Original Paper

The response of different soil management practices in a vineyard to water availability

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The effect of different soil management practices in a vineyard on water availability was studied. In 2006, an experiment of the different soil management practices in a productive vineyard in Rendzic Leptosol was established in the locality of Nitra-Dražovce (Nitra wine-growing area). In 2012, the soil samples were collected from all treatments: 1. G (grass without fertilization), 2. T (tillage), 3. T + FYM (tillage + farmyard manure), 4. G + NPK3 (grass + NPK 120-55-195 kg ha^{-1} – 3rd intensity of fertilization for vineyards), 5. G + NPK1 (grass + NPK 80-35-135 kg ha^{-1} – 1st intensity of fertilization for vineyards). The obtained results showed that the highest values of soil moisture were determined of T and T + FYM treatments. For G + NPK3, the average value of soil moisture was lower in comparison to other treatments. In the soil profile with the T treatment, the highest content of storage moisture (69.5 l m^{-2}) was observed, however, in the soil profile of G + NPK3, the lowest content (46.9 l m^{-2}) was determined. In comparison to control (G), the average values of available water capacity for T, T + FYM, G + NPK1 and G + NPK3 treatments were lower by 13 %, 7 %, 44 % and 65 %, respectively. The higher doses of nutrients had a negative effect on values of available water capacity. Soil management practices in the vineyard had a statistically significant influence on values of available water storage, while in T the highest value was observed. In G, G + NPK1 as well as in G + NPK3, this water category was absent. Between soil organic content, its labile forms, and soil moisture, negative correlations were observed. Hot-water soluble carbon (r = 0.405, P <0.05), quality (r = -0.502, P <0.01) and stability of soil organic matter (r = 0.359, P <0.05) correlated with available water capacity. At the same time the statistically significant correlation between particle-size distribution and parameters of water availability were determined.

Keywords: soil moisture, fertilization, soil organic matter, vineyards

1. Introduction

Vineyards are grown as a monoculture for many years in the same place and thus cause changes to the soil environment (Šimanský et al., 2009). Therefore, the establishment of a vineyard is a complicated process. There comes to a significant reshaping of the natural soil environment. This process is reflected in the biological, chemical and physical properties (Šimanský, 2012). In viticulture, attaining high quality grapes for winemaking is a priority for growers; therefore, the soil for vine growing has to be ideal. White (2009) identified the following key properties, with respect to an ideal soil for vine growing: soil depth, soil structure and water, soil strength, soil chemistry, and nutrient supply and soil organism. One of the most critical factors for the cultivation of the vine is the supply of water in the soil. Seguin (1986) also identified soil moisture as a major factor influencing crop yields, fruit composition and overall wine quality. It is important that vines have sufficient water to allow for adequate vine and berry growth, but not excess amounts which can lead to excess vigour and poor fruit composition and wine quality. Soil moisture affects fruit characteristics including colour, sugar content, flavour and aroma, and acidity (Chaves et al., 2007; Acevedo-Opazo et al., 2010). At present, Slovakia is prone to droughts and soil droughts, which negatively affect crop production, including major field crops (Mati et al., 2011). Therefore, we have to optimize soil management practices that manage available water in the soil.

The aim of this study was to investigate the effects of different soil management practices in a productive vineyard on water availability. We looked at the soil moisture in a vineyard subjected to tilled or grassed treatments in a dry year.

2. Material and methods

The study was carried out on an ongoing experiment with different management practices in a productive vineyard that had been running for seven years at Nitra-Dražovce, South

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Slovakia (48° 21‘ 6.16“N; 18° 3‘ 37.33“E). The experimental site has a mean annual temperature of 10 °C, and a mean annual precipitation of 550 mm. The average monthly precipitation and temperature in 2012, and their comparison with long-term averages are presented in Table 1. The year 2012 was assessed as dry in Slovakia. The soil, developed on limestone and dolomite is classified as Rendzic Leptosol according to the WRB Soil Taxonomy System (WRB, 2006). The soil texture is 56.9 ±2.3 % sand, 33.0 ±1.8 % silt, and 10.1 ±1.2 % clay. The soil at the start of the experiment had a pH of 7.18 and contained 7.0 ±1.6 g kg^{-1} of organic carbon, 1867 ±103 mg kg^{-1} of total N, 99 ±8 mg kg^{-1} of available P, 262 ±15 mg kg^{-1} of available K, and the base saturation percentage was 99.3 ±0.01 %.

