil water content during the trial was 15.5 ± 0.8%. Moreover, 18 inter-rows were selected in order to test the forward speed effect, ranging from 0.55 to 1.38 m s^{-1} (from 2 to 5 km h^{-1} ca.) on a 10% uniform slope. During this trial, the soil water content was 18 ± 0.6%.

In order to estimate the soil translocation distance, red coloured sand was used as tracer [28], following the methodology applied by Novara et al. [1]. In each inter-row, a strip of soil (1 m long, 0.2 m wide and 0.15 m deep) was collected and mixed with 2 kg of coloured sand of 3 mm particle size (diameter) and 1.4 Mg m^{-3} bulk density, then replaced in the strip and pressed down to the original ground level [1]. After installing the strips, soil tillage (upslope in an inter-row and downslope in the other one) was performed by means of a standard disk plough, manufactured by the company Errebi Officine [29], at a depth of 0.15 m. The main characteristics of the agricultural implement are described in Figure 1. The used standard disk plough is constituted by two axles, each mounting four disks having a diameter of 0.60 m, a disk angle of 34 degrees, and a tilt angle of 7 degrees (Figure 1). Three soil subsamples were collected along the slope every 0.30 m from the coloured strip for each test. The sand tracer of each sample was manually separated from the soil and weighed. The disk rotation speed was measured by counting the number of revolutions per second using a camera installed on the disk plough.

Figure 1. Standard disk plough used during the tillage tests: tilt angle (α) between the disk plane and the perpendicular to the field plane; disk angle (β) between the disk plane and the travel direction.

2.2. Calculations and Statistical Analysis

The mean translocation distance (T) (m) of sand tracer was calculated according to Equation (1).

$$T = \frac{\sum_{i=1}^{n}(t_i d_i)}{\sum_{i=1}^{n} t_i} \quad (1)$$

where:

t_i is the amount of tracer (coloured sand) in collected soil sample i;

d_i (m) is the distance of soil sampling from the installed strip.

Analysis of variance was carried out in order to test differences in soil translocation under the different forward speeds. Tukey test was used for mean differences at $p \leq 0.001$. Regression coefficient analysis and analysis of variances were carried out in order to test differences in soil translocation under different soil slopes. Both analyses were performed using SPSS software [30].

3. Results

3.1. Soil Translocation Distance and Slope

Soil translocation distance was significantly affected by tillage direction and slope (Table 1). The higher values were recorded along the upslope direction than the downslope one (Figure 2). The mean soil translocation distance ranged from 0.73 to 1.14 m along the upslope direction, while this distance ranged from 0.32 to 0.84 m along the downslope direction.

Table 1. Analysis of variance and statistics of the regression between slope and mean translocation distance (df = degrees of freedom; SS = Sum of Squares; F = Mean Square between groups/Mean Square within groups; Stat t = Statistical test).

	Df	**SS**	**F**
Regression	1	0.476	***
Residue	19	0.499	
Total	20	0.975	
	Coefficient	Stat t	F
Intercept	0.757	21.410	***
Slope	−0.011	−4.261	***

*** significance at 1‰.

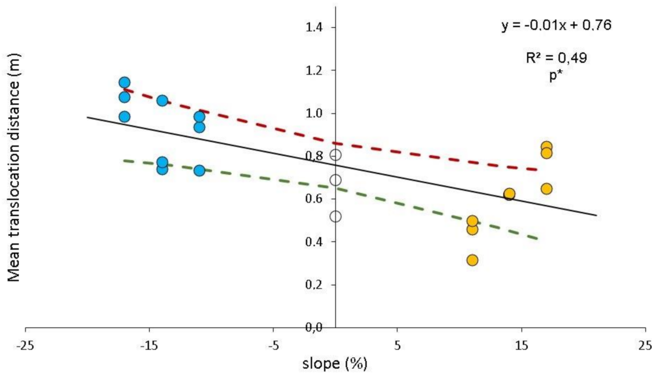

Figure 2. Mean soil translocation distance vs. slope. Negative and positive values of slope indicate upslope and downslope tillage, respectively ($p^* = p < 0.05$).

Along the downslope direction, the mean translocation distance ranged from 0.42 ± 0.10 m to 0.77 ± 0.10 m for 11% and 17% slope, respectively. Along the upslope direction, the mean translocation distance ranged from 0.89 ± 0.13 m to 1.07 ± 0.08 m for 11% and 17% slope, respectively.

The net translocation, the difference between downslope and upslope translocation, was −0.33 ± 0.12 m as the average of three slopes. Negative values of net translocation indicate a soil movement forward upslope.

3.2. Soil Translocation Distance and Forward Speed

Another factor analysed in this work was the effect of tractor forward speed on tillage erosion, which did not show significant differences.

