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Comparison of three soil management methods in the Tokaj wine region

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The comparison of three soil management methods (mechanical cultivation, straw mulch, barley cover crop) in vineyards planted with the variety 'Hárslevelü' has shown that every method influences the eco-physiological parameters, the grape quality and the soil conditions, too. Investigating soil compaction, differences were found in the upper layers. Straw mulch reduced soil compaction and increased soil moisture as it protected the soil surface from intensive transpiration. The nitrite and nitrate content of the soil was highest in case of mechanical cultivation. The lower values with the straw mulched and with the barley covered variant can be explained with the temporary decrease of the nitrogen content resulting from the decay of straw and the nutrient uptake of the barley, respectively. With the net CO_2 assimilation and with the transpiration rate of the vines differences were also found between the treatments. Both parameters were higher on the straw mulched plots and lower in the mechanically cultivated plots. The covering with straw mulch had a positive effect on the soil water content, while the cover crop caused a higher water demand. The effect of the different management methods manifested in the yield and the percentage of noble rotted berries, as well. Regarding the yield, the straw mulch variant proved to be the best. The highest percentage of noble rotted berries was found in the bunches from the plots with barley cover crop in the years 2008 and 2009.
Keywords: grapevine, *Vitis vinifera* L., green cover with barley, straw mulch, ecophysiological indicators, grape quality, yield

Vergleich unterschiedlicher Bodenpflegemaßnahmen im Weinbaugebiet Tokaj. *Die vergleichende Untersuchung dreier verschiedener Methoden des Bodenmanagements (mechanische Kultivierung, Strohmulch, Begrünung mit Gerste) in Weingärten (Weinbaugebiet: Tokaj; Rebsorte 'Hárslevelü') zeigte, dass jede Methode sowohl ökophysiologische Parameter wie auch Traubenqualität und Bodenbedingungen beeinflusst. Hinsichtlich der Bodenverdichtung wurden Unterschiede in den oberen Bodenschichten festgestellt. Strohmulch verringerte die Bodenverdichtung und erhöhte die Bodenfeuchtigkeit, da er eine zu starke Verdunstung an der Bodenoberfläche verhinderte. Die Nitrit- und Nitratgehalte waren bei der Variante mit mechanischer Bearbeitung am höchsten. Die niedrigeren Werte bei den Varianten mit Strohmulch und Begrünung mit Gerste können mit einer vorübergehenden Verringerung des Stickstoffgehalts als Folge des verrottenden Strohs bzw. der Nährstoffaufnahme durch die Begrünungspflanzen erklärt werden. Hinsichtlich der Netto-CO_2-Assimilation und der Transpirationsrate der Reben wurden auch Unterschiede zwischen den Varianten festgestellt. Beide Parameter waren bei den Varianten mit Strohmulch höher und bei der mechanisch kultivierten Variante niedriger. Mulchen mit Stroh hatte auch einen positiven Effekt auf den Wassergehalt im Boden, während die Variante mit Begrünung einen höheren Wasserbedarf zeigte. Auswirkungen der verschiedenen Bodenpflegemaßnahmen zeigten sich sowohl beim Ertrag als auch im Anteil edelfauler Beeren. Hinsichtlich des Ertrages war die Strohmulch-Variante am besten, der höchste Anteil an edelfaulen Beeren wurde bei der Variante Begrünung mit Gerste in den Jahren 2008 und 2009 festgestellt.*
Schlagwörter: Rebe, *Vitis vinifera* L., Begrünung mit Gerste, Strohmulch, ökophysiologische Indikatoren, Traubenqualität, Ertrag

