Soil erosion and earthworm population responses to soil management systems in steep-slope vineyards

S. Vršič

Faculty of Agriculture and Life Sciences, University Centre of Viticulture and Enology Meranovo, Hoče, Slovenia

ABSTRACT

This study is aimed at investigating the effect of different vineyard soil management systems on soil erosion and earthworm (Lumbricidae) population. Three soil management systems were investigated: permanent green cover (control), straw-cover and periodic soil tillage. Inter-row periodic soil tillage was applied in 2002 and 2003 (May and August), and straw-cover in May 2002. Periodic soil tillage resulted in increased erosion, i.e. 1746 kg/ha of soil/per year, on average. The greater portion of erosive events occurred after tillage in summer (August 2002), which was accompanied by heavy rainfall and slow renewal of grass cover (slower than in spring). The lowest average amount of soil erosion was observed in the treatment with straw-cover (56 kg/ha per year). This management system provided better environment for earthworm populations, most of which were found close to the soil surface, especially in the dry year 2003. In periodical soil tillage, the majority of earthworms were found in the soil horizon not disturbed by the tillage, i.e. at the depth of 10–20 cm. The lowest number of earthworms (only 2 per m^2) was recorded in the herbicide intra-row strip.

Keywords: grapevine; tillage; straw-cover; permanent green-cover

In the Central European wine region vineyards mainly occupy hillsides, which are sometimes very steep and, therefore, subjected to continuous soil erosion (Casali et al. 2009). Owing to low training systems in the past, soil tillage used to be applied for weed control. Repeated tillage speeds up the mineralization of organic compounds in the soil, but at the same time such soil cultivation decreases soil fertility and increases soil erosion (Ramos and Martínez-Casasnovas 2006, Materechera 2009). In addition, the use of heavy machinery in inter-rows results in severe soil compaction. These problems can be lessened by various types of soil cover. Thus, the biological activity of the soil can be significantly increased (Kobel-Lamparski and Lamparski 2000) and the population of natural predators (mites, ladybirds etc.) of grapevine pests (Mikulas 1996) can also be enhanced.

In some traditional wine producing regions, during higher precipitation periods (autumn, winter and early spring), vineyards are temporarily planted with fast-growing plants, but during intensive grapevine growth, regular inter-row soil tillage is carried out (Bauer et al. 2004). However, this type of soil management, especially in hilly areas, at times of higher rainfall, results in the soil erosion which vineyards are especially vulnerable to (Martínez-Casasnovas and Sánchez-Bosch 2000, Baumgartner et al. 2008, Ramos and Martinez-Casasnovas 2009). The surface runoff of water at the time of heavy rain is considerably higher (Battany and Grismer 2000, Martinez-Casasnovas et al. 2005, Ramos and Martinez-Casasnovas 2007) in vineyards without green or straw-cover. For this reason, permanent green or straw-cover in vineyards in hilly areas can be a highly beneficial practice (Vršič and Lešnik 2010).

In order to establish an efficient, permanent green cover we have to consider the plant species which do not compete too much with the grapevines for water and nutrients (McGourty et al. 2008, Vršič and Lešnik 2010). In comparison with periodic

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soil tillage (PST), permanent green cover (PGC) and straw-cover (SC) have several advantages, since they increase organic matter in the soil and intensify the activities of macro- and microorganisms (Kobel-Lamparski and Lamparski 2000). The positive influence on earthworm population and biomass was manifested in humus and total nitrogen (Iordache and Borza 2010). There is a strong positive correlation between the amounts of inorganic nitrogen applied and population of earthworms (Edwards and Lofty 2002), but the level of significance depends on the type of fertilizer treatment (Whalen et al. 1998). Several other studies, however, report that the application of chemical fertilizers can have a very negative effect on earthworm populations (Reinecke and Reinecke 2004). Copper concentration and soil tillage in vineyards reduces total abundance and biomass of earthworms (Paoletti et al. 1998).

