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# EFFECTS OF AMELIORATIVE AFFORESTATION ON THE ERODIBILITY FACTOR AND SOIL LOSS IN THE GRDELICA GORGE

## UTICAJ PROTIVEROZIONOG POŠUMLJAVANJA NA FAKTOR ERODIBILNOSTI I GUBITKE ZEMLJIŠTA NA PODRUČJU GRDELIČKE KLISURE

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**Abstract**

The paper presents research carried out in the area of Grdelica gorge in 60 years old black pine (*Pinus nigra* Arnold.) stands. The aim of this study was to determine whether the applied planting method of ameliorative afforestation had an impact on physical and chemical soil properties, soil erodibility and soil loss. The experimental fields were selected from the afforested areas where soil samples were taken from fixed depths and then were subjected to physical and chemical laboratory analyses. The soil erodibility factor K was calculated using the Wischmeier and Smith formula, whilst, soil loss was estimated according to Erosion Potential method – EPM by Gavrilović. According to the results of the research, in the studied period of 60 years there was a change in the soil physical and chemical properties. There was also a reduction in the soil erodibility factor and soil loss which can be the result of ameliorative afforestation. The afforestation method can affect the reduction of soil losses, while the erodibility factor may be affected indirectly (e.g. by increase in the organic matter content, forming structural aggregates) not immediately after afforestation, but in a long term period.

**Keywords**: ameliorative afforestation, gradone, planting in pits, soil erodibility, soil loss

## 1. INTRODUCTION / UVOD

Soil erosion is the main mechanism of land degradation (Lal, 2001; Dlamini et al., 2011 in Wu et al., 2017) and one of the most serious environmental problems in the world (Liu et al., 2012; Li et al., 2012, 2013; Bai et al., 2013; Pimentel and Kounang, 1998 in Zhi-Jie et al., 2014). In order to control erosion processes, according to Kostadinov (2008) the system of erosion control measures and works is a set of protective measures and methods that are directed towards the regulation of overland flow, protection of soil from erosion and establishment and increase in fertility of eroded soils. According to Blinkov et al. (2013) erosion control measures are consisted of technical and biological ameliorative works. Vegetation plays an important role in controlling soil erosion (Zhou et al., 2006; Kusumandari et al., 2012) and increases the C concentration and stocks in soil (Nymadzawo et al., 2008). Bruinsma (2003) emphasizes vital role of forests in controlling erosion processes and prevention of soil erosion and nutrient leaching, while Tanasković et al. (2015) assert afforestation as the most effective measure for soil protection on bare and degraded lands.

Soil Erodibility Factor (K) (Wischmeier & Smith, 1978) is one of the most important and key factors which determines soil particles resistance to be detached by water erosion (rainfall and/or runoff) forces (Imani et al., 2014).

Due to specific natural conditions Grdelica gorge is the area susceptible to land degradation processes, especially erosion. The first erosion control works in Serbia have been performed in this area, and they stand out as an example of good practice (Ristić, 2014). Various erosion control methods with the aim of soil protection were applied, e.g. biological and biotechnical works were performed (Braunović, 2013), which include afforestation in pits and on gradones.

The aim of this study was to determine whether the ameliorative afforestations had an impact on physical and chemical soil properties, soil erodibility and soil loss 60 years after afforestation. Also, the aim was to determine if there are differences in the efficiency of the most frequently used methods of afforestation, in pits and on gradones, in terms of changes of the soil erodibility factor and reduction of soil losses 60 years after afforestation.