Comparaison de différentes mesures d'entretien du sol dans la région viticole Tokaj. *L'examen comparatif de trois méthodes différentes de la gestion du sol (traitement mécanique, paillage, plantation d'orge) dans les vignobles (région viticole : Tokaj ; cépage 'Hárslevelü') a montré que chaque méthode influence tant les paramètres écophysiologiques que la qualité des raisins et les conditions du sol. En ce qui concerne le compactage du sol, on a constaté des différences dans les couches supérieures du sol. Le paillage réduisait le compactage et augmentait l'humidité du sol en empêchant une évaporation trop forte à la surface du sol. Les teneurs en nitrite et nitrate ont été les plus élevées pour la variante du traitement mécanique du sol. Les valeurs inférieures obtenues pour les variantes du paillage et de la plantation d'orge peuvent être expliquées par une diminution passagère de la teneur en azote suite à la paille pourrissante et/ou par l'absorption de substances nutritives par les plantes. On a également constaté des différences entre les variantes en ce qui concerne l'assimilation nette du* CO_2 *et du taux de transpiration des vignes. Les deux paramètres étaient plus élevés pour la variante du paillage et moins élevés pour la variante du traitement mécanique. La couverture du sol avec de la paille avait également un effet positif sur la teneur en eau du sol, tandis que la variante de la plantation avait besoin d'une plus grande quantité d'eau. Les effets des différentes mesures d'entretien du sol se sont manifestés tant dans le rendement que dans la quote-part de baies atteintes de pourriture noble. Au niveau du rendement, la variante du paillage était la meilleure, la quote-part la plus élevée de baies atteintes de pourriture noble a été constatée dans la variante de la plantation d'orge au cours des années 2008 et 2009.*

Mots clés: vigne, *Vitis vinifera* L., plantation d'orge, paillage, indicateurs écophysiologiques, qualité des grains de raisin, rendement

Soil management is one of the most important questions of viticulture. It has an effect not only on the soil, but indirectly on the plants as well. Therefore it is relevant to choose the proper cultivation method. Especially in the case of integrated and organic farming it is important to apply environmentally friendly soil management methods.

In case of vineyards located on steep slopes, erosion, which can be caused by heavy rainfalls or by improper mechanical soil management techniques, represents a major problem. Therefore erosion has to be minimized by the selection of a suitable soil management method. A suitable soil management method improves the soil structure and as consequences compaction, erosion and nutrient losses can be reduced. Furthermore it provides better living conditions for the existing soil organisms which consequently increases the biological activity in the soil, and the organic matter content of the soil can be preserved. Soil moisture also depends on the cultivation method. The preservation of soil moisture is especially important in arid areas with less than 500 mm of precipitation per year and in the time span from June to August, when evapotranspiration is higher than precipitation, which is the case in Hungary (Bauer et al., 2004). Today farmers also have to face the effects of the climate change, so the preservation of soil moisture and the protection against erosion in case of heavy rainstorms will be more and more important. Since the growth of the roots is influenced by soil structure, the growth of the grape is also related to the compaction and the soil moisture (Wheaton et al., 2008). The nutrient uptake of the grape is affected by soil compaction, soil moisture and soil temperature. For example a positive correlation exists between the high soil temperature and the uptake of nitrogen (N), potassium (K), calcium (Ca) and magnesium (Mg) (Bogoni et al., 1995). Abnormal circumstances in the soil, for example lack of water, may cause stress to the plants, which influences both growth and yield negatively (Fardossi, 2002). Since soil management methods have an effect on photosynthesis and the stoma regulation of the plants, drought stress can be determined by measuring the stomatal conductance (Medrano et al., 2002; Cifre et al., 2005; Pou et al., 2008) and the pre-dawn water potential of the leaves (Ojeda et al., 2002).

The lack of water influences the development of the canopy, especially when the drought occurs in the first part of the vegetation period, when the water demand of the plants is high (Escalona et al., 2003). In case of drought, the stomatal regulation has a significant role in the inhibition of photosynthesis (Moutinho-Pereira et al., 2004). When soil water is easily extractable, the transpiration follows the atmospheric demand, whereas when the soil is dry, transpiration is reduced according to soil water depletion. The lack of water leads to a decrease of photosynthetical activity, which causes a lower vigorous vegetative growth, less yield and lower grape quality (Azevedo et al., 2008; Escalona et al., 2003).

One of the most often used soil management methods in vineyards of Hungary is mechanical cultivation. But when it is used too often or inadequately, negative effects like dry soil caused by greater evapotranspiration, decaying soil structure, erosion and nutrient losses can be observed (Bauer et al., 2004; Aljibury and Christensen, 1972; Dijck et al., 2002). Incorrect mechanical soil management can also lead to long-term traffic topsoil and subsoil compaction. (Ferrero et al., 2005; Zanathy, 2006).