The vineyard was established in 2000, and in 2003, a variety of grasses were sown in the inter-rows of the vines. In 2006, an experiment on the different management practices in a vineyard was carried out (Table 2). In 2012, before sampling, in each treatment a pit was excavated (total five pits) and the soil samples were collected (in triplicate) after 10 cm layers to a depth of 70 cm (to the soil-forming substrate – limestone and dolomite) to cylinders with an inner diameter of 5 cm and height of 5 cm.

Soil moisture was assessed as gravimetric soil moisture expressed in percentage (%) and then recalculated on volume percentage according to equation (1):

$$\theta = w \times \rho \qquad (1)$$

where:
θ – soil moisture by volume (%)
w – soil moisture by weight (%)
ρ – bulk density (kg m^{-3})

The storage moisture (W_s) in percentage was calculated according to equation (2):

$$W_s = \theta \times h \qquad (2)$$

Table 1 Average monthly precipitation and temperatures in 2012 (evaluations of standard monthly precipitation and temperatures are based on long-term averages in 1961–2001)

Month	Precipitation in 2012			Temperature in 2012		
	long-term average	precipitation in mm	difference	long-term average	temperature in °C	difference
January	31	61	30	-1.7	1.4	-0.3
February	32	24	-8	0.5	-2.5	-2.0
March	33	3	-30	4.7	7.4	2.7
April	43	36	-7	10.1	11.2	1.1
May	55	20	-35	14.8	17.3	2.5
June	70	70	0	18.3	20.9	2.6
July	64	61	-3	19.7	22.8	3.1
August	58	7	-51	19.2	21.5	2.3
September	37	33	-4	15.4	17.0	1.6
October	41	76	35	10.1	10.5	0.4
November	54	35	-19	4.9	7.5	2.6
December	43	44	1	0.5	-0.9	-1.4

Table 2 The investigated treatments in vineyard (Nitra-Drážovce)

Treatment	Description
Control (G)	– sown grass in the rows and between vine rows, without fertilization
Tillage (T)	– every year medium tilth to the depth of 0.25 m with intensive cultivation between vine rows during the growing season
Tillage + farmyard manure (T + FYM)	– medium tilth to the depth 0.25 m with ploughed farmyard manure (FYM) in a dose of 40 t ha^{-1} and intensive cultivation between vine rows during growing season
Doses of NPK fertilizers in 3rd intensity for vineyards (G + NPK3)	– this means: 120 kg ha^{-1} N, 55 kg ha^{-1} P and 195 kg ha^{-1} K (Fecenko and Ložek, 2000). The dose of nutrients was divided: 2/3 applied into the soil in the spring (bud burst – on March) and 1/3 in flowering (on May). The grass was sown in and between the vine rows
Doses of NPK fertilizers in 1st intensity for vineyards G + NPK1	– this means: 80 kg ha^{-1} N, 35 kg ha^{-1} P and 135 kg ha^{-1} K (Fecenko and Ložek, 2000). The dose of nutrients was divided: 1/2 applied into the soil in the spring (bud burst – on March) and 1/2 in flowering (on May). The grass was sown in and between the vine rows

where:
θ – soil moisture by volume (%)
h – thickness of the soil layer (dm)

The available water capacity (*AWC*) in percentage was calculated according to equation (3):

$$AWC = \theta_{FC} - \theta_{wp} \quad (3)$$

where:
θ_{FC} – field capacity (%)
θ_{wp} – wilting point (%)

The available water storage (AW_s) in percentage was calculated according to equation (4):

$$AWs = \theta - \theta_{wp} \quad (4)$$

where:
θ – soil moisture by volume (%)
θ_{wp} – wilting point (%)

One-way analysis of variance was used to analyze differences in tested parameters. Non-parametric test (Kruskal-Wallis ANOVA) was used to test differences between observed parameters under different soil management practices. Correlations between soil organic matter, particle-size distribution and parameters of water availability were evaluated by calculating simple linear correlation coefficients (deeming results to be very significant and significant if $P < 0.001$, $P < 0.01$ and $P < 0.05$, respectively). Statgraphics Centurion XV.I (Statpoint Technologies, Inc., USA) was used for all of these statistical analyses.

