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Effect of soil management systems on erosion and nutrition loss in vineyards on steep slopes

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Abstract

Green cover in vineyards on steep slopes may play an important role in the reduction of soil erosion. The main objective of this study was to investigate the effect of a permanent green cover (PGC) on soil erosion, together with any loss of nutrients, and to compare it with periodic soil tillage (PST). PST took place in the spring (May) and summer (August), in each second area between rows, in a vineyard with permanent green cover. In the case of PST experimental treatments, on average, 1892 kg of soil ha^{-1} yr^{-1} eroded, together with the nutrients. In the case of PGC treatments, the amount of soil erosion was only 92 kg ha^{-1} yr^{-1}. The greater portion of erosive events occurred after tillage in summer, which was accompanied by heavy rainfall and slow renewal of grass cover (slower than in spring). PGC treatment provided a better environment for the activities of soil macro-organisms (*i.e.*, earthworms belonging to the family Lumbricidae), and most of the organisms were close to the soil surface. In PST treatment, the majority of macro-organisms were below the area disturbed by the tillage (between 10 and 20 cm). The results of our investigation indicate that, in order to adjust wine production activities to climatic changes in vineyards with permanent green cover, PST in area between rows is more advisable in spring (end of May) than in summer (first decade of August) owing to an earlier establishment of effective grass cover.

Key words

Viticulture, Soil management, Erosion, Climatic changes, Soil macro-organisms

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Introduction

Wine production in Central Europe traditionally represents an important agricultural and economic activity (*e.g.*, 12% in Slovenia). For centuries, it had a significant environmental implication and impact on the morphology of the landscape, since vineyards mainly occupy hill-sides. The slopes 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 a regular and commonly applied practice 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 area between rows results in severe soil compaction (Redl *et al*., 1996). These problems can be lessened by various types of permanent or temporary green 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 soil tillage is carried out in area between rows (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 (Martinez-Casasnovas and Sanchez-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 cover. For this reason, permanent green cover in vineyards in hilly areas can be a highly beneficial practice (Bergant and Kajfez-Bogataj, 2004).

In order to establish an efficient, permanent green cover we have to consider those plant species which develop strong root systems whilst, at the same time, do not compete too much with the grapevines for water and nutrients (Vrsic and Lesnik, 2005, McGourty, 2008). In comparison with periodic soil tillage (PST), permanent green cover (PGC) has several advantages, since it increases organic matter in the soil and intensifies the activities of macro- and micro organisms (Kobel-Lamparski and Lamparski, 2000). Despite reducing the occurrence of plant diseases, during dry seasons PGC (Corino *et al.,* 1996), it considerably impairs grapevine growth and reduces grape yield. It can also lead to rapid and atypical wine aging (Hillebrand *et al.,* 1995).

Higher temperatures in the cooler half of the year in northern latitudes are also among the consequences of global climatic changes (Kajfez-Bogataj, 2003). The estimated increase in temperature for Slovenia is from 0.5 to 2.5°C for the period 2001-2030. Due to intensified global warming over recent years, we can expect more frequent and longer dry seasons (Bergant and Kajfez-Bogataj, 2004) and occasional heavy rains, which may cause serious soil erosion (Vrsic *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 method, which would reduce any unwanted negative impact of PGC in the event of more severe droughts. One such possible option could be periodical soil tillage between rows (*e.g.*, each second area between rows) during the growing season. After each soil cultivation the tilled areas between rows are gradually covered by natural vegetation.

The main objective of this study was to investigate the effect of a permanent green cover (PGC) consisting of natural vegetation on soil erosion and loss of nutrients, and compare it with the periodic soil tillage (PST) in areas between rows permanently covered with natural vegetation in a vineyard planted with 'Sauvignon blanc', under specific Slovenia's climatic conditions.

Materials and Methods

The trials were conducted in the years 1997, 1998 and 2002, at the University Centre for Viticulture and Enology at Meranovo, Faculty of Agriculture and Life Sciences, Maribor, NE Slovenia (46°53' N, 15°56' E, 407 m a.s.l.), Central European climatic conditions. The experimental work was carried out in a six-year old plantation of 'Sauvignon blanc'. 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 over the whole year.