Due to intensified global warming over recent years, we can expect more frequent and longer dry seasons and occasional heavy rains, which may cause serious soil erosion (Vršič et al. 2004). Even in environments where PGC has become a commonly accepted practice, there is a growing need for soil erosion research. This is in order to establish the most appropriate vineyard soil management system, which would reduce any unwanted negative impact of PGC in the event of more severe droughts. One such possible option could be inter-row PST or SC during growth season. After each soil cultivation the tilled inter-row spacing is gradually covered by natural vegetation.

The main objective of this study was to investigate the impact of SC and PST on soil erosion and loss of nutrients, and compare them with PGC. Before the start of our investigation the inter-row spacing was permanently covered with natural vegetation in a steep-slope vineyard.

MATERIAL AND METHODS

The trials were conducted in NE Slovenia (46°53'N, 15°56'E, 407 m a.s. l) in 2002 and 2003 at the Maribor University Centre for Viticulture and Enology at Meranovo, managed by the Faculty of Agriculture and Life Sciences. The experimental work was carried out on a six-year old plantation of cv. Sauvignon Blanc, established in 1997. The mean annual air temperature of the investigated area, for the referenced period 1961–1990 was 9.7°C; the mean monthly minimum in January was –1.3°C, and the average monthly maximum in July was 19.6°C. The average annual rainfall was 1045 mm. Precipitations were, on average, more or less equally distributed all year round.

The vineyard surface inclination was 34%, the length of each row was 82 m, the inter-row spacing was 2.4 m. The grapevine rows ran vertically along the slope. The soil was medium deep loam, with a pH 5.3 (0.1 mol/L KCl). Based on the ammonium lactate extraction procedure the soil contained 35.9 mg soluble-P_2O_5-P, 45.7 mg soluble-K_2O-K, and 25.9 mg soluble-MgO-Mg per 100 g of air-dried soil from a soil layer of 0–30 cm. The soil samples were taken before the start of the trial (in April 2002) according to technical guidelines for integrated grapes production. Fertilizers were not applied during the experimental period.

Every spring until the start of the trials and during the experimental period, the soil surface around the grapevines (a 0.6 m strip) was treated with herbicide (glyphosate). Five years before the start of our experimental period, the remaining inter-row spacing (1.8 m width) had been grown over by natural vegetation and mulched six times a year. Three systems for vineyard soil management in inter-row spacing were compared: permanent green cover (PGC), straw-cover (SC), covered with 5 t straw per ha, and periodical soil tillage (PST) of each second inter-row spacing. A similar approach was described by Bauer et al. (2004) and Hacisalihoglu (2007). In PGC treatment, we mulched six times a year, while in the PST treatment, inter-rows were periodically tilled (May, August) with a rotary tiller when the sward reached 30 cm. The investigation of these three treatments began in 2002 and the soil cultivation in inter-rows was carried out during the 3rd decade of May and 1st decade of August. SC was applied in April 2002. Each treatment was replicated four times with three inter-rows representing one replication. In the PST treatment, the inter-rows were tilled periodically, in the SC treatment they were covered with straw all the time of the experiment, while in the PGC treatment, all inter-rows continued to be mulched regularly.

In order to establish the weight of the eroded soil, pits (240 × 30 × 40 cm) were dug at the foot of the hill to catch the soil eroded from those inter-rows included in the experiment. The eroded soil was taken from the pits once a month (May to September), dried at 80°C, and weighed. Chemical analyses of the soil samples were carried out to establish the content of P_2O_5-P, K_2O-K and MgO-Mg. The weight of the eroded soil and the quantity of eroded nutrients were calculated per hectare

with regard to the investigated inter-rows. The activity of soil was assessed in 2002 and 2003, by monitoring the number of earthworms (belonging to the family Lumbricidae) per m^2, in the soil profile at the depth of 0 to 60 cm.

Statistical evaluation of data was performed by the SPSS 15.0 program with one-way analysis of variance (ANOVA). Means were compared using the *LSD* test. Statistical significance was evaluated at $P \leq 0.05$.

