EVALUATION OF EFFECT OF VEGETATION COVER ON SOIL COMPACTION

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Abstract. In terms of ensuring the sustainability and permanent soil fertility, the key role in viticulture is played by short-term and permanent greening in the interrow. Additionally, the introduction of these systems can positively affect flora and fauna species diversity in monoculture plantations, like vineyards, which are an integral part of the contemporary cultural landscape. This paper focuses on the evaluation of penetrometric measurements carried out in the years of 2015 and 2016 at 5 sites with different soil conditions and different greening (a mixture of annual greening, a mixture of durable greening, a mixture of durable greening with various plants species, a mixture of durable greening for arid conditions and a mixture of annual greening for pollinators) in the region of South Moravia. Penetrometer measurements were conducted using a manual penetrometer EIJKELKAMP. The water content in the soil at the time of the measurement, expressed in weight percentage was determined by the gravimetric method. Soil samples for moisture determination were collected in triplicate from the depths of 0-0.10 m, 0.10 to 0.20 m and from 0.20 to 0.30 m. The measured results show that the average values of penetrometric resistance from the soil surface to the depth, in different habitats and treatments mixtures ranged in 2015 at a depth 100-200 mm between 1.66-1.83 MPa, at a depth of 200-300 mm between 2.20-2.32 MPa and at a depth 200-300 mm between 2.43-3.19 MPa. In 2016, then the rate was at a depth 100-200 mm between 1.40-1.50 MPa, at a depth 200-300 mm between 1.52-1.67 MPa and at a depth 200-300 mm between 1.97-2.15 MPa. The results showed that a treatment of a mixture of annual greening and a mixture of durable greening with various plant species differs only slightly and based on the evaluation they are clearly the best. Comparisons between the two monitored years show very good agreement in the evaluation of alternatives.

Keywords: grapevine, vegetation cover, soil compaction, penetrometry, penetration resistance.

Introduction

Cropping systems in viniculture are increasingly focusing on technologies using the plant cover in between rows of vines. A suitable solution is the use of grassland systems made of diverse species of plant mixtures [1], which are the main tools in maintaining the soil fertility and partially a tool of quality management in viniculture [2-4].

Plant cover in between rows of vines helps in the formation of humus, improving of the soil structure and optimization of the water regime in soil [5-7]. Moreover, these aspects are reinforced by the increase of biodiversity and not only in the soil environment, but also above the soil surface in between vines. The whole complex of these factors can, with careful management, contribute to the increase of natural resistance of grapevine bushes, which in the final effect may be reflected also into increased quality of grapes [8; 9].

Vegetation cover fulfils also other significant functions. An important role is represented by the ability to dampen travel of mechanization vehicles and protection of soil against erosion effects [1; 10-13]. Gradwell [14], Prosdocimi et al. [15], Comino et al. [16] and Peacock [17] in their research works describe the positive effect of vegetation cover on maintaining a favourable soil structure, which helps reduce the extent of compaction. Because of these facts, in the recent years, the attention has been focused primarily on the use of various herbal mixtures, which are deliberately introduced between rows of vines [18]. From the perspective of ensuring good soil properties, legume or legume-cereal mixtures appear to be highly beneficial. Fabaceous plants of the family Fabaceae are valued especially. It is a huge family, containing a variety of plants, of which legumes are the most important (beans, peas, broad bean, etc.), but also fodder crops (clover, alfalfa, etc.). These plants are capable of producing a very rich root system, which may penetrate to a greater depth, in many cases up to 3 m. Thus, precipitation water has the opportunity to penetrate into the soil and it is not received only by shallow roots of plants just below the soil surface. Thanks to the higher content of humus caused by the activity of microorganisms, there is simultaneously the soil structure improved and the retention capacity of the soil is increased. There is no competition between grapevine and plants for water and nutrients [19]. An important role is played by the type and density of vegetation, which influence the effective hydraulic conductivity [20].