## 2. AREA OF RESEARCH / ISTRAŽIVANO PODRUČJE

Research area (Figure 1) is located in Grdelica gorge which is in the composite valley of South Morava in northeast Serbia, 34 km long, 550 m deep and has an area of 430 ha. In geological terms, crystalline shales dominate the research area. Crystalline shales show an erodible character (Spotila et al., 2002). Dystric Cambisol and Leptosol, are represented on the studied area. Considering climatic conditions, the investigated area is situated on the Mediterranean and Continental climate with a mean annual air temperature of 10.9 °C and a total annual precipitation of 672 mm (RHMZ 1949–2015). Considering the vegetation at altitudes up to 600 m a.s.l. the association of Turkey oak and Hungarian oak (*Quercetum frainetto-cerris*) is the most com-


**Figure 1**. Research area / **Slika 1**. Istraživano područje

mon forest type. In addition, Mountain beech forest (*Fagetum moesiacae montanum*) is also present in this region at higher altitudes, from 800 to 1300 m a.s.l. In the valley of the South Morava River, the most common associations are forests of pedunculate oak and broom (*Genisto elatae-Quercetum roboris*) and forests of poplar and willow (*Salici-Populetum albae*) (Lukić et al., 2015). The composition of plant species in the area of the Grdelica gorge is characterized by the presence of rare and fragmentary represented forest communities, as well as relict and endemorelict examples (*Juglando-Fagetum submontanum* Jov., *Fago-Aceri intermediae-colurnetum* Jov., *Querco-Aceri intermediae colurnetum* Miš. et Din., *Lauroceraso-Fagetum montanum* Jov.).

## 3. METHOD / METOD

Seven experimental fields were selected on the afforested areas planted in pits and on gradones (the excavation technique of gradones and preparation of soil for planting are shown in Figure 1.) The experimental fields are on slopes from 25% to 54%. Black pine (*Pinus nigra* Arlnold.) was used for the ameliorative afforestation in the Grdelica gorge.

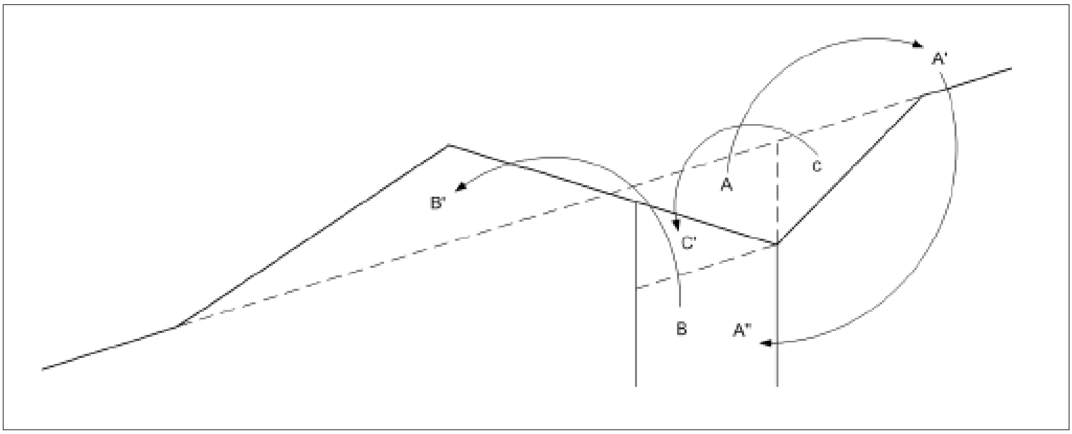


**Figure 2**. The excavation technique of gradon and preparation of soil for planting / **Slika 2**. Tehnika iskopa gradona i priprema zemljišta za sadnju

Soil samples taken from fixed depths were subjected to physical and chemical laboratory analyses. The mechanical properties of the soil were determined by the pyrophosphate method, which is a combination of screening methods using the sieve and international pipet method (JDPZ 1997, 2007; ISO-11277:1998). The humus content is determined according to the Tjurin method (JDPZ 1966, 2007; ISO 14235:1998).

The soil erodibility factor K was calculated using formula of Wischmeier and Smith (1978) for the surface layer of the soil (0–10 cm):

$$K = \frac{0.00021 \cdot M^{1.14} \cdot (12 - OM) + 3.25 \cdot (C_{soilstr} - 2) + 2.5(C_{perm} - 3)}{100}$$

*K* - soil erodibility factor (t·ha·h·ha$^{-1}$·Mj$^{-1}$·mm$^{-1}$), *M* - particle size parameter (% silt +% fine sand) * (100%-clay), *OM* - % of organic matter content, $C_{soilstr}$- soil structure code and $C_{perm}$- soil permeability class.

