Savremena poljoprivredna tehnika, vol. 42, br. 1, str. 1-72, mart 2016.
Cont. Agr. Engng. vol. 42, no. 1, pg. 1-72, march 2016.

Biblid: **0350-2953 (2016) 42(1): 61-72**
UDK: 658.2

Originalni naučni rad
Original scientific paper

EVALUATION OF INFILTRATION CAPACITY OF SOILS ON PLOTS WITH DIFFERENT CULTURES

PROCENA INFILTRACIJE KAPACITET ZEMLJIŠTA NA PARCELAMA SA RAZLIČITIM KULTURAMA

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ABSTRACT

This paper deals with the infiltration capacity of soils in experimental plots of Faculty of Horticulture, Mendel University. Measurements of soil infiltration capacity took place in spring and autumn in three variants–vineyard, orchard, and vegetable plots. The results suggest that the best infiltration values are in vegetable plots. This alternative proved to be the best both at the beginning and at the end of the growth season. In contrast, the worst values of infiltration were found in the vineyard variant, in which measurements pointed to a totally unsatisfactory condition of the soil. Measured values of infiltration were used for determining the hydraulic conductivity of the soil, which in orchards decreased 1.5 times and in vineyards even 15 times compared to the vegetable plots.

Keywords: soil, infiltration capacity of soil, hydraulic conductivity.

1. INTRODUCTION

Tillage can have both positive and negative effects on the physical properties of soil. If the soil treatment is carried out primarily under increased soil moisture, crushing of stable soil aggregates takes place, which dramatically reduces macroporosity of soil (Matula, 2003; Philips, 1968). Some studies have shown that aggregation of soil and other important physical properties, such as density, porosity, capillary capacity of soil, soil compaction, and so on, affect the decrease of the infiltration rate (Brady, 1999).

In practice we use several techniques and evaluation methods of water infiltration into the soil. The most common methods for evaluation of water infiltration into the soil include measurements using a rain simulator or measurements performed using a circular Mini Disk Infiltrometer. This type of infiltrometer is intended for evaluating the water holding capacity of soil and especially the hydraulic conductivity of soil (Defossez, 2003). Hydraulic conductivity of soil is one of the most important hydraulic properties, which affects water movement in soil. Measurements of soil hydraulic conductivity in the field are difficult and time consuming (Smetem, 1992; Warrick, 1992; Haverkamp *et al.*, 1994). For evaluation of the data, obtained using circular infiltrometer, several methods have been developed (Ankety *et al.*, 1991; Raynolds, 1991), which are based on the Wooding's approximation of a steady state of infiltration (Wooding, 1968).

To simulate the movement of water in the unsaturated soil, it is necessary to know the hydraulic functions, especially the retention capacity of soil C(h) and the function of unsaturated hydraulic conductivity K_{unsat}. Zhang (1997) in a study has simplified the determination of unsaturated hydraulic conductivity of soil using a circular Mini Disk Infiltrometer. This type of infiltrometer expands the possibilities of data collection during measurements in the field.

Theoretical determination of the infiltration process is described by Richards equations, which were derived from physical laws for water flow in unsaturated soil environment (Darcy–Buckingham law and the equation of continuity). In addition to the numerical solution of Richards equations, there are simplified analytical solutions (Zhang, 1997; Šindelář *et al.*, 2008), based on the basic equation of the infiltration curve, whose parameters are soil sorptivity and the root of infiltration, which excludes the effects of gravity:

$$I = S.t^{1/2} \quad (1)$$

Where:
I – Cumulative infiltration of water per unit area (m^2)
S – Sorptivity of soil ($m.s^{-1/2}$)
t – Time (s)

This equation is valid only within a very short period of infiltration and only for vertical flow of water in the soil (Kroulík, 2010). In reality, it is very difficult to measure cumulative infiltration in a sufficient number of samples within a short time interval for which formula (1) is valid (Ferrero, 2005; Yang, 2011). This problem is even greater during field measurements for obtaining reliable values for soil sorptivity by measuring the cumulative water infiltration into soil using a circular infiltrometer (Šindelář *et al.*, 2008).