3. Results and discussion

Soil management practices in the vineyard had statistically significant influence on values of soil moisture (Table 3). In soil profile where the doses in 3rd intensity of fertilization for vineyards were applied, the average value of soil moisture was the lowest in comparison to other soil management practices. Higher doses of nutrients added to the soil had a positive effect on increased production of biomass in rows and inter-rows in the vineyard (Šimanský, 2011), which is the reason for higher evapotranspiration and lower soil moisture. In T and T + FYM treatments, the highest values of soil moisture (without statistical significance) were determined (Fig. 1). In these cases, cultivation of topsoil (during vegetation of vine) was the cause of disconnecting the capillary pores, which resulted in a decrease of evaporation. For example, Schönberger (2013) recommended in a climatically dry year, that deeper soil cultivation be practised in order to create a high content of gravitational pores. This measure will allow a faster infiltration of water into the soil during high rainfall, leading to an increase of total water storage. The storage moisture expresses the soil water content in the soil layer at the time of collection (Fulajtár, 2006). The content of storage

Table 3 Statistical evaluation of parameters of water availability – Kruskal-Wallis test (Average rank)

Treatments	θ	*AWC*	AW_s
G	15.7	27.6	13.0
T	25.2	19.8	22.2
T + FYM	23.2	22.0	25.8
G + NPK3	8.10	6.14	13.0
G + NPK1	14.7	10.6	13.0
P-value	0.010	0.000	0.001
t-test	13.24	22.41	18.24

G – control, T – tillage, T + FYM – tillage + farmyard manure, G + NPK3 – doses of NPK fertilizers in 3rd intensity for vineyards, G + NPK1 – doses of NPK fertilizers in 1st intensity for vineyards
θ – soil moisture, *AWC* – available water capacity, AW_s – available water storage

moisture decreased in the following order: T (69.5 l m^{-2}) > T + FYM (66.5 l m^{-2}) > G (61.0 l m^{-2}) > G + NPK1 (58.4 l m^{-2}) > G + NPK3 (46.9 l m^{-2}). In the depth from 0.3 to 0.6 m, the content of storage moisture decreased in the following order: T + FYM (38.7 l m^{-2}) > T (38.5 l m^{-2}) > G (29.0 l m^{-2}) > G + NPK1 (26.4 l m^{-2}) > G + NPK3 (22.5 l m^{-2}). The results show that tillage and tillage with farmyard manure had positive effect on the moisture storage capacity of Rendzic

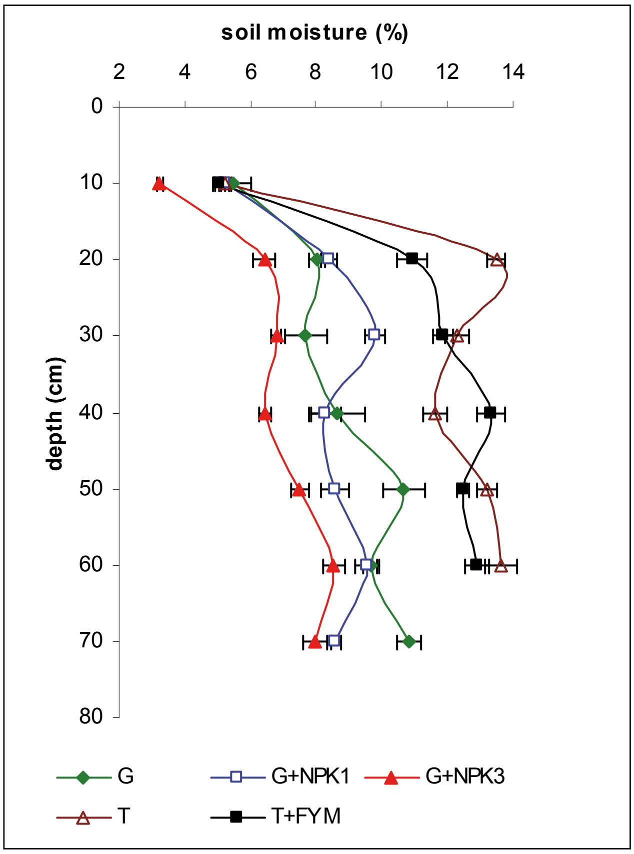

Figure 1 Soil moisture in soil profiles under different soil management practices