The vineyard surface inclination was 34%, the length of each row was 82 m, the distance between rows was 2.4 m, and the average area of each replication was 197 m^2. The grapevine rows ran vertically along the slope. The soil was medium deep loam, with a pH (0.1 M KCl) of 5.3. Based on the ammonium lactate extraction procedure, the soil contained 35.9 mg soluble-P_2O_5, 45.7 mg soluble-K_2O, and 25.9 mg soluble-MgO per 100 g of air-dried soil from a soil layer of 0-20 cm. 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 a herbicide (glyphosate). Five years before the start of our experimental period, the remaining space between the rows (1.8 m wide) had been grown over by natural vegetation and mulched, 6 times a year. Two experimental practices for vineyard soil management in areas between rows (in a vineyard with permanent green cover) were compared: treatment with permanent green cover (PGC) and treatment with periodical soil tillage (PST) of each second area between rows. Similar, although not the same practice was described by Bauer *et al.* (2004) and Hacisalihoglu (2007). In PGC treatment, we mulched 6 times a year, while the PST treatment was tilled with a rotary tiller when the sward reached 30 cm. The remaining areas between rows in this treatment were mulched at the same time. Investigation of these two practices began in 1997 and the soil cultivation in areas between rows was carried out during the 3rd decade of May and 1st decade of August. Each treatment was replicated four times; three areas between rows representing one replication. In the PST treatment, the central areas between rows were tilled while, in the PGC treatment, all areas 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 areas between rows included in the experiment. Samples of the eroded soil were taken from the pits once a month, dried at 80 °C, and weighed. Chemical analyses of the samples were carried out to establish the content of P_2O_5, K_2O and MgO. The weight of the eroded soil and the quantity of eroded nutrients were calculated per hectare with regard to the investigated area between rows. The activity of soil macro-organisms was assessed in 2002, by monitoring the number of earthworms (belonging to the family *Lumbricidae*) per m^2, in the soil profile from 0 to 60 cm deep.

In order to estimate climatic change, we analysed the data associated with ripening of the cv. 'Sauvignon blanc', collected during the period 1980-2008, in the same vine-growing region (NE Slovenia). Based on the content of sugar and titratable acids, trends towards a shortening growing season and the recommended date of harvest in a particular year were calculated. The harvest took place when the sugar content in grape juice reached approximately 18-20 °Brix.

Statistical evaluation of data was performed by the SPSS 15.0 program with one way analysis of variance (ANOVA). Means

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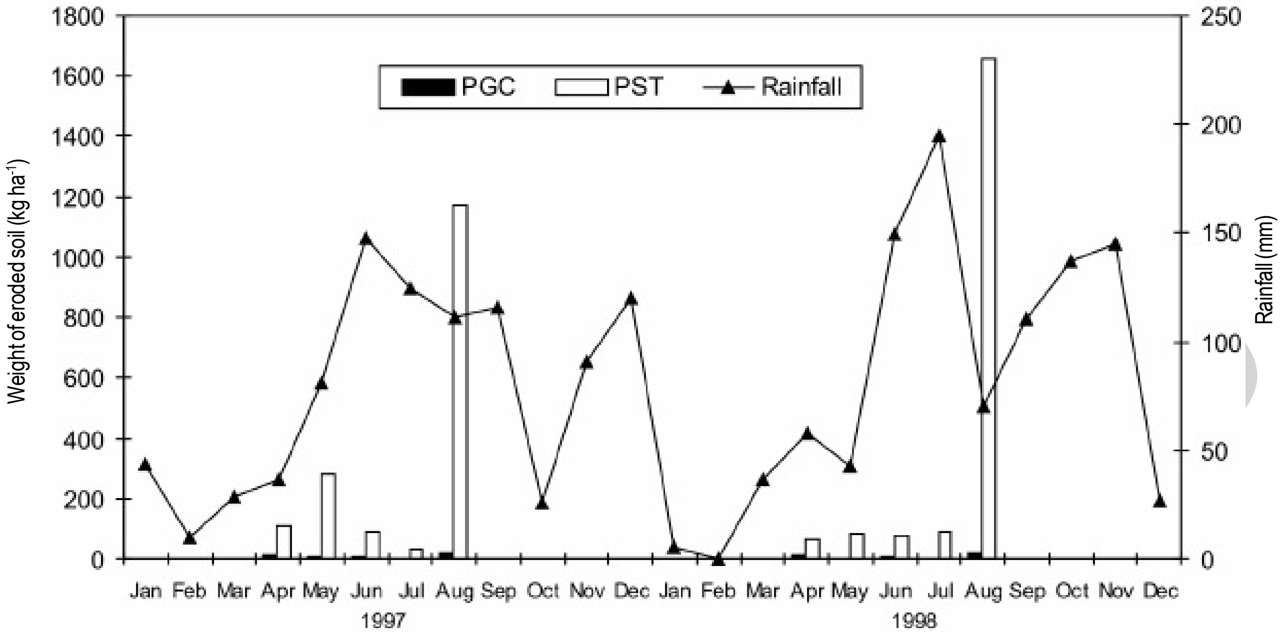