For example Zhang (1997) and Nimmo *et al.* (2002) used in their studies a dimerous mathematical equation describing the infiltration process under a circular infiltrometer:

$$I = C_1.\sqrt{t} + C_2.t \quad (2)$$

Where:
C_1 – Function parameter ($m.s^{-1/2}$)
C_2 – Function parameter ($m.s^{-1}$)

These parameters relate to soil sorptivity and hydraulic conductivity of soil according to the following equations:

$$C_1(h_0) = A_1.S(h_0) \quad (3)$$

$$C_2(h_0) = A_2.K_{sat}(h_0) \quad (4)$$

Where:
A_1 and A_2 – Dimensionless coefficients
h_0 – Voltage value of infiltrometer used in an infiltration process

By modifying equations (3) and (4) we get equations for calculating the soil sorptivity and hydraulic soil conductivity:

$$S(h_0) = C_1/A_1 \quad (5)$$

$$K_{sat}(h_0) = C_2/A_2 \quad (6)$$

Where:
S – Soil sorptivity ($m.s^{-1/2}$)
K_{sat} – Hydraulic conductivity of soil ($m.s^{-1}$)

Parameters C_1 and C_2 are obtained by modifying of non-measured values of the cumulative water infiltration versus time using equation (2). Function parameter C_2 is related to hydraulic conductivity and function parameter C_1 has a relationship to soil sorptivity. Coefficients A_1 and A_2 are dimensionless and are changeable with a total time of infiltration. However, the variability of coefficients with increasing measuring time of infiltration decreases to values which can be regarded as constants (Šindelář *et al.*, 2007).

For the coefficients A_1 and A_2 as functions of parameters of soil retention, infiltration and initial soil moisture, empirical numerical relationships were fixed. A study by ZHANG (1997) described three types of assessment of the coefficients A_1 and A_2, according to the difference in the retention function of soil. These are the van Genuchten type (VG-type), Russe type (GR-type), and Zhang-Genuchten-type (ZV-type). All three types of assessment of the A_1 and A_2 coefficients are dependent on retention parameters of soil, pressure energy of infiltrometer, radius of the circular infiltrometer, and initial soil moisture. The A_2 parameter calculation for determining the hydraulic conductivity of soil for Mini Disk Infiltrometer was performed according to VG-type:

$$A_2 = \frac{11.65\,(n^{0,1} - 1).\exp\left[2.92\,(n - 1.9)\alpha h_0\right]}{(\alpha r_0)^{0,91}} \quad \text{for } n \geq 1.9 \qquad (7)$$

$$A_2 = \frac{11.65\,(n^{0,1} - 1).\exp\left[7.5\,(n - 1.9)\alpha h_0\right]}{(\alpha r_0)^{0,91}} \quad \text{for } n \leq 1.9 \qquad (8)$$

Where:
n and α – Retention soil parameters
h_0 – Pressure energy of infiltrometer (≤ 0)
r_0 – Radius of circular infiltrometer (mm)

Table 1 below shows the results of van Genuchten equations (7) and (8) that were used for round Mini Disk Infiltrometer with radius r_0=22 mm to calculate the parameter value A_2 for 12 basic soil types and for different adjustable infiltrometer suction height h_0.

Tab. 1. Calculation of the parameter A_2 for 12 basic soil textures for different adjustable suction height for infiltrometer h_0 using van Genuchten equations (Carsel and Parrish, 1998).

Texture	α	n	h_0						
			–0.5	–1.0	–2.0	–3.0	–4.0	–5.0	–6.0
			A_2						
Sand	0.145	2.68	2.9	2.5	1.8	1.3	0.9	0.7	0.5
Loamy sand	0.124	2.28	3.0	2.8	2.5	2.2	1.9	1.6	1.4
Sandy loam	0.075	1.89	4.0	4.0	4.0	4.0	4.0	4.1	4.1
Loam	0.036	1.56	5.6	5.8	6.4	7.0	7.7	8.4	9.2
Silt	0.016	1.37	8.1	8.3	8.9	9.5	10.1	10.8	11.5
Silt loam	0.020	1.41	7.2	7.5	8.1	8.7	9.4	10.1	10.9
Sandy clay loam	0.059	1.48	3.3	3.6	4.3	5.2	6.3	7.6	9.1
Clay loam	0.019	1.31	6.0	6.2	6.8	7.4	8.0	8.7	9.5
Silty clay loam	0.010	1.23	8.1	8.3	8.7	9.1	9.6	10.1	10.6
Sandy clay	0.027	1.23	3.4	3.6	4.2	4.8	5.5	6.3	7.2
Silty clay	0.005	1.09	6.2	6.3	6.5	6.7	6.9	7.1	7.3
Clay	0.008	1.09	4.1	4.2	4.4	4.6	4.8	5.1	5.3

This paper aims to monitor the infiltration capacity of soils and to determine the hydraulic conductivity of soils in experimental plots of the Horticulture Faculty with different cultures.