Covering methods are ecological soil management techniques. As soil covering several materials (straw, reed, sedge, etc.) or cover crops can be used. Straw mulch is a relatively cheap and easily available material. Application of mulch has a lot of agronomic advantages, including the control of weeds and erosion as well as an improvement of the physical structure of the soil. The presence of mulch eliminates the need for frequent soil tillage in agro-ecosystems. It protects the soil like an umbrella from heavy rainstorms thus reducing erosion (Schuch and Jordan, 1981; Rinaldi et al., 2000; Varga and Májer, 2004). Maintaining a good soil structure is important, because soil moisture in the whole profile depends primarily on the intensity of rainfall, not on the total amount of it. At high intensities soil moisture increases only in the surface layer, but no significant increases were observed in deeper layers, where most of the roots are found. Under low intensity rainfalls, the increase in soil water content occurred in the whole profile (Ramos and Martinez-Casanovas, 2006). The water budget of the soil improves due to the better structure and the straw reduces water loss by evaporation. It enhances the soil environment for existing soil organisms by improving soil nutrient availability and reducing soil temperature fluctuations (Jacometti et al., 2007). When the straw decays it adds valuable nutrients to the soil, but because its C:N ratio is wide, additional fertilization with nitrogen (N) is needed. While the soil organisms incorporate the decaying straw into the soil, the nitrogen content can be temporarily reduced, which has a negative effect on the grapes (Fox, 1981).

Besides straw or other mulching materials, several crops can be used for soil covering. Permanent or only seasonal covering crops, legumes, but also non-legumes, are appropriate to cover the soil between the rows. Cover crops compete with weeds, prevent erosion and soil compaction and in addition, they increase the complexity of the agro-ecosystems. Cover crops facilitate the filtering of water into the soil and improve soil structure as well as the biological activity of the soil (Varga et al., 2007; Diófási et al., 2000). They have a positive effect on the nutrient content of the soil, especially when a leguminous plant is used, because of the biological fixation of atmospheric nitrogen (Bauer et al., 2004; King and Berry, 2005; Wheaton et al., 2008). However, cover crops also have negative effects on the vine performance since they compete with the vine for water and nutrients in the soil. Vineyards where precipitation is not high enough are not suited for permanent cover crops, because of the competition for water. In such cases a lower vine performance can be observed. The vegetative growth is reduced, which, however, can also have positive effects. Because of the lower canopy density, the microclimate of the plantation changes so that the vapor content of the air decreases, and as a consequence the infection of the grape with fungal diseases, for example *Botritys cinerea*, is reduced (Monteiro and Lopez, 2007; Steinberg, 1981; Varga and Májer, 2004). In some cases this effect can be disadvantageous, for example in the Tokaj wine region of Hungary, where the noble rot of the berries caused by *Botrytis cinerea* is important for the production of Aszú wines. Infection with Botrytis requires humid conditions, but later for the rotting period, it needs a drier climate. If the weather stays wet, grey rot of the bunches can be observed (Lehoczky and Reichart, 1968). There is an increased light penetration into the thin canopy, so the titratable acidity of the berries can be reduced and the sugar content will improve (Ingels et al., 2005).

Materials and methods

The experiment was set up in the Tokaj wine region in the year 2007, the measurements were performed from 2008 to 2009. The study was carried out on Royat cordon vines (with 1 × 1.8 m row and vine spacing). The investigated variety was 'Hárslevelü' clone K9 grafted on 'Teleki 5C' rootstocks. The following three soil management methods were tested: mulching with straw, barley cover crop (*Hordeum vulgare* L. convar. vulgare MSF.) and mechanical cultivation. Every treatment was located in five rows, in four replications per treatment. The plantation was located in a steepslope area on loess soil in the site of Hétszôlô ('Hárslevelü') where the prevention of erosion is especially important.