The soil loss was estimated according to Erosion Potential Method - EPM (Gavrilović 1972):

$$Wyr = T \cdot Hyr \cdot \pi \cdot \sqrt{z3} \cdot F$$

$W_{yr}$- annual yield of erosive material (m$^3$ yr$^{-1}$), *T* - temperature coefficient,

$$T = \sqrt{0.1 + \frac{t^{\circ}}{10}}$$

*t°* - mean air temperature (°C), $H_{yr}$-mean annual precipitation (mm), π -3.14, *F* - size of the sample plot (km²), *z* - erosion coefficient,

$$z = y \cdot Xa \cdot (\varphi + \sqrt{Imean})$$

*y* - coefficient of soil resistance to erosion, *Xa* - land use coefficient, *φ* - coefficient of visibly expressed erosion processes, $I_{mean}$- mean slope angle of sample plot.

The Erosion Potential Method - EPM (Gavrilović 1972) was developed in Serbia, according to extensive research in the area of Grdelica gorge. It is currently widely applied (Dragićević et al., 2016).

Differences in soil properties, erodibility factor and soil loss in the observed period of 60 years were tested using t-test and the correlation strength between erodibility factor and soil properties was tested in the SPSS software (version 20).

## 4. RESULTS / REZULTATI

Table 1 shows the content of organic matter (0–10 cm) before afforestation and 60 years after. There was a lower content of organic matter in soils before afforestation (3.08 ± 1.68%) in regard to soils after afforestation (3.57 ± 0.71%), but that difference is without statistical significance. In terms of content of silt and sand, there is a higher content of silt (42.98 ± 8.27%) and lower content of sand (64.74 ± 14.59%) before afforestation compared to the content of those fractions after afforestation when lower content of silt (33.51 ± 5.46%) and higher content of sand (69.17 ± 8.65%) were measured. The difference in silt content was statistically significant and there was no statistically significant difference in sand content. The clay content was slightly higher 60 years after afforestation (11.47 ± 2.93) compared to the condition before afforestation (10.70 ± 3.84), but this difference has no statistical significance.

**Table 1**. Organic matter, silt, sand and clay in soil before and 60 years after afforestation /
**Tabela 1**. Organska materija, čestice praha, peska i gline pre i 60 godina nakon pošumljavanja

| **Indicator** / Pokazatelj | **Before afforestation** / Pre pošumljavanja | **60 years after afforestation** / 60 godina nakonpošumljavanja | **Level of significance** / Nivo značajnosti |
|---|---|---|---|
| Organic matter content % / Sadržaj organske materije % | 3.08 ± 1.68 | 3.57 ± 0.71 | N.S. |
| Silt content % / Sadržaj praha % | 42.98 ± 8.27 | 33.51 ± 5.46 | p < 0.05 |
| Sand content % / Sadržaj peska % | 64.74 ± 14.59 | 69.17 ± 8.65 | N.S. |
| Clay content % / Sadržaj gline % | 10.70 ± 3.84 | 11.47 ± 2.93 | N.S. |

**Napomena / Note**: p < 0.05 - the difference is statistically significant / p < 0.05 - razlika je statistički značajna; N.S. - the difference is not statistically significant / N.S- razlika je bez statističkog značaja

Table 2 shows the mean value of soil erodibility factor (K) before afforestation (0.37 ± 0.10). Sixty years after ameliorative afforestation, erodibility factor has significantly decreased in relation to the state before afforestation. The erodibility factor in the areas afforested by planting in pits was 0.26 ± 0.03, while on the areas afforested by planting on gradones was 0.27 ± 0.02, and this difference is not statistically significant.