RESULTS AND DISCUSSION

Under partial soil tillage (PST), the erosion calculated as a total per year varied from 1.480 kg/ha soil in dry year 2003 to 2.012 kg/ha in average year (2002). In PGC and SC treatments, soil erosion amounted, on average, to about 48 kg/ha (SC 2003) and 98 kg/ha per year (PGC 2002) (Table 1); which is, on average, less than 5% of the eroded soil in PST treatments. Regarding the PST treatment, together with eroded soil, nutrients loss also occurred: 721 g P_2O_5-P, 919 g K_2O-K and 531 g MgO-Mg per ha (calculated as average per year 2002). Substantially fewer nutrients were lost in PGC and SC treatment.

The weight of the eroded soil and, consequently, the level of nutrient loss were lower in PST treatment than in experiments performed in vineyards in Germany by Hacisalihoglu (2007). An even higher weight of eroded soil was established by Martinez-Casasnovas and Ramos (2006) in Mediterranean conditions. However, owing to differences in pedoclimatic conditions and the fact that in our trial inter-row spacing was only periodically tilled, our results cannot be directly compared. Yet, the lower amount of eroded soil in our trial (PST) shows that such soil management could be recommended.

A more-detailed analysis of eroded soil and nutrient loss under PST treatment (Figure 1) shows that a greater portion of total soil erosion occurred during one particular period, namely in August in both years; 2003 (592 kg/ha) and 2002 (1.269 kg/ha). During every year, this maximum erosion occurred shortly after tillage and was caused by slower renewal of grass cover compared to the spring period. In the case of the soil tillage performed in May, the erosion was significantly lower all year round. Thus, apart from soil characteristics, slope inclination and the amount of precipitation, soil erosion is also affected by the time of tillage. In our case, the effect of the time of tillage on the amount of eroded soil can also be connected with the fresh growth of sward after tillage, which is much more vigorous in May than in late summer. Generally, the lower contents of soil erosion and nutrient loss were achieved by PGC and SC treatment.

The coverage of the soil surface by plants in the PST treatment was lower by 23% and the sward composition changed significantly, especially in the dry year of 2003 in comparison to that in the PGC treatment. A similar occurrence is also established by Florineth (2000) for vineyards in dry areas. In our trial, some weeds, which are known as host plants for grapevine phytoplasm carriers (e.g. Bois noir) Sforza et al. (1998), did not occur at all, although the soil tillage applied in our investigation could promote their growth and multiplication.

PGC and SC provided better environment for the activities of macroorganisms (i.e. earthworms). The average earthworms population (*Lumbricus* spp.) in 2002 and 2003 in PGC and SC treatment, was almost 3-times higher (68 earthworms per m^2 in PGC and 65 earthworms per m^2 in SC treatment,

Table 1. Effect of soil management on erosion and loss of nutrients in the experimental vineyard during 2002 and 2003 (averages per year in g/ha)

Year	Treatment	Soil erosion (kg/ha)	P_2O_5	K_2O	MgO
2002	SC	64[b]	23[b]	29[b]	17[b]
	PGC	98[b]	35[b]	45[b]	26[b]
	PST	2012[a]	721[a]	919[a]	531[a]
2003	SC	48[b]	17[b]	22[b]	12[b]
	PGC	70[b]	25[b]	32[b]	18[b]
	PST	1480[a]	528[a]	672[a]	380[a]

PGC – permanent green cover; PST – periodic soil tillage, SC – straw-cover. Means with the same letter are not significantly different at *LSD* test ($P < 0.05$)