Comparing different implements, Lobb et al. [18] found that forward speed affected soil translocation only using a tandem disk harrow. In a further test using a mouldboard plough, no relationship was found between soil translocation distance and forward speed over a range of 3.5–7.4 km h^{-1} [31].

The range of the forward speeds tested in this work did not determine a different disk speed rotation, and probably, for this reason, no difference was found in mean translocation distance.

In fact, mean translocation distance was not significantly affected by the considered forward speeds (Figure 3). The mean translocation distances were statistically different between the two directions, with a value of 1.10 m and 1.02 m along the upslope and downslope directions, respectively. The different forward speeds did not determine differences in the number of disk revolutions for second neither along the upslope direction nor along the downslope one. The number of disk revolutions ranged between 0.37 to 0.48 revolution s^{-1}.

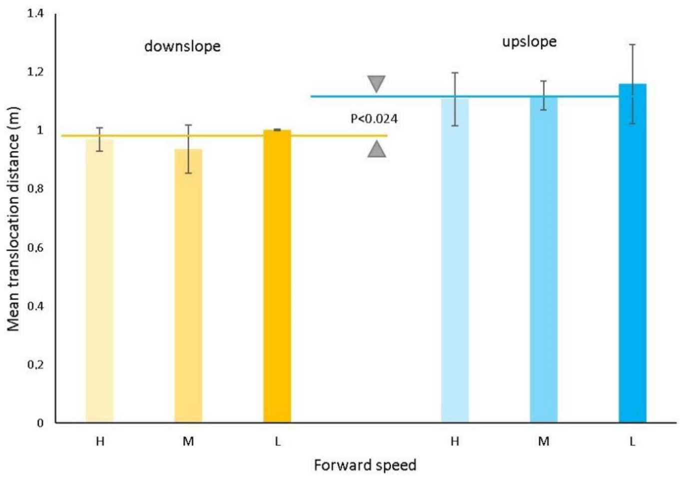

Figure 3. Mean translocation distance under three forward speeds (H = high, M = medium, L = low) along the upslope and downslope directions. The horizontal lines indicate the average over speed, separately for upslope and downslope directions, while the bars indicate the standard deviation (n = 3).

The average values of mean translocation distance during the second test with a slope of 10% were higher than those of the first trial. The soil water content was also higher in the second trial.

4. Discussion

In the performed tests, the soil translocation distance resulted unexpectedly higher along the upslope direction than the downslope one, opening new exciting opportunities for soil conservation and soil remediation in eroded vineyards and starting a scientific debate about the impact of tillage in soil reallocation in agricultural land. Until now, tillage has been considered negative management due to the damage to the soil structure, removal of vegetation cover and plough-pan development. Pires et al. [32] found changes in the soil porosity and soil structure due to the tillage, and this confirmed previous research that shows an increase in runoff and soil loss after 24 years of tillage [33]. Tillage also has a negative impact due to the changes in the soil hydraulic properties [34]. The development of plough pans induces soil compaction and reduces soil infiltration rates [35,36]. A third negative impact of tillage is the reduction or elimination of the vegetation. From a soil erosion point of view, this contributes to the acceleration of the runoff generation as the interception of plants is null, the raindrop impact very effective, and the runoff velocity is higher [37,38]. Roots also play a crucial role in protecting the soil due to their cohesion [39,40].

The negative aspects of tillage, including soil translocation, mainly depend on the frequency, and proper use of tillage equipment could be useful for sustainability achievement in semiarid cropping systems [41–43]. Very few studies have analysed the effect of tillage on soil translocation, and their results generally show an erosive effect of the agricultural disk implement [18,24]. These researchers highlighted the net downslope that is the difference of mean soil translocation distance between downslope and upslope directions. Marques da Silva et al. [24] found a net downslope soil translocation of only 5 cm with a tilt angle of 20 degrees and a slope of 11%. In the same study, higher net downslope soil translocation values, up to 47 cm, were recorded with increasing slope and tilt angle. Kachanoski et al. [26] found a positive mean soil translocation distance along the downslope direction, but the results for low slope showed negative values of net downslope translocation, indicating that used tandem disk can move more soil along upslope direction rather than downslope one. Moreover, in this latter study, net soil translocation distance values were positive with higher slopes.

Contrarily to the most of literature, in this work, we found under different slopes an average of the net downslope direction of -0.33 ± 0.12 m. However, most of the previous studies do not provide extensive information on disk shape and soil physical-mechanical parameters, so that the comparison among different observations could be difficult. Moreover, studies focused on a tillage operation using a specific agricultural implement generally have limited replications that generate highly variable data due to several factors [26].