Fig. 1: Monthly rainfall (1997 and 1998) and weight of eroded soil in vineyards with permanent green cover (PGC) and periodic soil tillage (PST) treatments

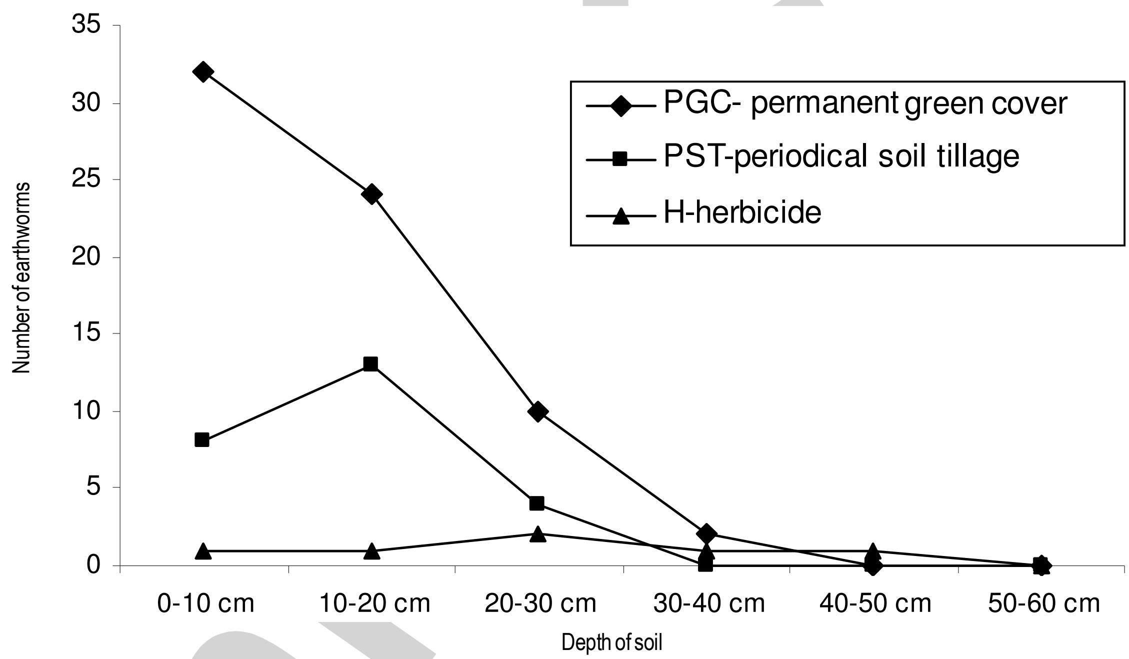

Fig. 2: The number of earthworms in different soil management systems

were compared using the LSD test. Analyses were carried out on data for grape yield, pruning weight, botrytis on the grape (%), weight of eroded soil, and loss of nutrients. Statistical significance was evaluated at $p \leq 0.05$.

Results and Discussion

Soil erosion and nutrient loss: Under partial soil tillage (PST), the erosion calculated as a total per year varied from 1,680 kg soil ha^{-1} (1997) to 2012 kg ha^{-1} (2002). In PGC treatment, soil erosion amounted, on average, to about 92 kg ha^{-1} yr^{-1} (Table 1) and 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: 676 g P_2O_5, 861 g K_2O and 491 g MgO ha^{-1} (calculated as average per year). Substantially fewer nutrients were lost in PGC treatment, only 33 g P_2O_5, 42 g K_2O in 24 g MgO ha^{-1}.