With mechanical cultivation, the soil was cultivated three times after the autumn ploughing. On the plots with barley cover crop (100 kg barley/ha) no cultivation was applied after the seed bed preparation and sowing. The straw mulch was applied in the year 2007 (5 kg/m^2), and it was renewed in May 2008 and 2009. Soil compaction was measured monthly from June to September in 2008 with a ScoutDat 900 penetrometer (Spectrum Technologies, Inc., Plainfield, USA). The nitrite (NO_2) and nitrate (NO_3) contents of the soil were measured from March to September, in the last pentade of the months in 2008 and 2009. The soil samples were collected from the upper (0 to 30 cm) and a medium (30 to 60 cm) soil layer. The transpiration rate and the net carbon dioxide (CO_2) assimilation were measured with an infrared gas analysator (LCi, ADC Bioscientific Ltd., Hoddeston, UK) on ten plants (vines) per treatment.

The pre-dawn and mid-day water potential of the leaves were measured with a pressure chamber (SPKM 4000; Skye Instruments Ltd., Llandrindod Wells, Powys, UK) on ten leaves per treatment.

The grapes were harvested in September and October (15. 09. 2007; 29. 09. 2008.; 16. 10. 2009) and the yield per vine was determined. Simultaneously the percentage of the noble rotted berries from 100 bunches per treatment was determined.

Data were analyzed by ANOVA (IBM SPSS Statistics 20). Differences were considered as significant at the 5 % level.

Results and discussion

Regarding soil compaction, in the deeper soil layers higher values were measured (more than 3500 kPa in some cases) than in the upper layers. This can be caused by the regular passing over with machines. This compaction was not influenced by mechanical cultivation, because it had only an effect in the upper layers (15 to 20 cm). Figures 1 (a to c) show that the compaction generally increased over the vegetation period, except on the straw mulched plots, where the compaction was lower in September due to the positive effect of the mulch.

Comparing the nitrite and nitrate content of the two investigated soil layers in the year 2009 the highest values in the medium soil layer were measured with the mechanically cultivated variant between the rows, because this cultivation method helps to decay the organic materials in the soil (Table 1). With the barley cover crop variant the nitrogen content was higher in April after the seed bed preparation in March. The lower values in September 2009 with the straw mulch and the barley cover crop variants can be explained with the pentosan effect, caused by the decaying straw and the nitrogen uptake of the cover crop, respectively. In the year 2008 the high nitrogen content in the upper layer (0 to 30 cm) was reduced on the mechanically cultivated plot from June to July (Table 2). The highest NO_2 and NO_3 contents were measured with mechanical cultivation in July in the medium layer (30 to 60 cm). Probably it can be explained with the mechanical cultivation treatment by the end of June and the extreme amount of precipitation in this period (68.7 mm). As a consequence of the treatment and the precipitation, the nutrients were washed into deeper layers. However, in these layers the nutrients are not so easily available for the vines. Because of this, it is not advisable to apply deep mechanical cultivation during the vegetation period.

Investigating the gas exchange parameters differences between the three treatments were also observed. The net CO_2 assimilation of the vines with the straw mulch was higher than that of the other treatments. The lowest values of transpiration rate and CO_2 assimilation were measured on the mechanically cultivated plots (Table 3 and 4). The results show, that during the measurements in August 2008, there was not a notable water stress, because the net CO_2 values were not below 4 µmol/m^2/s (Figure 2a and 2b).

The water potential of the leaves in the straw mulched plots was significantly lower than with the vines with mechanical cultivation and barley as cover crop. These results of the pre-dawn and mid-day water potential (Fig. 3) show the lowest values with the straw mulch variant because of its water demand. Higher water potential than with the variants with barley cover crop was observed with the mechanically cultivated plots, which also demonstrates the water consumption of the cover crops.

Comparing the yield and the percentage of noble rotted berries, differences could be observed between the variants over the whole experimental period. In both years the highest yield was measured with the plots with straw mulch, the lowest with the plots with barley as cover crop.