Soil loss (Table 3) on sites afforested by planting in the pits decreased by 5.25 ($m^3 \cdot ha^{-1} \cdot yr^{-1}$) for the period of 60 years of afforestation, but this difference has no statistical significance ($p > 0.05$). On the sites afforested by planting on gradones the soil losses were significantly reduced ($p < 0.05$) by 12.64 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ for the period of 60 years of afforestation.

**Table 2**. Erodibility factor before afforestation and 60 years after afforestation by planting in pits and on gradones / **Tabela 2**.. Faktor erodibilnosti pre pošumljavanja i 60 godina nakon na površinama pošumljenim metodom sadnje u jame I na gradone

| | **Before afforestation** / Pre pošumljavanja | **60 years after afforestation** / 60 godina nakon pošumljavanja | | **Level of significance** / Nivo značajnosti |
|---|---|---|---|---|
| | | **Pits** / Jame | **Gradones** / Gradoni | |
| Erodibility factor (K) / Faktor erodibilnosti (K) | 0.37 ± 0.10 | 0.26 ± 0.03 | 0.27 ± 0.02 | p < 0.05 |

**Table 3**. Estimated soil losses in afforested areas / **Tabela 3**. Gubici zemljišta na pošumljenim površinama

| **Soil loss** / Gubici zemljišta [$m^3 \cdot ha^{-1} \cdot yr^{-1}$] | **Pits** / Jame | **Gradones** / Gradoni |
|---|---|---|
| Before afforestation / Pre pošumljavanja | 9.19 ± 5.31 | 15.03 ± 3.08 |
| 60 years after afforestation / 60 godina nakon pošumljavanja | 3.94 ± 2.42 | 2.38 ± 1.08 |
| Level of significance / Nivo značajnosti | N.S. | p < 0.05 |

Table 4 shows the correlation between erodibility factor and some soil properties (silt, sand, clay and organic matter content). There is statistically significant ($p < 0.01$) positive correlation between erodibility factor and silt content ($r = 0.81$) There is statistically significant negative correlation between erodibility factor (K) and organic matter content ($R = -0.61$, $p < 0.01$) and sand content ($r = -0.39$, $p < 0.05$). Correlation between erodibility factor (K) and soil loss in layer 0–5 cm is positive($r = 0.23$) but not statistically significant.

**Table 4**. The relationship among erodibility factor (K), soil properties and soil losses / **Tabela 4**. Veza između faktora erodibilnosti, karakteristika zemljišta i gubitaka zemljišta

| | **K** | **Silt** / Prah | **Clay** / Glina | **Organic matter content** / Sadržaj organske materije | **Sand** / Pesak | **Soil loss** / Gubici zemljišta |
|---|---|---|---|---|---|---|
| K | 1 | | | | | |
| Silt / Prah | 0.81** | 1 | | | | |
| Clay / Glina | 0.00 | 0.13 | 1 | | | |
| Organic matter content / Sadržaj organske materije | -0.61** | -0.16 | -0.21 | 1 | | |
| Sand / Pesak | -0.39* | -0.72** | -0.34 | -0.05 | 1 | |
| Soil loss / Gubici zemljišta | 0.23 | 0.08 | -0.09 | -0.19 | -0.04 | 1 |

**Napomena / Note**: *statistically significant difference at 95% (p < 0.05) / *statistički značajna razlika (p < 0.05); ** statistically significant difference at 99% (p < 0.01). / **statistički značajna razlika (p < 0.01)

## 5. DISCUSSION / DISKUSIJA

Before the afforestation, area of Grdelica gorge was covered with bare lands with very serious erosion processes. In such conditions afforestation is an instrument for rehabilitation of degraded forest sites and restoration of forests (Lukić et al., 2015). According to Mercurio & Schirone (2015) afforestation in a highly degraded land should be carried out by methods of planting in the pits and on gradones, as was done in the research area.

The soil properties are among the indicators of the efficiency of ameliorative afforestation

(Lukić, 2013), i.e. the existence of A horizon, which is, according to Ćirić (1962), an indicator of the genetic-evolutionary development of soil. According to Moussavou Boussougou et al. (2010) forest ecosystems have a great potential to improve soil quality of degraded lands, while ameliorative afforestation, in the frame of restoration works, improves some physical and chemical soil properties (Mongli-M et al., 2016).