The weight of the eroded soil and, consequently, the level of nutrient loss were lower in PST treatment than in experiments performed on vineyards in Germany (6.47 t eroded soil ha^{-1} yr^{-1}), according to Hacisalihoglu (2007). An even higher weight of eroded

Table - 1: Effect of soil management on erosion and loss of nutrients in the experimental vineyard during 1997, 1998 and 2002 (values are averages per year)

Treatment	Soil erosion (kg ha^{-1})	P_2O_5 (g ha^{-1})	K_2O (g ha^{-1})	MgO (g ha^{-1})
PGC 1997	88	32	40	23
PST 1997	1680*	599*	763*	432*
PGC 1998	92	33	42	24
PST 1998	1976*	708*	903*	511*
PGC 2002	98	35	45	26
PST 2002	2012*	721*	919*	531*

PGC – permanent green cover; PST – periodic soil tillage, *Significant differences at 95 % confidence level

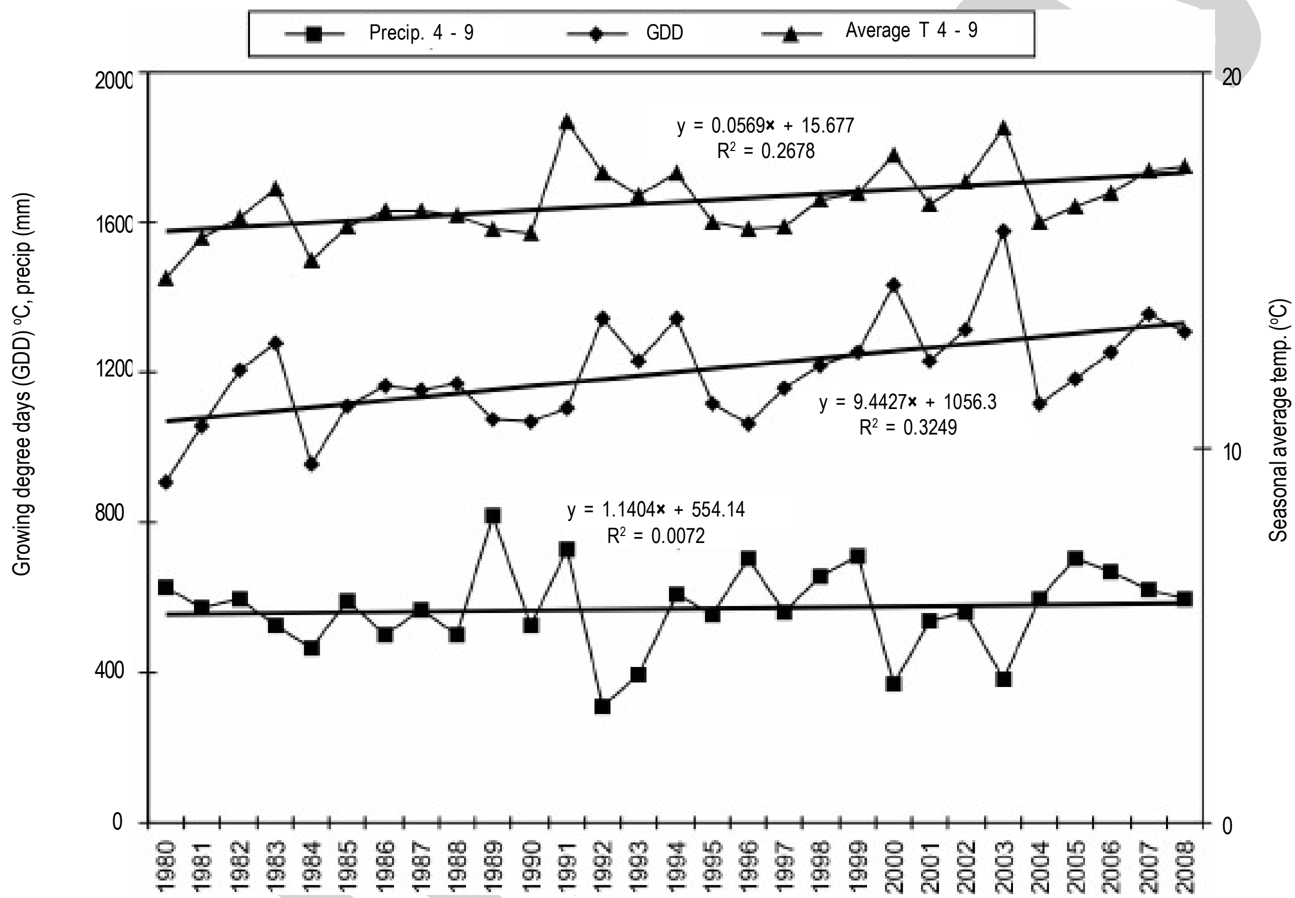

Fig. 3: Seasonal precipitation rates (mm), average seasonal temperature (°C) and growing degree days (GDD) for the period 1980-2008

soil was established by Martinez-Casasnovas and Ramos (2006) in Spain (19.5 t ha^{-1} yr^{-1}). However, owing to differences in pedoclimatic conditions and the fact that in our trial each second area between rows was periodically tilled, our results can not be directly compared. However, 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 (Fig. 1) shows that a greater portion of total soil erosion occurred during one particular period, namely in August for all years; 1997 (1174 kg ha^{-1}), 1998 (1662 kg ha^{-1}) and 2002 (1836 kg ha^{-1}). During every year, this maximum erosion occurred shortly after tillage and was caused by slower renewal of grass covering, compared to the spring period. In the case of the soil tillage performed in May, the erosion was significantly lower over all the years. Thus, apart from soil characteristics, slope inclination and the amount of precipitation, soil erosion is also affected by the time of tillage, as discoverd by Redl *et al*. (1996) and Bauer *et al*. (2004). However, 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 obtained by PGC treatment.

The coverage of the soil surface by plants in the PST treatment was lower by 23% and the sward composition changed significantly in comparison to that in the PGC treatment. A similar occurrence is also confirmed by Florineth (2000) for vineyards in