Fisher et al. [21] found that spatial and temporal changes in soil hydraulics can be explained by biotic processes, especially by the presence of certain functional plant groups influencing the quantity of earthworms, while the soil texture had no significant effect. Therefore, they suggest taking the biotic parameters into consideration in hydrological applications.

The objective of the work was to evaluate the influence of the vegetation cover in various species composition on the penetrometric resistance of soil between rows of vines with different soil conditions.

Materials and methods

Experimental sites

Experimental measurements were carried out in the years 2015-2016 at 5 sites with different soil conditions. The basic geographical and soil characteristics are stated in the following overview:

The site Mikulov/Bavory – Mi. Degraded chernozem soil on loess. Influenced by the anthropogenic activity (terracing of vineyard). The region – the outer Carpathians and Klippen Belt, coordinates 48º49´21,7″ North Latitude 16º37′39.5″ East Longitude, soil typology: PRm – modal pararendzina.

The site Popice/Gotberg – Go. Degraded chernozem soil on loess, sandy-loam to loam-sandy sediment. Influenced by the anthropogenic activity (terracing of vineyard). The region - the outer Carpathians and Klippen Belt, coordinates 48º56′06.0″ North Latitude 16º41′20,0″ East Longitude, soil typology: CEc: CEcp – carbonate black soil (pelic).

The site Popice/Sonberk – So. Degraded chernozem soil on loess, sandy-loam to loam-sandy sediment. The region - the outer Carpathians and Klippen Belt, coordinates 48º55′40,3″ North Latitude 16º41′52.1″ East Longitude, soil typology: CEc:CEcp – carbonate black soil (pelic).

The site Znojmo/Hnízdo – Zn. Sedimentary rocks of the tertiary sea, which form the lowland of the Jaroslavická board. The region – the Czech Highlands and the Western Carpathians, coordinates 48º45′18.2″ North Latitude 16º08′58,0″ East Longitude, soil typology: CEc – carbonate black soil.

The site Bzenec/Syrovín – Bz. The soil is created by unpaved sediment with the proportion of clay and sand, sometimes with proportion of gravel. The region – the Carpathians and the Vienna Basin, coordinates 49º01′57.0″ North Latitude 17º15′39.2″ East Longitude, soil typology: HNm – brown modal soil.

The sites are located with the altitudes of 223 until 325 m. The climate of the place is warm/summery and humidity is continental (type Dfb according to the Köppen classification). The overview of average annual temperature and total of rainfall from the experimental measured places is stated in Table 1.

Table 1

Values of particular meteorological parameters

Parameter	**Year**	**Experimental sites**				
		Mi	So	Go	Zn	Bz
Average annual temperature (ºC)	2015	11.6	11.6	11.0	10.9	11.3
	2016	10.9	11.0	10.5	10.2	10.7
Annual rainfall (mm)	2015	421.3	401.6	467.0	363.4	389.5
	2016	615.1	520.7	521.1	531.6	566.3

Equipment and soil penetration resistance measuring methods

Penetration resistance of soil in individual layers in the soil horizon was measured by the penetrometer of type Eijlkelkamp Eikelkamph P1.25. The device consists of a measuring needle tip, tensometric load cell sensor, optical sensor for depth measuring and electronics evaluation with a microprocessor and battery. Actual penetrometric measurements were performed in the area between rows of vines with the evaluated treatments of the vegetation cover. At all sites and for each experimental treatment, there were 30 measurements carried out in the depth range 0-520 mm. The measured values were corrected based on the determined soil humidity according to Lhotský [22]. The water content in % of the weight in soil was determined by the gravimetric method.

Experimental treatments of vegetation cover

At each site, there were 4 treatments of the vegetation cover evaluated, the species composition of which is stated in Table 2.