In the research area, afforestation has contributed to the increase of organic matter content (Table 1).

According to Martin-Peinado (2016), the afforestation of the degraded area with black pine had led to the improvement of soil properties over a longer time period in terms of the content of organic matter, the C:N ratio and the capacity of the cation exchange.

According to the results of this research, erodibility factor (K) is statistically significantly higher before afforestation (0.37 ± 0.10) in regard to 60 years after (0.26 ± 0.03), which can indicate to the effect of ameliorative afforestation in terms of reducing the soil erodibility factor over a longer period of time. Jiao et al. (2010) who investigated the ecological effects of afforestation after 40 year·s, found that afforestation positively affects the increase in the ability of the soil to resist erosion processes.

According to Wang et al. (2011), the erodibility factor can be related to soil properties, such as texture, structure and organic matter content. In the research area, the ratio of the silt and sand content was changed in the period of 60 years after afforestation (Table 1). The listed soil properties are according to Panagos et al. (2011), the most important soil properties in terms of triggering erosion processes and the erodibility factor could be determined by them (Song et al., 2005). According to Imani et al. (2014), soil erodibility increases with the reduction of organic matter content. Soils with higher sand content has lower erodibility (Ifeloluwa, 2004; Bonilla & Johnson 2012), and with increasing silt content, soil erodibility increases (Bonilla & Johnson, 2012). In the observed period, change of the erodibility factor can be related to changes in the physical and chemical properties of the soil, since the erodibility factor depends on the physical and chemical properties of the soil (Pranvera et al., 2016).

Correlation analysis (Table 4) showed positive statistically significant correlation between erodibility and silt content ($r = 0.81$, $p < 0.01$) and negative statistically significant correlation with organic matter content ($r = -0.61$, $p < 0.01$) and sand ($r = -0.39$, $p < 0.05$). Soil organic matter reduces the K factor value because it produces compounds that bind soil particles in structural aggregates and reduce their susceptibility to detachment by raindrop impact and surface runoff. Also, organic matter by increasing soil aggregation increases infiltration and reduces runoff and erosion. According to Di Stefano & Ferro (2002), sand particles are easily separated or eroded due to their weight, vice versa with silt particles.

The effects of ameliorative afforestation were investigated in two the most frequently used afforestation methods. According to the results, both methods were efficient in terms of soil loss reduction. Irrespective of the applied planting method, in all experimental fields, soil loss was reduced for the period of 60 years after afforestation. The method of afforestation on gradones is more effective in reducing soil losses than the planting method in the pits. Considering gradones there were statistically significantly reduced soil losses (12.64 $m^3 \cdot ha^{-1} \cdot yr^{-1}$) compared to the reduction of soil loss where the planting method in pits was applied (5.25 $m^3 \cdot ha^{-1} \cdot yr^{-1}$). Although according to Lukić (2013), the planting method in pits is more effective in reducing soil loss in the long term, in term of soil erodibility factor, there is no significant difference between the studied methods of planting. Higher efficiency of gradones in reducing soil loss can be attributed to the effects of terraced land, which significantly contributes to the reduction of the erosion process in the basin, and consequently to reduction of soil loss (Zhang et al., 2017), as well as in the preparation of soil for planting, which creates better conditions for planted seedlings. In a study of Vallauri et al. (2002) in a mountainous area, erosion processes have been reduced by 50% by afforestation of degraded areas with black pine trees.

The reduction on the erodibility factor affects positively the ability of the soil to resist the action of aggressive forces of water (pluvial and fluvial) (Imani, et al., 2014). In this study was not denoted statistical significance of positive correlation between soil loss and erodibility factor (Table 3), due to the fact that, besides erodibility, soil loss is influenced by a large number of other factors, such as: rainfall intensity (Vaezi et al., 2017) as the key factor in the development of the water erosion process (Kadović, 1999), then the slope of the terrain (Kadović,1999; Nazir et al., 2016), land use (Vaezi et al., 2017 ) etc.