2. MATERIALS AND METHODS

Measuring Equipment

Mini Disc Infiltrometer, which was selected for the data acquisition, is very simple, small, and with low demands on the operator. The main advantage of this type of infiltrometer is its low water consumption, of about 135 ml per measurement, when compared to other methods. An important advantage is also its handling by only one person. Infiltrometer consists of a polycarbonate tube with a diameter of 31 mm and a height of 327 mm, which is divided into two parts. Both parts are filled with water. The upper part, also called the bubble chamber, is used to set the air intake. Water, filled into the lower part through a semipermeable stainless steel membrane at the bottom of a tube with a radius h_0=22 mm, infiltrates into the soil. Suction height h_0 can be changed according to the type of soil by shifting the control intake pipe with a scale. On the bottom of the polycarbonate tube is a scale, from which after 60 seconds, the value of the water volume in ml is read.

Measuring Procedure

At the beginning of the measurement, it is necessary to thoroughly prepare a site for three circular infiltrometers. These sites must be at least 80 mm in diameter. Selected sites must be perfectly straight, without any cracks in the soil or plant debris so that the entire surface of the membrane was in contact with the soil surface during the actual measurement (Chang, 2011). Subsequently, on a circular infiltrometer the upper plug is taken off and the bubble chamber is filled with water up to the upper end of the tube. We return the plug and insert the control suction tube down until it lands on the sealing partition. We seal the other end of the control intake pipe with the finger and turn the infiltrometer around. Then, we remove the stainless steel semipermeable membrane from the polycarbonate tube and fill the tank with water up to the rim. Next, we put the stainless steel membrane back to infiltrometer and turn it back. Afterwards, we leave the control suction tube inserted into the sealing partition. Subsequently, we use the same procedure to prepare the remaining infiltrometers. We place the circular infiltrometers onto previously prepared surfaces. Into the pre-printed table, to time 0, we write the readings from the scale of the circular infiltrometer. We start measuring time on a stopwatch, while on the first infiltrometer we set the value of the suction height h_0 by shifting the control intake pipe according to the soil texture. The set value on the control suction pipe is aligned with the water level in the bubble chamber. In intervals of 20 seconds, we repeat the same process for the second and third infiltrometer. Subsequently, in 60 second intervals, we write down the readings in millilitres from the scale to table. The scale on the suction control pipe is divided from –5 mm to –60 mm. The suction height is adjusted according to the type of soil. For sandy soil, where the water infiltration into soil is very quick, we adjust the suction height to h_0=–60 mm. In contrast, for heavy clay soils, where the water infiltration into soil is small, we set the suction height to h_0=–5 mm. For most clay soils, we usually set the suction height to h_0=–20 mm.

Graph 1 shows the obtained values expressed graphically using graphs that represent dependence of cumulative water infiltration (mm) on the square root of time ($s^{1/2}$). Through the measured values, we fit a curve showing the equation including the value of R^2. From the equation curve, we express the function parameter C_2 which is associated with the hydraulic conductivity of the soil. According to soil type and the set value h_0 we can determine the coefficient A_2 from Table 1. Then, using the formula (6), we calculate the hydraulic conductivity of soil K_{sat}.

3. **RESULTS AND DISCUSSION**

Infiltration capacity of soil is one of the important factors in soil protection against water erosion (Matula, 2003). Water infiltration into soil and the water loss due to surface runoff in arable soils depend on the topsoil layer conditions. Insufficient infiltration properties of the soil surface restrict water infiltration into the soil. This in combination with high intensity or longer duration rainfall can cause formation of surface runoff and associated negative erosion phenomena. Homogeneity and composition of soil have the greatest influence on measurement (Zhang, 1997). Čermák (2012) in his BS thesis examined the influence of soil structure on soil hydraulic properties. He maintains that soils with a well-developed structure are losing infiltration capability more slowly. Also, in structural soils the initial infiltration is quick and gradually slows down. In a non-structural soil, initial infiltration is slower and decreases very rapidly. Therefore on a non-structural soil surface, a thin and poorly permeable crust develops due to disintegration of pseudo-aggregates. Air in the pores cannot easily escape from this layer, which significantly reduces the rate of infiltration. Water from these soils runs off on the surface and inadequately moisturizes deeper horizons.