When data are separately considered for upslope and downslope directions, the absolute values of mean soil translocation distance observed are much higher than those found by other researchers. Lobb et al. [18] and Tiessen et al. [44] found a mean soil translocation distance along the downslope direction ranging from 0.20 to 0.35 m. These values, considerably lower than those found in this work, can be attributed to the difference in tillage implement. Lobb et al. [18] used a tandem disk equipped with 0.36 m-diameter concave disk blades at 0.18 m spacings, while Tiessen et al. [44] a disk plough having three 60 cm diameter disks in only one line.

Disk diameter, the number of disks lines, tilt, and disk angle could explain the differences in soil translocation distance of these findings in relation to the abovementioned studies.

For a mouldboard plough or a tine harrow, the higher soil translocation along the downslope direction is determined by gravity force. Instead, other forces are applied to the soil for a standard disk plough, so that a different trend of soil translocation is achieved.

The main forces involved in the disk, along the two tillage directions, represented in Figure 4, are gravity force, cohesion (maximum in clay soils), internal friction (minimum with high soil water content, however neglectable in clay soils), adhesion (maximum in clay soils having high water content), and external friction (lower in clay soils) [25].

All the above forces are not dependant on soil slope and travel direction. Along the upslope and downslope directions, the soil parameters (texture, water content, cohesion, adhesion, and external friction) and tillage characteristics (tractor forward speed and, therefore, the rotation speed of disks) were kept constant. Therefore, the differences in soil translocation for the two directions are due to the different arcs of the circumference that each soil particle travels before falling down (Figure 5).

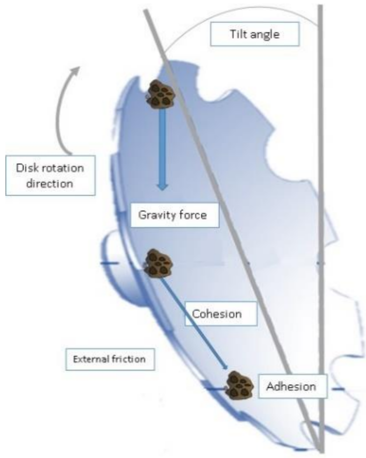

Figure 4. Scheme of the forces acting on soil particles during soil tillage.

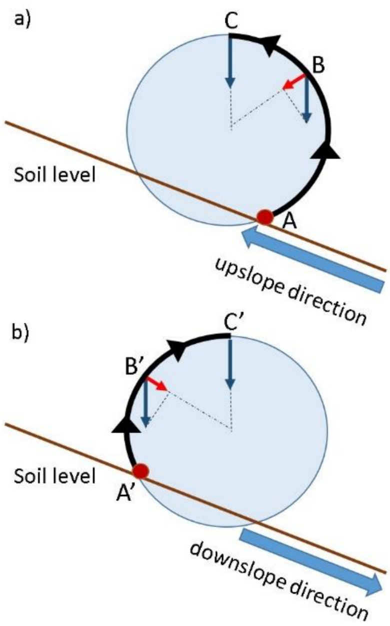

Figure 5. Schematic representation of involved forces along upslope (**a**) and downslope (**b**) directions.

Figure 5 schematically shows the forces involved on a soil particle in the case of a disk along both directions. In points C and C′, when the gravity force has the same direction of its radial component, the soil particle is dragged for a longer arc of the circumference (AC) along the upslope direction rather than along the downslope direction (A′C′) (Figure 5). Even if soil particles can fall down during all the arc of circumference, only in point C and C′ are subjected to the highest force, which increase the probability of detachment from the disk.

5. Conclusions

Effective control of human-induced accelerated erosion is essential to sustainable development, improving the environment and maintaining an acceptable level of furnished ecosystem services. Accelerated soil erosion influences a set of ecosystem services such as water quality, SOC (Soil Organic Carbon) sequestration for mitigation of global warming, food and nutritional security, and biodiversity. Therefore, soil conservation, erosion control, and main restoration of eroded soils have essential policy implications. The goal is to encourage farmers and stakeholders to adopt recommended soil and crop management practices to improve soil quality and fertility. The European Union also requests these challenges to achieve sustainability in agricultural soils.

It is well known how vineyard systems are prone to losing soil quality and fertility, mainly through soil translocation and soil erosion. Considering the promising results achieved in this research, in the semiarid environment where those phenomena were found very active, the standard disk can be considered an implement for shallow tillage in vineyards that will support soil ecosystem services.

In fact, upon our results here, we recommend using the standard disk plough implement above all in sandy and loam soils and in clay ones, where the water content is low. The use of tested standard disk plough for shallow tillage, contrarily to other implements used in vineyards [1], determined soil remediation due to a negative net soil translocation. The results of this work could have important implications for soil conservation and remediation in sloping agricultural landscapes.

In any case, further studies are needed to evaluate the effects of the shape of tillage implements under a broader range of soil conditions (soil texture and water content) on soil translocation.

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