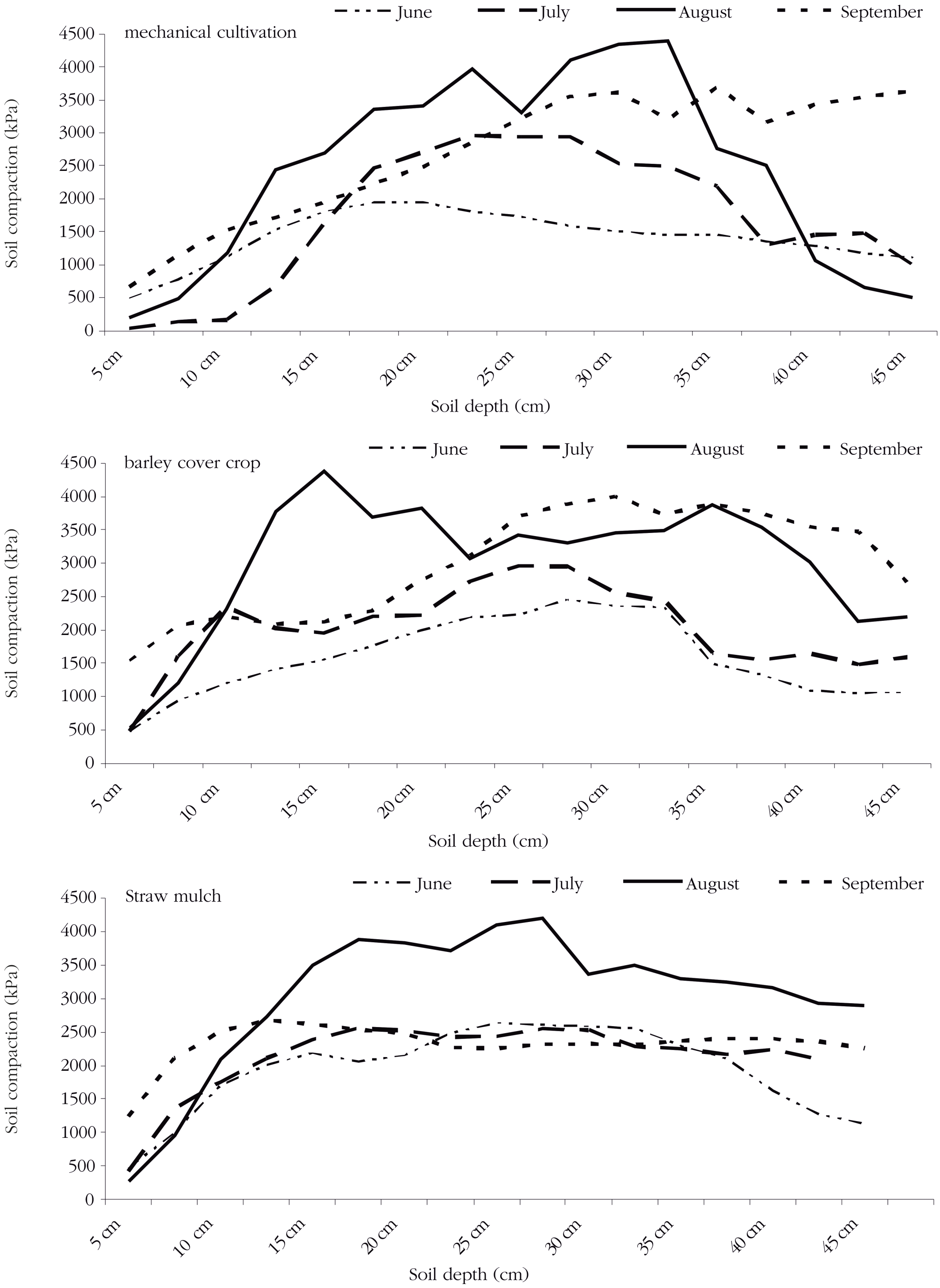


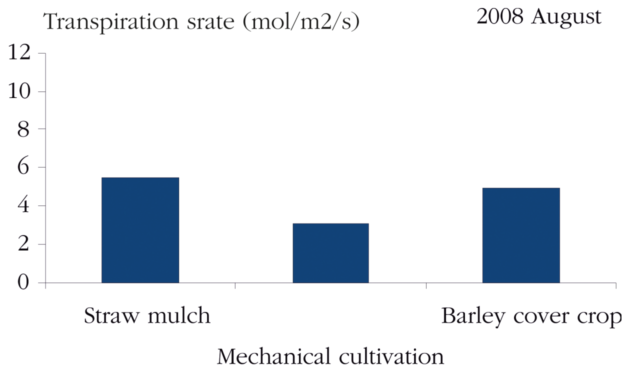
Fig. 1 a, b and c: Soil compaction, depending on soil depth from June to September (Tokaj, 2008) in case of mechanical cultivation (a), barley cover crop (b) and straw mulch (c)