Tables 2 to 4 and Graphs 1 to 3 evaluate the water infiltration into the soil in all monitored variants. The course of the infiltration capacity of the soil is given by the shape of curves, which indicate good or bad homogeneity of the soil profile. Best infiltration characteristics of the soil were measured in the vegetable plots (Graph 1). The soil homogeneity in this variant facilitated good infiltration capability throughout the soil horizon. In the orchards, the water infiltration was smaller, while the least favourable values came from the vineyards. Here the water infiltration was below the critical threshold due to excessive compaction. Graphs 1 to 3 show a better infiltration capacity of the soil in the spring compared with the autumn season

Tab. 2 - Average measurement values using Mini Disk Infiltrometer in vegetable plots

Time (s)	Square Root of Time ($s^{1/2}$)		Measured Value (ml)		Cumulative Infiltration (mm)	
	Spring	Autumn	Spring	Autumn	Spring	Autumn
0	0	0	91	91	0	0
60	7.75	7.75	87.9	88.4	1.1	0.9
120	10.94	10.94	86.4	87.1	1.9	1.4
180	13.42	13.42	85.6	86.0	2.5	2.1
240	15.49	15.49	80.7	81.3	3.3	2.7
300	17.32	17.32	77.5	77.9	3.9	3.4

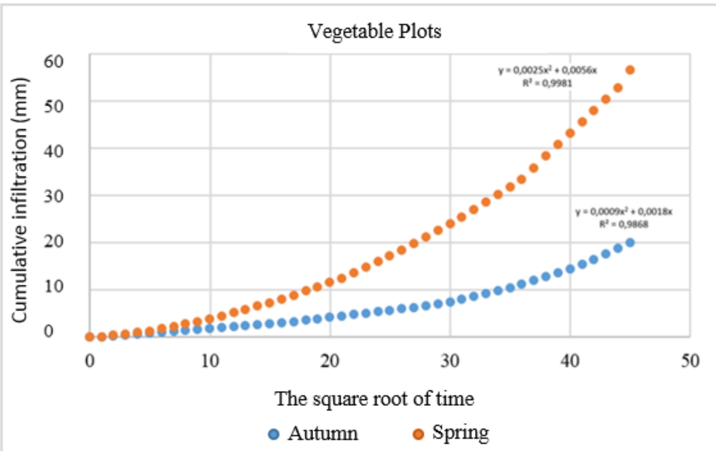

Fig. 1: Dependence of cumulative water infiltration on the square root of time in vegetable plots

Graph 1 shows the soil infiltration capacity measured in an experimental station of vegetable plots. The graphs show an improved infiltration rate at the beginning of growth season as compared to its end. Badalíková *et al.* (2014) performed measurements of soil infiltration in three variants with different compositions of grass mixtures used for landscaping pond dams. The results of their measurements show that in clay soils, water infiltration into the soil is more regular at the beginning of the growth season. In contrast, Pellegrini (2014) studied the effects of rock fragments on the actual water infiltration into soil. His results show that higher levels of gravel in the soil significantly improve the infiltration capacity of the soil (Čermák, 2012).

Table 3: Average measurement values using Mini Disk Infiltrometer in orchards

Time	Square Root of Time		Measured Value		Cumulative Infiltration	
(s)	($s^{1/2}$)		(ml)		(mm)	
	Spring	Autumn	Spring	Autumn	Spring	Autumn
0	0	0	91	91	0	0
60	7.75	7.75	88.9	89.1	1.1	1.0
120	10.94	10.94	87.1	87.4	1.4	1.3
180	13.42	13.42	85.6	86.2	1.8	1.6
240	15.49	15.49	81.7	82.3	2.1	1.9
300	17.32	17.32	78.2	79	2.3	2.1