Table 2

Designation and composition of evaluated mixtures

Treatment	Working designation of the mixture	Species composition (% representation of species in the mixture)
A	Yearling mixture	*Lolium multiflorum* (25 %), *Phalaris canariensis* (15 %), *Phacelia congesta* (5 %), *Phacelia tanacetifolia* (5 %), *Trifolium alexandrinum* (10 %), *Camelina sativa* (10 %), *Fagopyrum esculentum* (5 %), *Sinapis arvensis* (5 %), *Trifolium resupinatum* (10 %), *Lotus ornithopodioides* (5 %), *Trifolium campestre* (5 %)
B	Perennial mixture - diverse	*Festuca ovina* (20 %), *Festuca rubra* (10 %), *Festuca arundinacea* (10 %), *Trifolium repens* (5 %), *Medicago lupulina* (15 %), *Trifolium pannonicum* (5 %), *Lotus corniculatus* (5 %), *Onobrychis viciifolia* (10 %), *Securigera varia* (5 %), *Anthyllis vulneraria* (15 %)
C	Perennial mixture - dry	*Festuca ovina* (40 %), *Trifolium repens* (20 %), *Festuca rubra* (20 %), *Medicago lupulina* (20 %)
D	Yearling mixture - pollinators	*Fagopyrum esculentum* (30 %), *Phacelia congesta “Fiona”* (20 %), *Calendula officinalis* (20 %), *Camelina sativa* (10 %), *Phalaris canariensis* (10 %), *Lolium multiflorum* (10 %)

Statistical analysis

A statistical analysis was carried out using the software package “Statistica 12.0” (StatSoft Inc., Tulsa, Oklahoma, USA). Analysis of variance was conducted and the results were compared using the Tukey’s multiple range test ($\alpha = 0.05$).

Results and discussion

As it is evident from the soil characteristics, individual experimental sites differ in the soil conditions, which may influence the values of the penetrometric resistance, but also differences between treatments at a given site. For the basic comparison of sites and experimental treatments representing individual grass mixtures, there were average values of penetration resistance at a given site used, determined based on the values measured in the horizon 100-520 mm for the spring and autumn term of the measurement (except the station Mikulov, where the average was determined in the horizon 100-300 mm). The overview of the average values of penetrometric resistance of soil and soil humidity at the time of the measurement is stated in Table 3.

The criterion to classify the influence of the used variant of plant mixtures was the evolution of the penetration resistance absolute values in time.

For the observed treatments in 2015, where the course of penetration resistance in the autumn time of measurement shows significantly lower values than in the spring measurement, there can be deduced a beneficial influence of individual treatments. This corresponds to the results of different authors as well [2; 23]. For evaluation by average values, there were averages determined from the measurement of the penetration resistance of soil for the horizon 100-520 mm, where there is the assumption that the root system has the highest influence on the soil properties. The positive influence is obvious especially at the site Zn, where the variant Zn-A reaches the average values of penetration resistance 2.29 MPa in the spring time and 2.03 MPa in the autumn time. From the evolution of values, there can be observed also the maximum depth of 400 mm, up to which this beneficial influence is applied. Similarly, in the variant Zn-B, the average values of penetration resistance reached 2.10 MPa in the spring time and 1.64 MPa in the autumn time. The beneficial influence of the treatment is applied up to the depth of 370 mm.

Table 3

Average values of penetrometric resistance of soil

Site	Treatment of mixture	Year 2015				Year 2016			
		Spring		Autumn		Spring		Autumn	
		SH*, weight %	APR*, MPa	SH, weight %	APR, MPa	SH, weight %	APR, MPa	SH, weight %	APR, MPa
Mi	A	12.7	2.36	18.9	1.34	14.4	1.58	19.7	1.17
	B		2.22		1.25		2.30		1.23
	C		1.26		1.36		2.02		1.33
	D		1.84		1.59		1.89		1.32
Go	A	10.5	2.18	21.2	2.46	16.9	1.18	11.2	1.33
	B		1.85		2.57		1.15		1.58
	C		2.28		2.48		1.22		1.46
	D		2.30		2.31		1.21		1.43
So	A	9.3	2.54	20.1	1.92	15.3	1.49	10.9	1.93
	B		1.87		2.32		1.58		1.84
	C		2.41		2.10		1.50		2.05
	D		2.09		2.06		1.61		2.00
Zn	A	13.8	2.29	23.7	2.03	12.9	1.35	16.7	1.45
	B		2.10		1.64		1.34		1.46
	C		2.15		2.78		1.30		1.45
	D		2.23		2.60		1.56		1.16
Bz	A	11.3	1.97	18.9	2.80	10.5	1.68	16.4	1.71
	B		2.34		2.69		1.43		1.78
	C		2.12		3.02		1.65		1.85
	D		2.23		2.86		1.82		1.86