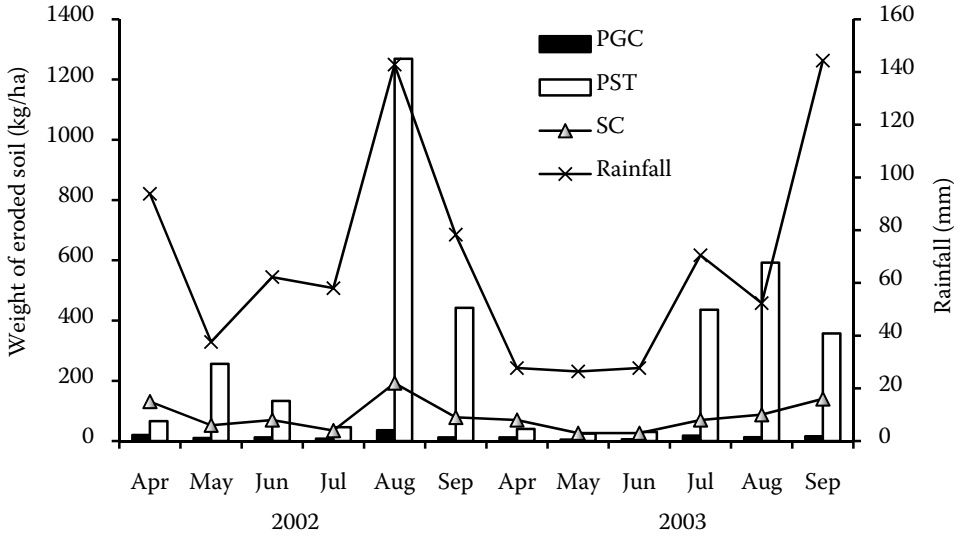

Figure 1. Monthly seasonal rainfall (2002 and 2003) and weight of eroded soil in vineyards with permanent green cover (PGC), periodic soil tillage (PST) and straw-cover (SC) treatments

respectively) than in PST treatment (25 earthworms per m^2). The soil management system also influenced the distribution of earthworms in the soil profile. In PGC and SC treatment, the highest earthworm population was found between 0 and 20 cm, whereas in PST treatment, the majority of earthworms were slightly deeper, between 10 and 20 cm. In SC treatment the highest earthworm population was in the upper 10 cm of soil profile. The biological activity of the studied earthworms was mostly diminished within the area treated with herbicide (a 0.6 m intra-row strip). In this area there were, on average, only six earthworms per m^2 and no more than two earthworms per 10 cm of depth (per m^2) (Figure 2). The investigation showed that the earthworm population could be considered as a direct indicator of the vineyard soil management quality. Soil macroorganisms were the most numerous and the most active in PGC and SC treatments. However, the establishment and maintenance of PGC is possible only in areas with sufficient rainfall during the vegetation season.

We are about to enter a period of much more rapid changes in wine-growing regions in Slovenia due to global warming. Figure 3 presents bioclimatic indicators, namely the sum of the effective temperatures (growing degree days), the average air temperature, and precipitation rates. The average temperatures in the growing seasons during the period 1980–2009 increased by 1.1°C, and the average annual temperature by 1.2°C over the last 20 years, compared to the annual average of the reference period from 1961–1990 (16°C). The analysis of data obtained by the monitoring of grape ripeness showed a trend towards earlier ripening and the growing season was shortened by 2–3 weeks over the last decade. During this period, the influence of climatic change on the shortening

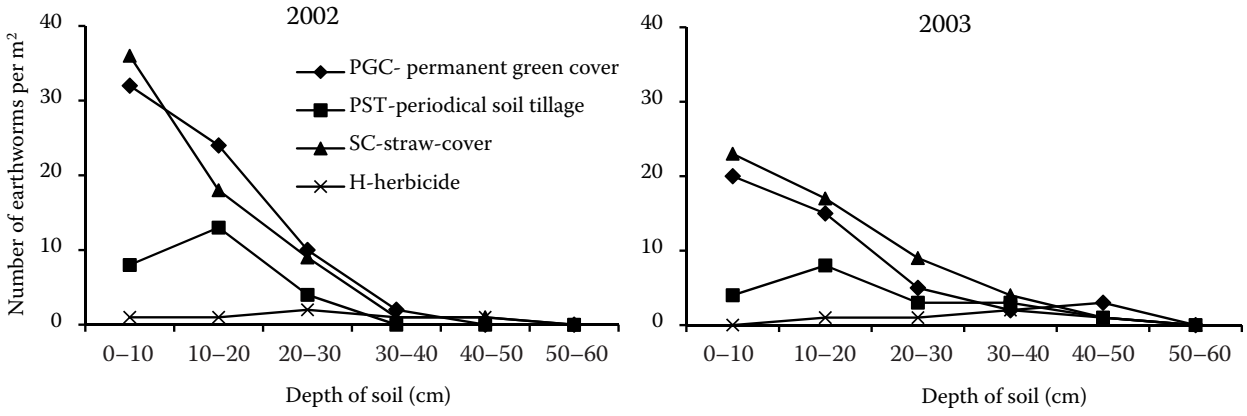

Figure 2. The number of earthworms in different soil management systems (PGC, PST, SC, H) in years 2002 and 2003 (dry year). Means within each soil depth with the same letter are not significantly different at *LSD* test ($P < 0.05$)