Table 1: Influence of soil management on nitrite and nitrate content (mg/kg) in upper and medium soil layers (2009; * $P < 0.05$)

Upper soil layer (0-30 cm)	March	April	May	June	July	Aug.	Sept.	Mean
Straw mulch	0.75	9.07	10.35	11.88	12.32	5.41	0.58	7.19*
Mechanical cultivation	2.89	3.55	3.30	12.35	9.16	0.14	12.75	6.31*
Barley cover crop	0.99	8.00	4.71	1.53	0.97	2.30	6.28	3.54*
Medium soil layer (30-60 cm)	**March**	**April**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Mean**
Straw mulch	4.47	2.71	2.61	7.92	4.68	1.87	0.52	3.54
Mechanical cultivation	1.98	4.89	1.75	14.46	4.92	5.24	3.40	5.23
Barley cover crop	1.91	3.42	1.85	5.04	0.52	1.29	2.44	2.35

Table 2: Influence of soil management on nitrite and nitrate content (mg/kg) in upper and medium soil layers (2008; * $P < 0.05$)

Upper soil layer (0-30 cm)	March	April	May	June	July	Aug.	Sept.	Mean
Straw mulch	1.73	0.52	0.92	4.15	2.26	7.49	2.96	2.86*
Mechanical cultivation	3.03	3.89	3.96	11.22	7.24	7.06	10.19	6.66*
Barley cover crop	3.02	2.84	1.32	2.84	2.74	4.48	5.99	3.32*
Medium soil layer (30-60 cm)	**March**	**April**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Mean**
Straw mulch	1.97	0.35	0.80	2.26	3.63	0.95	1.60	1.65
Mechanical cultivation	6.65	1.25	2.44	4.96	11.79	3.89	9.32	5.76
Barley cover crop	2.12	0.48	1.28	1.78	0.65	1.34	2.56	1.46



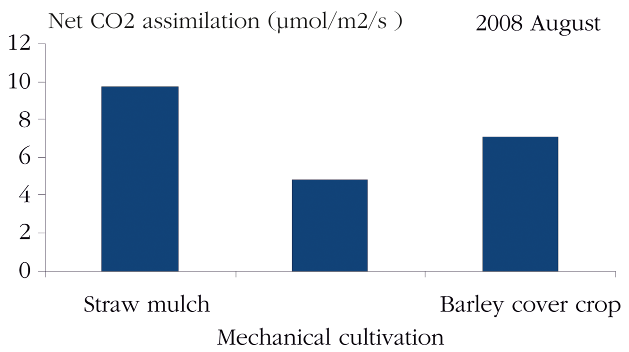


Fig. 2a: Transpiration rate on plots treated with different soil management methods
Fig. 2b: Net CO_2 assimilation on plots treated with different soil management methods

Table 3: Transpiration rate of vines during vegetation period at different plots treated with different soil management methods

Transpiration rate											Mean
Straw mulch	1.6	2.7	4.1	5.9	7,1	7.5	6.6	7.1	3.9	6.5	5.33
Mechanical cultivation	1.4	4.6	2.2	3.5	1.6	3.5	3.7	3.9	2.8	3.2	3.01
Barley cover crop	7.1	5.1	6.9	6.2	6.8	7.3	4.2	3.6	3.5	4.2	5.54

Table 4: Net CO_2 assimilation rate of vines over the vegetation period at different plots treated by different soil manage-ment methods (* $P < 0.05$)

Net CO_2 assimilation											Mean
Straw mulch	3.8	1.2	10.1	13.3	12.5	14.2	10.8	10.6	5.7	11.7	9.39*
Mechanical cultivation	3.0	8.9	0.7	3.6	3.5	5.9	5.8	5.2	5.9	5.1	4.76*
Barley cover crop	12.0	6.8	11.9	13.6	1.3	10.5	6.6	6.3	0.9	6.8	7.85*