Table 4 Correlation coefficients between soil organic matter, particle-size distribution and parameters of water availability

Parameters	C_{org}	C_L	C_{HWD}	Q_{HS}	Q_{HA}	$C_{HA} : C_{FA}$	Sand	Silt	Clay
θ	-0.405*	-0.443*	-0.349*	n.s.	n.s.	n.s.	-0.540**	0.453**	0.589***
AWC	n.s.	n.s.	0.405*	n.s.	0.359*	-0.502**	-0.504**	0.379*	0.609***
AW_s	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-0.549**	0.557***	0.471**

$P > 0.05$ = n. s.; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$
C_{org} – organic carbon, C_L – labile carbon, C_{HWD} – hot water-soluble carbon, $C_{HA} : C_{FA}$ – the carbon of humic acids to carbon of fulvic acids ratio, Q_{HS} – colour quotient of humic substances, Q_{HA} – colour quotient of humic acids, θ – soil moisture, *AWC* – available water capacity, AW_s – available water storage.

Leptosol, however, sown grass together with fertilizer added to the soil did not increase the soil's capacity for moisture storage. Soil management practices in a productive vineyard had statistically significant influence on values of available water capacity (Table 3). Available water capacity decreased in comparison to control (G), in T (by 13 %), T + FYM (by 7 %), G + NPK1 (by 44%) and in G + NPK3 (by 65 %) (Fig. 2). This means that higher doses of fertilizer added to the soil resulted in lower values of available water capacity. A higher root biomass due to higher doses of fertilizer had a higher demand for water, which led to the decrease of available water capacity. Available water capacity is influenced by field water capacity (in laboratory conditions by retention water capacity) and by wilting point (Fulajtár, 2006). The retention water capacity and wilting point are influenced by particle-size distribution. Soils with higher clay content have a higher retention capacity than sandy soils. The mentioned soil had been evaluated according to FAO classification as medium (WRB, 2006) with relatively low clay content (10 %). The clay particles are able to orientate nearby plant roots (Tisdall and Oades, 1982) and the root system of plants has a higher amount of available water. On the other hand, at higher ground biomass due to fertilization, the amount of available water in the soil may decrease (Fig. 2). High formation of root exudates may result in dispersions of clay (Reid and Goss, 1981), or the root mucilages, such as polygalacturonic acid, can act hydrophobic and water resistant (Czarnes et al., 2000). In our case, more water for the vine was in the treatment that is intensely cultivated, which is also confirmed by data on the available water storage. On the other hand,

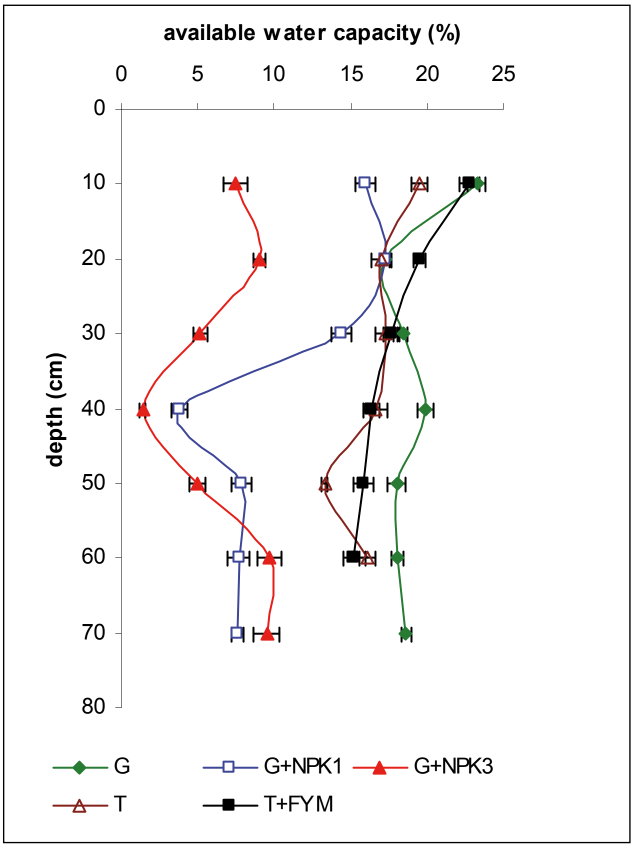

Figure 2 Available water capacity in soil profiles under different soil management practices