** SH – Soil Humidity; APR – Average value of penetro-metric resistance of soil*

There can be similarly evaluated also treatments at the site So. In the variant So-A, the average of the measured values of penetration resistance in spring was 2.54 MPa, the autumn values showing the average of 1.92 MPa, while reduced values of penetration resistance were measured up to the depth 320 mm. Also in the variant So-C, there can be stated a beneficial influence of the soil properties with respect to the average value 2.41 MPa from the spring measurements and 2.10 MPa from the autumn measurements. The depth of the influence of the experimental treatment on decreasing the penetration resistance is 300 mm.

In terms of the depth of direct influence on soil properties, the variant Go-C (290 mm) and the variant Mi-A (260 mm) are comparable to the results of other authors [1; 2]. Opposite results were obtained by Smith et al. [24] and Rosa et al. [25], whose findings indicate the compaction increase in the cultivation of the topsoil layer until the depth 280 mm.

With respect to the applied aspects, the influence of planting was not absolutely shown at the site Bz. All variants (Bz-A to BZ-D) showed a clear shift of the measured values of penetration resistance from the autumn measuring above the values measured in spring. This state is visible also in the variant So-B or the variant Mi-C. Moreover, the stated variants showed the highest absolute values of penetration resistance in the range of 2.80-3.40 MPa. In terms of classification, which is stated by Arshad [26], these values mean high penetration resistance. According to the critical values [27], the variants Bz-A to Bz-D (loamy soil) showed penetration resistance of values just below the critical one, which are 3.4-4.2 MPa. Moreover, these values were measured in the depth 150-220 mm, in contrast to other variants, where the value of penetration resistance 3.00 MPa was measured at the depth 300-350 mm.

When assessing the influence of treatment of the vegetation cover on reduction of the values of penetration resistance by evaluation of the measured values from 2015, the treatment A (yearling mixture) and the treatment B (perennial mixture – diverse) can be considered the most effective at all sites (except for Bz). The treatment C (perennial mixture – dry) and the treatment D (yearling mixture – pollinators) applied a beneficial influence only at sites So and Go with the sandy loam soil type. The correct variant composition of mixture adopted to the conditions Linares [2], Uliarte et al. [28], Gago et al. [29], Smith et al. [24] and Agostinetto et al. [30] consider to be important as well.

In terms of average values of penetrometric resistance of soil in 2016 at the evaluated sites, there were found the lowest values at site Znojmo (loam-sandy soil on loess), ranging from 1.16-1.46 MPa according to individual treatments. At site Gotberg, the average values ranged from 1.33-1.58 MPa. The site Sonberk, which has the same soil type as Gotbert and average values of penetrometric resistance measured in the spring time were comparable here, showed the average values measured in the autumn between 1.84-2.05 MPa. There clearly appeared the influence of agricultural technology, i.e. greater frequency of travels. The site Bzenec (clay loam soil) showed average values in the range of 1.81-1.86 MPa. These values correspond to the degree of compaction in this soil type.

As a criterion for assessing the impact of specific plant treatment on the green landscape (A-D) at sites with different soil conditions the average values of soil penetrometer resistance measured in the depths of 100-200 mm, 200-300 mm and 300-400 mm were used.