## 6. CONCLUSION / ZAKLJUČAK

The results of this research indicate that the increases in the content of organic matter and sand and decrease of silt content tend to increase the ability of the soil to resist erosion processes. The applied methods of ameliorative afforestation contribute to the reduction of erodibility in a longer period of time and directly, influencing the changes in the physical and chemical properties of the soil.

Also, both ameliorative afforestation methods contribute to the reduction of soil loss in the observed period and afforestation method on gradones has proven to be more effective in soil loss reduction.

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## Sažetak

U radu su prikazana istraživanja sprovedena na području Grdeličke klisure u sastojinama crnog bora (*Pinus nigra* Arnold.) starim 60 godina. Cilj istraživanja je da se utvrdi efekat primenjenih metoda antierozionih pošumljavanja na fizičke i hemijske osobine zemljišta, faktor erodibilnost (K) i smanjenje gubitaka zemljišta.

Na površinama gde je vršeno pošumljavanje sadnjom u jame i na gradone (tehnika iskopa gradona i priprema zemljišta za sadnju je prikazna na Slici 2), izdvojeno je sedam oglednih polja, na kojima su otvoreni pedološki profili. Ogledna polja se nalaze na nagibima od 25% do 54%. Uzorkovanje zemljišta je vršeno na fiksnim dubinama i laboratorijski su određene osnovne fizičke i hemijske osobine. Mehanički sastav zemljišta određen je pirofosfatnom metodom koja predstavlja kombinaciju metoda prosejavanja pomoću sita i međunarodne pipet metode (JDZP 1997, 2007; ISO-11277:1998). Sadržaj humusa je određen po metodi po Tjurinu (JDZP 1966, 2007; ISO 14235:1998). Faktor erodibilnosti određen je pomoću jednačine Wischmeier & Smith (1978) za površinski sloj zemljišta (0–10 cm). Gubici zemljišta određeni su metodom Potencijala erozije po Gavriloviću (1972).

Rezultati pokazuju da je u proučavanom periodu došlo do promene u fizičkim i hemijskim osobinama zemljišta (Tabela 1), faktoru erodibilnosti (Tabela 2) i gubicima zemljišta (Tabela 3). Ustanovljena je korelacija između faktora erodibilnosti i sadržaja čestica peska, praha i sadržaja organske materije (Tabela 4).

Karakteristike zemljišnog profila su jedan od pokazatelja efikasnosti meliorativnih radova (Lukić, 2013), odnosno postojanje A horizonta, koji je prema Ćirić (1962) indikator razvijenosti zemljišta u genetsko-evolucionom smislu. Prema Moussavou (2010) šumski ekosistemi omogućavaju poboljšanje kvaliteta zemljišta na degradiranim područjima, a obnavljanjem vegetacije poboljšavaju se fizičke i hemijske karakteristike zemljšta (Mongli-M et al., 2016). Promena faktora erodibilnosti, u posmatranom periodu, može da bude dovedena u vezu sa promenama u fizičkim i hemijskim osobinama zemljišta, jer faktor erodibilnosti zavisi od fizičko-hemijskih karakteristika zemljišta (Pranvera et al., 2016).

Prema dobijenim rezultatima, obe metode pošumljavanja pokazuju efikasnost u smanjenju gubitaka zemljišta uzimajući u obzir da su nezavisno od primenjene metode sadnje na svim oglednim poljima gubici zemljišta smanjeni u odnosu na stanje pre izvedenih protiverozionih radova (Tabela 3) Primenjene metode pošumljavanja doprinose smanjenju erodibilnosti u dužem vremenskom periodu i indirektno, uticajem na promene fizičkih i hemijskih karakteristika zemljišta.

**Ključne reči**: erodibilnost zemljišta, gradoni, gubici zemljišta, protiverioziono pošumljavanje, sadnja u jame