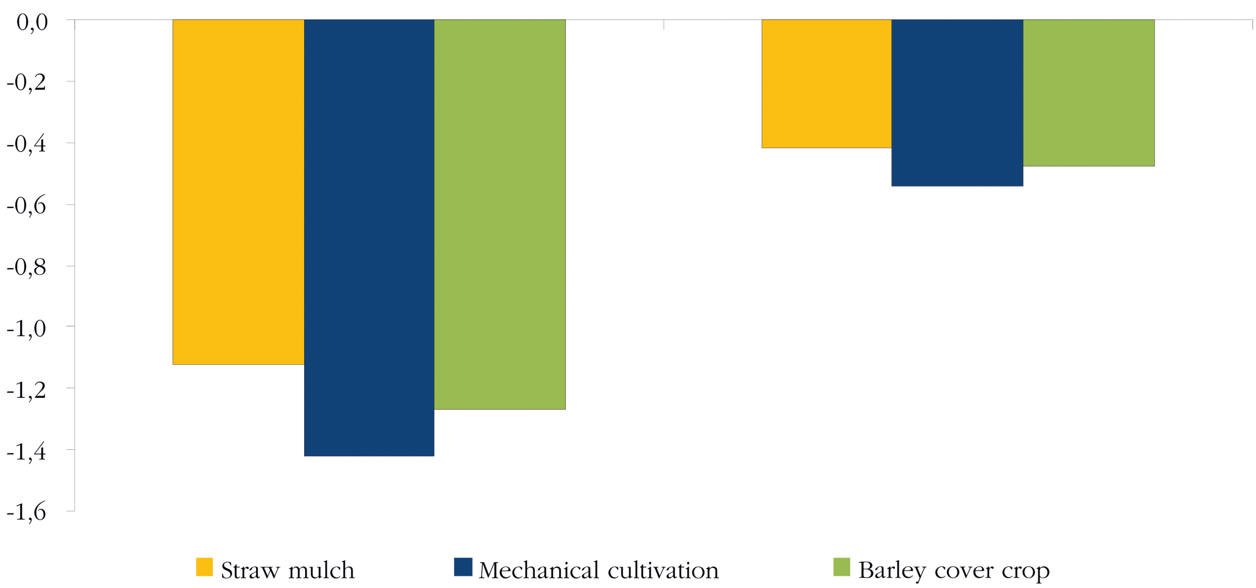
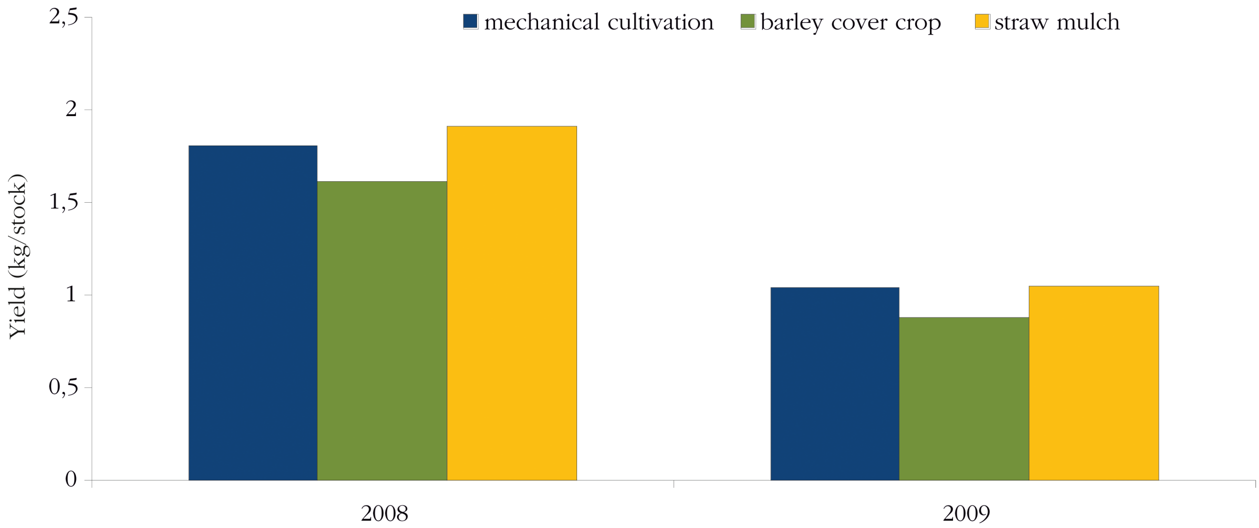