In those monitored treatments, where the values of penetrometric resistance from the autumn observation are lower than the values measured in spring, there can be assumed a beneficial influence on soil generated by the root system of green cover. It is obvious especially at site Znojmo for all treatments. Moreover, the variant Zn-D showed these values as lower up to the depth of 350 mm. This fact suggests particular suitability of this variant for these soil conditions. Soil conditions at the sites Sonberk and Gotberg are almost identical, nevertheless, this beneficial influence is shown only by variants So-A and So-C and maximally up to the depth 240 or 190 mm. But most likely, in all variants at the site Gotberk, there appeared the above-mentioned influence of frequency of travel or heavier vehicles (for chemical protection) similarly to what Lagacherie [1] states. For comparison of the influence of the cover treatment, there can be used the fact that the root zone of plant community affects the soil horizon mostly up to the depth 300-400 mm. Therefore, it can be stated that the evolution of values of penetrometric resistance as well as its absolute values will be in correlation with a positive influence of the treatment. This can be visible in the variants Bz–B, Bz–D, Go–B, Go–C, also partially in So–B and Zn–B.

The stated comparisons from the year 2016 suggest a very good influence especially in the treatment B (perennial mixture – diverse) and the treatment A (yearling treatment).

For a comprehensive comparison of the effect of the monitored treatments, there were further the analysis of variance and average values of penetrometric resistances used in 3 partial horizons in the depths 100-200 mm, 200-300 mm and 300-400 mm. The evaluation is based on the assumption that the lowest sum of the average values of penetrometric resistance of these 3 horizons corresponds to the treatment with the most beneficial influence of vegetation on soil compactness. The average values of penetrometric resistance in 3 monitored horizons and the resulting order of monitored treatments from the perspective of their beneficial influence on soil environment for the period 2015-2016 are stated in Table 4 and Table 5.

Table 4

Average values of penetrometric resistance of soil (MPa) according to the depth, site and treatment of mixture (2015)

Year 2015	**Experimental sites**	**Treatment of mixture**			
		A	B	C	D
The depth of the soil horizon 100-200 mm	Mi	1.03±0.28ab	0.95±0.24a	1.35±0.50ab	1.46±0.43b
	Go	1.56±0.50a	1.84±0.27a	1.51±0.25a	1.56±0.33a
	So	1.72±0.43a	1.69±0.43a	1.27±0.26a	1.46±0.53a
	Zn	1.95±0.01c	1.18±0.16a	1.74±0.14b	2.22±0.07d
	Bz	2.63±0.16ab	2.66±0.38ab	2.82±0.32b	2.44±0.19a
	Average	1.78	1.67	1.74	1.83

Table 4 (continued)

Year 2015	**Experimental sites**	**Treatment of mixture**			
		A	B	C	D
The depth of the soil horizon 200-300 mm	Mi	1.71±0.57a	1.55±0.51a	1.37±0.79a	1.73±0.78a
	Go	2.90±0.29c	2.65±0.32bc	2.23±0.33a	2.43±0.40abc
	So	2.62±0.22a	2.40±0.22a	1.90±0.39b	2.70±0.21a
	Zn	1.89±0.06b	1.43±0.03a	2.42±0.22d	2.08±0.07c
	Bz	2.76±0.22ab	3.02±0.29a	2.96±0.27a	2.66±0.14b
	Average	2.37	2.21	2.17	2.32
The depth of the soil horizon 300-400 mm	Mi	2.49±0.83a	2.53±0.38a	2.52±0.70a	2.51±0.83a
	Go	3.00±0.22a	2.87±0.16a	3.06±0.12a	2.98±0.26a
	So	2.08±0.50b	2.62±0.39a	3.04±0.31a	2.66±0.23a
	Zn	1.90±0.10a	1.74±0.17a	3.35±0.29c	2.51±0.27b
	Bz	2.63±0.22a	2.80±0.24ab	3.21±0.15c	2.94±0.15b
	Average	2.42	2.51	3.04	2.72
Sum		6.57	6.39	6.95	6.87
Order		**2**	**1**	**4**	**3**

Data is expressed as means ± standard deviation (n = 30), different letters in the same row represent significant difference (p < 0.05).