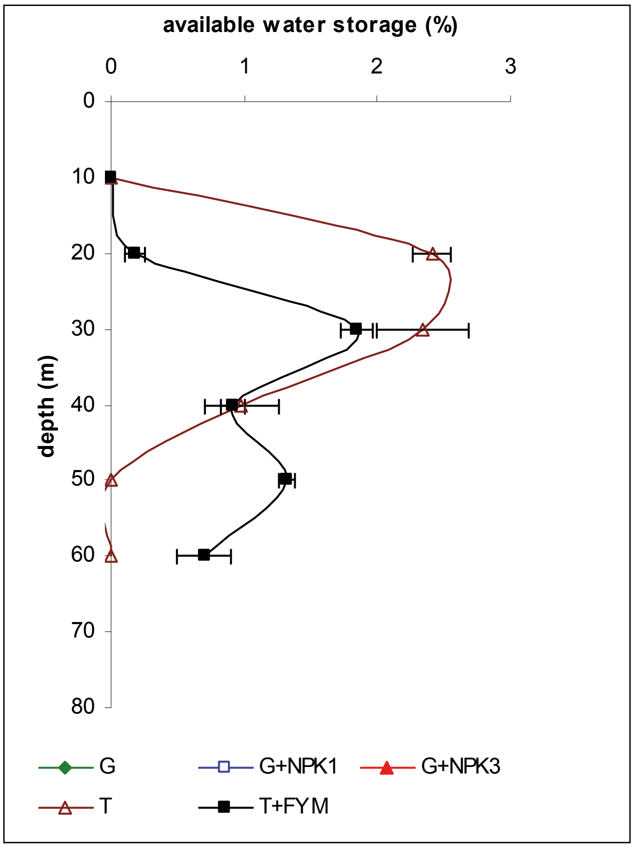

Figure 3 Available water storage in soil profiles under different soil management practices

Fernández-Ugalde et al. (2009) reported higher levels of available water capacity under no-till. This mechanism is explained through increasing the content of capillary pores with a higher retention capacity as well as through accumulation of organic matter. As is mentioned in Table 3, soil management practices in the vineyard had statistically significant influence on the values of available water storage (AW_s). In T, the highest values of AW_s were determined, however, in G, G + NPK1 and in G + NPK3 this category was absent (Fig. 3) because of the high evapotranspiration (evaporation of water from soil covered by vegetation). Overall, the value of AW_s in T and T + FYM can be evaluated as very low (Kutílek, 1966). The content of water in soil depends on the soil organic matter as well as particle-size distribution (Kutílek, 1966; Fulajtár, 2006; Fernández-Ugalde et al., 2009). In this case, the parameters of soil organic matter under different soil management practices in a vineyard were evaluated (Šimanský et al., 2013), and now in Table 4, correlations are presented between soil organic matter, particle-size distribution and parameters of water availability. The organic carbon and its labile forms negatively correlated with soil moisture due to the highly hydrophobic nature of organic matter (Czarnes et al., 2000). On the other hand, the higher CHWD contents and QHS values in soil resulted in higher values of available water capacity. Nevertheless, the humus quality was negatively correlated with available water capacity. At the same time, we determined statistically significant correlations between particle-size distribution and parameters of water availability (Table 4).

4. Conclusion

Soil type and climate have a major impact on soil management practices in the vineyards. Not all soil types and climatic conditions, in terms of their water storage capacity and rainfall, are suitable for the establishment of a vineyard. The areas with Rendzic Leptosol and with lower rainfall are not suitable for vineyards and there the tillage systems (of course taking into account the erosion processes – terrace slopes) or planting grass between the rows of vine that alternate with tilled rows of vine are better. Viticulture is unusual in that it is often conducted on sites considered unsuitable for most crops. The obtained results force us to think about the use of soil management practices that are friendlier to the soil environment and utilize advantages and weaknesses of a particular area. Before the foundation of a future vineyard, winemakers have to proceed in a preventive manner and assess the suitability of the area. After establishing and planting vineyards, they implement a system of management that reasonably manages the water in the soil.

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