Fig. 3: Water potential of leaves on plots treated with different soil management methods (Tokaj, 2009)

The percentage of the botrytized berries was counted within the bunches. More infected berries were found in the bunches from the barley covered plots while the grapes from the mechanically cultivated rows contained fewer infected berries (Fig. 4a and 4b).

Conclusions

The results of this study show that in accordance with literature the different cultivation methods have an effect on the soil, but indirectly on the plants as well. Investigating the soil compaction, differences were found in the upper layers. Straw mulch had a positive effect on the soil compaction (Ferrero et al., 2005). The nitrate and nitrite contents of the soil were higher with mechanical cultivation. The lower values on the straw mulched and on the barley covered vines can be explained with the pentosan effect, resulting from the decaying straw and the nutrient uptake of the barley, respectively (Fox, 1981). With net CO_2 assimilation and transpiration rate of the vines also differences between the cultivation methods were found (Medrano et al., 2002). Both parameters were highest with the



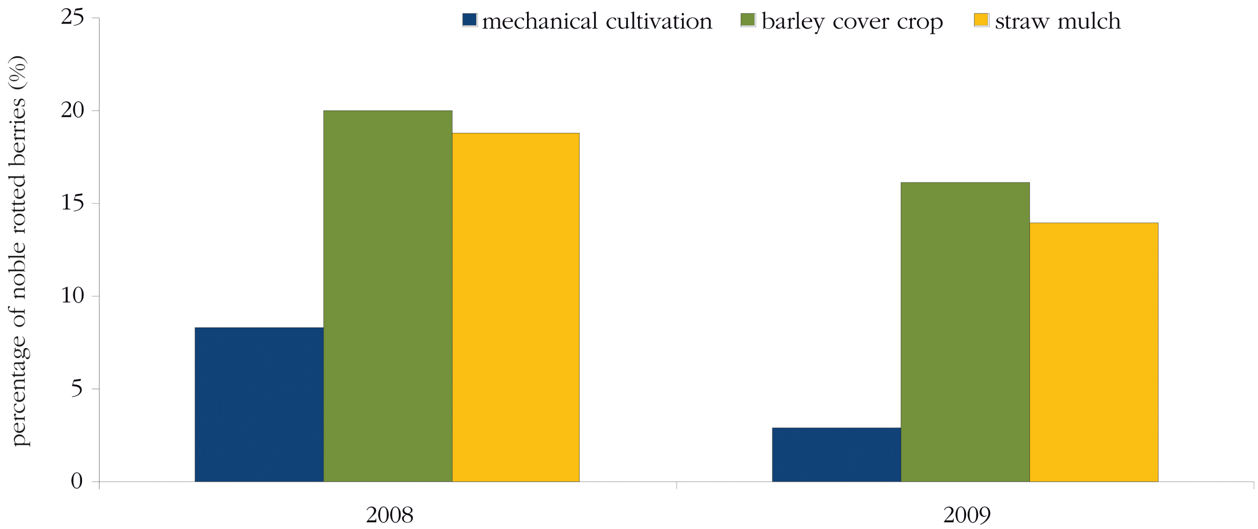


Fig. 4a: Yield from plots treated with different soil management methods in Tokaj
Fig. 4b: Percentage of noble rotted berries per bunch from plots treated with different soil management methods in Tokaj

straw mulched plots and lowest with the mechanically cultivated plots. The water potential of the leaves in the straw mulched plots was significantly lower than with the mechanically cultivated vines and with the barley covered variant, which may be caused by the higher moisture content of the mulched soil (Ojeda et al., 2002). Regarding the yield, the straw mulch variant proved to be the best technique (Varga and Májer, 2004). The percentage of noble rotted berries, which is the most important parameter in Tokaj regarding grape quality was highest with the barley covered variant (Göblyös, 2008).

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