Table 5

Average values of penetrometric resistance of soil (MPa) according to the depth, site and treatment of mixture (2016)

Year 2016	Experimental sites	Treatment of mixture			
		A	B	C	D
The depth of the soil horizon 100-200 mm	Mi	1.84±0.07a	1.93±0.15a	1.97±0.27a	1.92±0.19a
	Go	1.35±0.05ab	1.46±0.03c	1.42±0.03bc	1.29±0.10a
	So	1.80±0.05d	1.36±0.06a	1.46±0.06b	1.54±0.02c
	Zn	0.96±0.10c	0.83±0.05a	0.83±0.11a	0.52±0.12b
	Bz	1.49±0.02b	1.73±0.03a	1.82±0.09c	1.74±0.04a
	Average	1.49	1.46	1.50	1.40
The depth of the soil horizon 200-300 mm	Mi	1.50±0.63a	1.49±0.56a	1.77±0.66a	1.73±0.29a
	Go	1.29±0.03a	1.55±0.07b	1.35±0.04a	1.50±0.07b
	So	1.84±0.07a	1.46±0.09b	2.04±0.32a	1.85±0.20a
	Zn	1.43±0.18a	1.26±0.27a	1.22±0.13a	0.96±0.16b
	Bz	1.60±0.08b	1.83±0.03a	1.95±0.50c	1.80±0.07a
	Average	1.53	1.52	1.66	1.57
The depth of the soil horizon 300-400 mm	Mi	0.25±0.22a	0.40±0.19a	0.42±0.28a	0.45±0.19a
	Go	1.34±0.09c	1.66±0.07ab	1.55±0.11a	1.70±0.07b
	So	2.07±0.35a	1.93±0.20a	2.89±0.25b	2.74±0.33b
	Zn	2.16±0.14b	2.02±0.14ab	1.90±0.20a	1.43±0.15c
	Bz	1.87±0.03a	2.04±0.12bc	1.93±0.09ab	2.14±0.14c
	Average	1.54	1.61	1.74	1.69
Sum		4.56	4.59	4.90	4.66
Order		**1**	**2**	**4**	**3**

Data is expressed as means ± standard deviation (n = 30), different letters in the same row represent significant difference (p < 0.05).

Conclusions

1. In the years 2015-2016, there were experimental measurements carried out focused on the issue of the influence of the vegetation cover in between rows of vines on reduction of soil compaction. The measurements were carried out at 5 sites with different soil conditions. At each site, there were 4 treatments of vegetation cover evaluated with different species composition with the

working designation yearling mixture, perennial mixture – diverse, perennial mixture – dry and yearling mixture – pollinators.

2. In terms of the classification, which is stated by Arshad [26], soil conditions at individual sites are classified into the group with medium to high levels of penetrometric resistance.
3. The evaluation of the results implies that the treatment A – yearling mixture as well as the treatment B – perennial mixture – diverse have a significant influence on reduction of penetrometric resistance of soil and their sowing in between rows of vines can be recommended as a corrective measure restricting soil compaction.
4. The results might be used in grapevine practice when optimizing generic representation and at the same time at the procentric compound of mixture. The experiments show that limiting of compaction helps spread the mixture of a typical compound, mostly generis of *Phacelia, Trifolium, Sinapis a Lotus*.