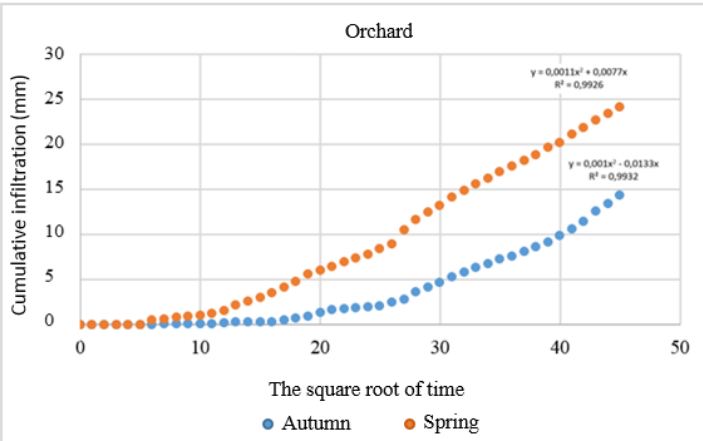

Fig. 2: Dependence of cumulative water infiltration on the square root of time in orchards

Graph 2 shows the curves of the measured values in the orchard variant. The values here were fairly balanced, though the better infiltration rate was measured at the end of the growth season.

Tab. 4 - Average measurement values using Mini Disk Infiltrometer in vineyards

Time	Square Root of Time		Measured Value		Cumulative Infiltration	
(s)	($s^{1/2}$)		(ml)		(mm)	
	Spring	Autumn	Spring	Autumn	Spring	Autumn
0	0	0	91	91	0	0
60	7.75	7.75	89.6	89.8	0.1	0.1
120	10.94	10.94	88.8	89.1	0.3	0.2
180	13.42	13.42	87.6	88.2	1.0	0.4
240	15.49	15.49	85.7	86.3	2.1	0.5
300	17.32	17.32	83.4	84.1	2.4	0.6

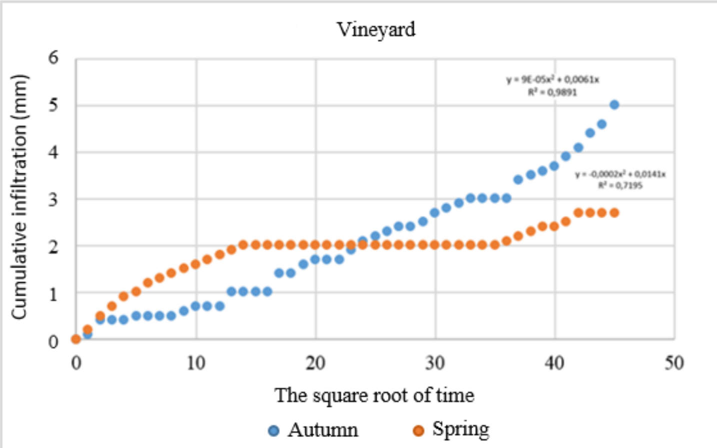

Fig. 3: Dependence of cumulative water infiltration on the square root of time in vineyards

In Graph 3, we see an interesting difference when compared with previous variants, when the infiltration of water into soil was initially better, but gradually declined to a level below the values measured at the end of the growth season.

From the values measured in spring and autumn in all experimental variants, it is clear that the best values of the cumulative infiltration are in vegetable plots, which was demonstrated by the uniform infiltration of water during the entire measurement. In comparison with vegetable plots, the average cumulative infiltration was on average 1.5 times lower in orchards and 3 times lower in vineyards. The work by Zhang (1997) states that the longer, regular tillage increases the infiltration capacity of soil up to three times.

Matic (2010) and Sochorec (2011) evaluated the impact of technology with limited tillage on water infiltration into soil by using other methods as positive. Such methods included the assessment of infiltration of water through rain simulator, using two concentric cylinders.

Ambasht (2008) reported that reduced tillage can cause reduced water infiltration in the topsoil profile and an increased compactness of surface layers. In his work, he evaluated the impact of different tillage on hydraulic conductivity of soil K_{sat}. The results suggest that repeated traditional ploughing after three years changed resulting values K_{sat} only slightly. It means that insufficient soil processing, which occurs between rows in orchards and vineyards may over several years significantly affect infiltration rate values v(t). These assumptions were also confirmed by Yang *et al.* (2011), who devoted themselves to designing new suitable coefficients for the prediction of wave patterns in smaller bodies of water.