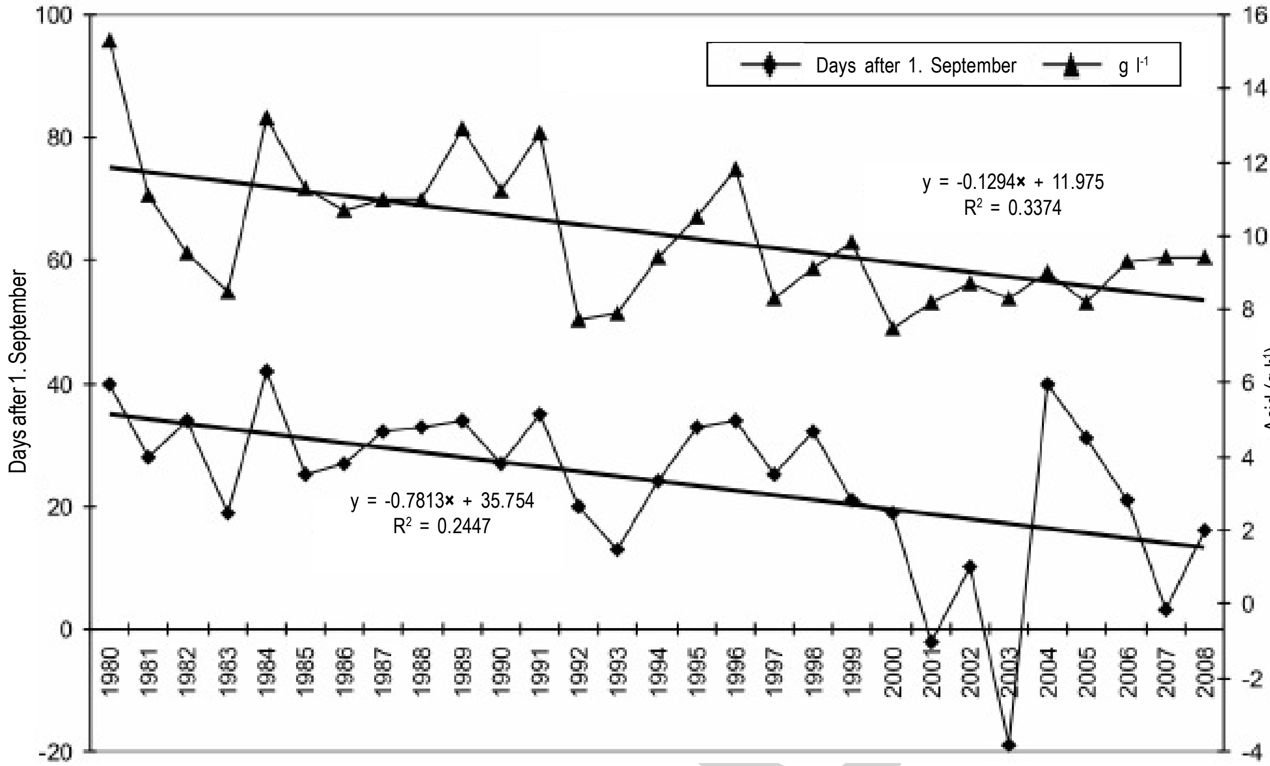

Fig. 4: The content of total titratable acids in grape juice and the date of harvest of the cv. 'Sauvignon blanc' in the period from 1980 to 2008

dry areas. In our trial, some weeds (*e.g.*, *Convolvulus arvensis* L.), 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 provided better environment for the activities of macro-organisms (*i.e.*, earthworms). The average number of earthworms in 2002, in PGC treatment, was almost 3-times higher (68 earthworms m^{-2}) than in PST treatment (25 earthworms m^{-2}). The soil management system also influenced the distribution of earthworms in the soil profile. In PGC treatment, the highest density was found between 0 and 20 cm, whereas in PST treatment, the majority of earthworms were a slightly deeper, between 10 and 20 cm. The biological activity of the studied macro-organisms was mostly diminished within the area treated with herbicide (around grapevines, a 0.6 m strip). In this area there were, on average, only 6 earthworms m^{-2} and no more than 2 earthworms per 10 cm of depth (per m^2) (Fig. 2). The investigation showed that the number of earthworms could be considered as a direct indicator of the vineyard soil management quality. Soil macro-organisms were the most numerous and the most active in PGC treatments. However, the establishment and maintenance of PGC is possible only in areas with sufficient rainfall during the vegetation season.

In comparison with PGC, PST treatment significantly increased the grape yield and the pruning dry weight over both years. The increased grape yield obtained in PST treatment, however, can be ascribed especially to the increased mineralization of organic matter in periodically tilled vineyard soil and to the increased availability of nutrients in the soil, especially nitrogen, as found by Bauer *et al.* (2004).

Effects of climatic changes on the cv. Sauvignon Blanc: This is confirmed by calculated bioclimatic indicators, namely the sum of the effective temperatures (growing degree days), the average air temperature, and precipitation rates (Fig. 3). Hot summers result in earlier grape ripening and vintages. These influences can also be seen in the Maribor wine-production region (NE Slovenia).