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References

1. Lagacherie P., Coulouma G., Ariagno P., Virat P., Boizard H., Richard G. Spatial variability of soil compaction over a vineyard region in relation with soils and cultivation operations. Geoderma, vol. 134, 2006, pp. 207-216.
2. Linares R., De La Fuente M., Junquera P., Lissarrague J.R., Baeza P., Aurand J.M. Effects of soil management in vineyard on soil physical and chemical characteristics. BIO Web of Conferences, vol. 3, 2014, pp. 1-8.
3. Zalamena J., Cassol P.C., Brunetto G., Grohskopf M.A., Mafra M.S.H.M. Estado nutricional, vigor e produção em videiras cultivadas com plantas de cobertura. Revista Brasileira de Fruticultura, vol. 35, 2013, pp. 1190-1200. (in Portuguese).
4. Zalamena J., Cassol P.C., Brunetto G., Panisson J., Filho J.L.M., Schlemper C. Produtividade e composição de uva de vinho de videiras consorciadas com plantas de cobertura. Pesquisa Agropecuária Brasileira, vol. 48, 2013, pp. 182-189.
5. Fourie, J.C., Agnbag, G.A., Louw, P.J.E. Cover crop management in a Sauvignon Blanc/Ramsey vineyard in the semi-arid Olifants River Valley, South Africa. 3. Effect of different cover crops and cover crop management practices on the organic matter and macro-nutrient contents of a sandy soil. South Afr. J. Enol. Vitic., vol. 28, 2007, pp. 92-100.
6. Uliarte E.M., del Monte R.F., Parera C.A. Influencia del manejo de suelo mediante coberturas vegetales en el microclima de vi ˜nedos bajo riego (cv. Malbec). Le Bulletin de l’OIV, vol. 79, 2006, pp. 5-22. (in Spanish).
7. Uliarte E.M., Del Monte R.F., Parera C.A., Catania C.D., Avagnina de Del Monte S.M. Influencia del manejo de suelo mediante coberturas vegetales establecidas en el desarrollo vegetativo, produccion y caracteristicas de vinos en vi ˜nedos bajo riego superficial (cv. Malbec). Le Bulletin de l’OIV vol. 82, 2009, pp. 205-227. (in Spanish).
8. Göblyös J., Zanathy G., Donkó Á., Varga T., Bisztray G. Comparison of three soil management methods in the Tokaj wine region. Mitteilungen Klosterneuburg, vol. 61, 2011, pp. 187-195.
9. Hunter J.J., Archer E., Van Schalkwyk D., Strever A.E., Volschenk C.G. Grapevine roots: interaction with natural factors and agronomic practices. Acta Horticulturae, vol. 1136, 2016, pp. 63-80.
10. Boone F.R., Veen B.W. Mechanisms of crop responses to soil compaction. In: Soil compaction in crop production, Soane B.D., van Ouwerkerk C. (eds.). Elsevier Sci. Publ., 1994, Amsterdam, pp. 237-264.
11. Ferrero A., Usowicz B., Lipiec J. Effects of tractor traffic on spatial variability of soil strength and water content in grass covered and cultivated sloping vineyard. Soil and Tillage Research, vol. 82, 2005, pp. 127-138.