Table V shows the calculation of hydraulic conductivity K_{sat} values for individual experimental variants. The best variant seemed to be the vegetable plot, where the average value of the hydraulic conductivity of soil from autumn and spring measurements amounted to 2.5×10^{-6} $m.s^{-1}$. In the orchard variant, the computed average value of hydraulic conductivity of soil was at the level of 1.6×10^{-6} $m.s^{-1}$ and in the vineyard variant, it was 2.1×10^{-7} $m.s^{-1}$.

Tab. 5 – Calculation of the hydraulic conductivity of soil K_{sat} ($m.s^{-1}$)

	Vegetable Plot		Orchard		Vineyard	
	Spring	Autumn	Spring	Autumn	Spring	Autumn
C_2	0.0025	0.0009	0.0011	0.0010	0.00009	0.0002
A_2	6.8	6.8	6.8	6.8	6.8	6.8
K_{sat}	3.7×10^{-6}	1.3×10^{-6}	1.6×10^{-6}	1.5×10^{-6}	$1,3\times10^{-7}$	2.9×10^{-7}

These results clearly indicate that the values of the hydraulic conductivity of soil decreased mostly in vineyards, namely 15 times. This decrease in value can have a number of negative consequences, such as increased surface runoff, reduced water retention in the profile, affecting the crop yield, increased compactness of surface layers, and risk of erosion (Van Dijck, 2002).

4. CONCLUSION

Our results suggest that the best values for infiltration come from vegetable plots. Water infiltration in this variant took place regularly, both at the beginning and at the end of the growth season. In contrast, the worst values were measured at the vineyard variant in which measurements pointed to a totally unsatisfactory condition of the soil. The poor soil infiltration in the vineyard variant was probably partly due to high soil compaction caused by repeated crossings of machinery in the space between rows.

Also the largest hydraulic conductivity of soil K_{sat} was calculated for the vegetable plot variant. When evaluating the calculated values of soil hydraulic conductivity K_{sat}, the highest values were 3.7×10^{-6} $m.s^{-1}$ for spring and 1.3×10^{-6} $m.s^{-1}$ for autumn for the vegetable plot variant. In the orchard variant the values were 1.6×10^{-6} $m.s^{-1}$ for spring and 1.5×10^{-6} $m.s^{-1}$ for autumn. In the vineyard variant, the values were 1.3×10^{-7} $m.s^{-1}$ for spring and 2.9×10^{-7} $m.s^{-1}$ for autumn. This may be due mainly to insufficient treatment of the soil to the required depth, which led to decrease of water retention in the soil profile and increased compaction of surface layers.

The results of infiltration measurements will be used for assessing agronomic interventions and working operations in soil processing and soil erosion control.

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Acknowledgements : This research was created with the support of IGA–ZF/2016–DP009 project and TA04020464 project of the Technology Agency of CR.

PROCENA INFILTRACIJE KAPACITET ZEMLJIŠTA NA PARCELAMA SA RAZLIČITIM KULTURAMA

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REZIME

Ovaj rad se bavi kapacitetom infiltracije zemljišta u oglednim parcelama Fakulteta za hortikulturu, Mendel Univerziteta. Merenja kapaciteta zemljišne infiltracije obavljena su u proleće i jesen u tri varijante - vinograd, voćnjak, i povrtnjak. Rezultati pokazuju da su najbolji infiltracionim vrednosti u povrtnjaku. Ova alternativa se pokazala kao najbolji i na početku i na kraju sezone rasta. Nasuprot tome, najlošije vrednosti infiltracije su registrovani u vinogradu, u kojima merenja pokazuju na potpuno nezadovoljavajuće stanje zemljišta. Izmerene vrednosti infiltracije su korišćeni za određivanje hidrauličnih provodljivost tla, koji je u voćnjacima smanjen 1,5 puta a u vinogradima čak 15 puta u odnosu na povrtnjak.

Ključne reči: tlo, infiltracioni kapacitet zemljišta, hidraulička provodljivosti.

Primljeno: 27. 02. 2016. god. **Prihvaćeno**: 15. 03. 2016. god.