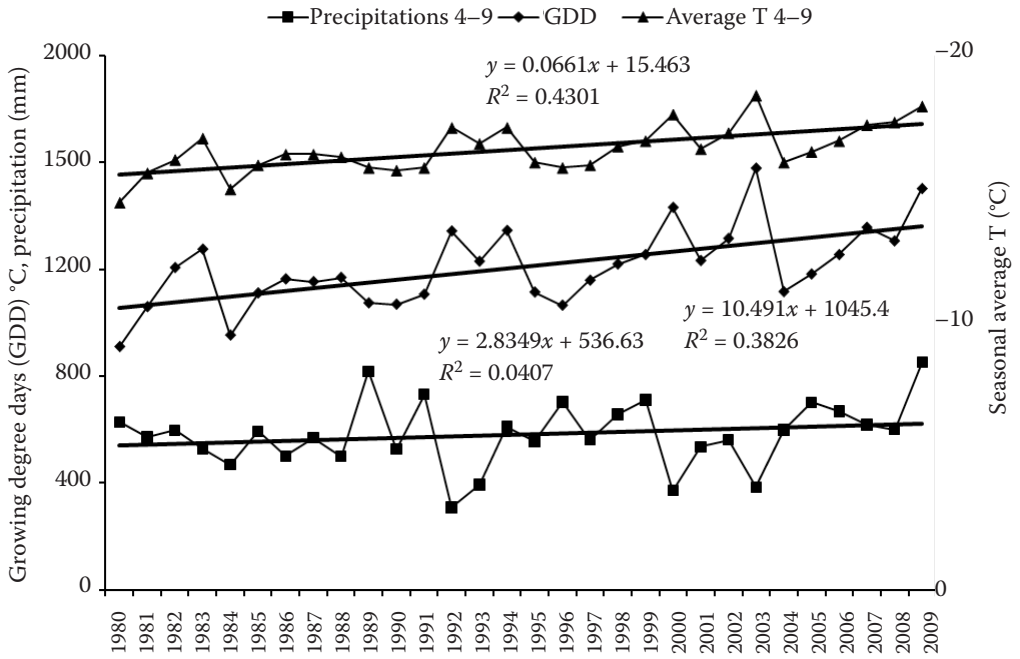

Figure 3. Seasonal precipitation rates (mm), average seasonal temperature (°C) and growing degree days (GDD) for the period 1980–2009

of the growing season can be very clearly seen in dry years (2001, 2003, and 2007). Hot summers result in earlier grape ripening and vintages.

Periodical soil tillage of inter-row spacing in our trials induced substantial soil erosion only when accompanied by heavy rainfall during the late summer months. Therefore, this soil management system can be recommended only in spring, when the sward fairly quickly overgrows the soil surface (it is very important in steep-slope vineyards) and in dry years. The surface runoff of water in vineyards with PST at the time of heavy rains is considerably higher than in vineyards with PGC and SC. Therefore in the light of adapting wine-growing techniques to the threatening climate changes in regions with permanently green covered vineyards, the PST soil management system should be further investigated, due to the fact that it is difficult to predict consequences of soil erosion accurately. In order to reduce erosion and the competition of plants in the green cover (PGC) of grape vine, straw cover may represent a possible alternative. The SC has other several advantages, since it increases organic matter in soil, reduces evaporation (dry year 2003) and intensifies the activities and population of earthworms.

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Corresponding author:

Prof. Stanko Vršič, University Centre of Viticulture and Enology Meranovo, Faculty of Agriculture and Life Sciences, Pivola 10, SI-2311 Hoče, Slovenia
e-mail: stanko.vrsic@uni-mb.si