The average temperatures in the growing seasons during the period 1980-2008 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 of the cv. 'Sauvignon blanc' (Fig. 4) 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 of the growing season by 'Sauvignon blanc' can be very clearly seen in dry years (2001, 2003 and 2007).

The trend towards reducing the content of total titratable acids can be considered as a result of higher temperatures during the growth period of the berries and grape ripening. In the case of the cv. 'Sauvignon blanc', this difference is approximately 4 g l^{-1} (Fig. 4). From the aspect of the contents of total titratable acids, this influence of higher temperatures is positive only for late ripening varieties, since the trend towards the reduction of acids is approaching optimal values.

Periodical soil tillage of row middles in our trials induced substantial soil erosion only when accompanied by heavy rainfall during the late summer months. Therefore, this practice can be recommended only in spring, when the sward fairly quickly overgrows the soil's surface. The surface runoff of water at the time of heavy rains is considerably higher than in vineyards with permanent green cover. The results of our trials show that vine vigour and yield of grapes increased in treatment with periodical soil tillage of the row middles. Therefore in the light of adapting winegrowing to the threatening climate changes in regions with permanently green covered vineyards, the practice of periodical soil tillage should be further investigated. It will be particularly useful to find solutions for adapting periodical soil tillage to forecasts of longer dry and rainy periods, which affect the mineralization of organic substances in the soil and play an important role in providing an optimal nutrient supply - especially nitrogen - for grapevines.

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