12. Mahdavi S., Fallahi E. Drought and Biostimulant Impacts on important Attributes of Perennial Ryegrass for Orchard and Vineyard Floor in the Intermountain West Region of the United States. J Am Pom Soc., vol. 70, 2016, pp. 216-223.
13. Rodrigo Comino J., Iserloh T., Lassu T., Cerdà A., Keestra S.D., Prosdocimi M., Brings C., Marzen M., Ramos M.C., Senciales J.M., Ruiz Sinoga J.D., Seeger M., Ries J.B. Quantitative comparison of initial soil erosion processes and runoff generation in Spanish and German vineyards. Science of The Total Environment, vol. 565, 2016, pp.1165-1174.
14. Gradwell M.W. Compaction of pasture topsoils under winter grazing. In: Proc. 9th Int. Soil Science Conf. University of Adelaide, SA, 1968, pp. 429-435.
15. Prosdocimi M., Jordán A., Tarolli P., Keesstra S., Novara A., Cerdà A. The immediate effectiveness of barley straw mulch in reducing soil erodibility and surface runoff generation in Mediterranean vineyards. Sci. Total Environ., vol. 547, 2016, pp. 323-330.
16. Rodrigo Comino J., Brings C., Lassu T., Iserloh T., Senciales J., Martínez Murillo J., Ruiz Sinoga J., Seeger M., Ries J. Rainfall and human activity impacts on soil losses and rill erosion in vineyards (Ruwer Valley, Germany). Solid Earth, vol. 6, 2015, pp. 823-837.
17. Peacock B. Managing Compacted Soils in Vineyards. 26 January 1999, Symposium on University of California Cooperative Extension – Tulare County.
18. Escalona J.M., Flexas J., Bota J. Distribution of leaf photosynthesis and transpiration within grapevine canopies under diff erent drought conditions. Vitis, vol. 42, 2003, pp. 57-64.
19. Bauer K., Fox R., Ziegler B. Moderne Bodenpflege im Weinbau: Ziele, Möglichkeiten, Massnahmen. Leopoldsdorf: Agrarverlag, 2004. 78 p. (in German).
20. Zhang X.C., Nearing M.A., Risse L.M. Estimation of Green-Ampt conductivity parameters: Part II Perennial crops. Transactions of the ASAE, vol. 38, 1995, pp. 1079-1087.
21. Fischer C., Roscher Ch., Jensen B., Eisenhauer N., Baade J., Attinger S., Scheu S., Weisser W.W., Schumacher J., Hildebrandt A. How Do Earthworms, Soil Texture and Plant Composition Affect Infiltration along an Experimental Plant Diversity Gradient in Grassland? PLoS One, vol. 9, 2014, e98987.
22. Lhotský J. Zhutňování půd a opatření proti němu: (studijní zpráva). Praha: Ústav zemědělských a potravinářských informací, 2000. 61 p. ISBN 80-7271-067-2. (in Czech).
23. Biddoccu M., Ferraris S., Opsi F., Cavallo E. Long-term monitoring of soil management effects on runoff and soil erosion in sloping vineyards in Alto Monferrato (North–West Italy). Soil and Tillage Research, vol. 155, 2016, pp. 176-189.
24. Smith R., Bettiga L., Cahn M., Baumgartner K., Jackson L.E., Bensen T. Vineyard floor management affects soil, plant nutrition, and grape yield and quality. California Agriculture, vol. 62, 2008, pp. 184-190.
25. Rosa J.D., Mafra A.L., Medeiros J.C., Albuquerque J.A., Miquelluti D.J., Nohatto M.A., Ferreira E.Z., De Oliveira O.L.P. Soil physical properties and grape yield influenced by cover crops and management systems. Revista Brasileira de Ciência do Solo, vol. 37, 2013, pp. 1352-1360.
26. Arshad M.A., Lowery B., Grossman B. Physical Tests for Monitoring Soil Quality. In: Doran, J.W. and Jones, A.J., Eds., Methods for Assessing Soil Quality, Soil Science Society of America, Madison, 1996, pp. 123-142.
27. Šimon, J., Lhotský J. Zpracování a zúrodňování půd. Praha: SPN, 1989. 317 p. ISBN 80-209-0048-9. (in Czech).
28. Uliarte E.M., Schultz H.R., Frings C., Pfister M., Parera C.A, Del Monte R.F. Seasonal dynamics of CO2 balance and water consumption of C3 and C4-type cover crops compared to bare soil in a suitability study for their use in vineyards in Germany and Argentina. Agricultural and Forest Meteorology, vol. 181, 2013, pp. 1-16.
29. Gago P., Cabaleiro C., García J. Preliminary study of the effect of soil management systems on the adventitious flora of a vineyard in northwestern Spain. Crop Protection, vol. 26, 2007, pp. 584-591.
30. Agostinetto D., Ferreira F.B., Stoch G., Fernandes F., Pinto J.J. Adaptação de espécies utilizadas para cobertura de solo no Sul do Rio Grande do Sul. Revista Brasileira de Agrociência, vol. 6, 2000, pp. 47-52. (in Portuguese).