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Impact of Fast-Growing Trees Planting on Degraded Land from Perspectives of Ecosystem Services—Case Study from Slovakia

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Abstract

The aim of the study was to assess the effect of natural phytoremediation, impact of growing fast-growing trees on contaminated agricultural land on ecosystem services using a Matrix evaluation system. The Matrix system is a table that links an ecosystem to its potential to provide ecosystem services. To determine the monetary price of natural capital for the provision of ecosystem services, we chose the value transfer method, based on which it is possible to assign a price (1 point = 40.7 EUR) to point values. Monitoring of the study site Kuchyňa (Mollic Fluvisol) is running since year 2010. The fast-growing willow was planted (between 2006 to 2018 year) on an area of about 43 hectares. During the monitoring of soil parameters, we observed a slight decrease in the value of the active soil reaction, a negative trend in the content of available phosphorus and a positive trend in the development of the total content risk elements in the soil. The phytoremediation ability of willow regarding risk elements was manifested by an increase in the value and price of production and regulatory ecosystem services at the monitored location. The price of natural phytoremediation of fast-growing willow on the given area was 218762.5 EUR for production services and 171509.8 EUR for regulatory services.

Keywords

Ecosystem Services, Soil Parameters, Fast Growing Trees

1. Introduction

The decline of natural resources and the deteriorating quality of the environment causes constant pressure on ecosystems. The growing demands of satisfying social needs call for a sustainable way of managing the landscape, which requires the implementation of tools for the evaluation and assessment of ecosystem services (ESS). Ecosystem services are essentially determined by mutual interaction between ecological and social systems, because only those ecosystem processes that contribute to the fulfillment of human needs are defined as ESS (Birghofer et al., 2015). The main idea of the concept of ESS is to realize the value of natural capital (ecosystems that provide services are referred to as natural capital), its contribution to society, its contribution to environmental protection, as well as understanding the connection between natural capital and human well-being.

Since soil conditions influence many ESS, it also reflects the conflict of their cooperation. For example, the provision of supply ESS is often in conflict with the provision of regulatory or cultural ESS (Makovníková et al., 2017). High biomass production can often be achieved only at the expense of soil pollution with heavy metals introduced into the soil by mineral fertilizers or pesticides, which negatively affect the quality of the soil. Such interaction creates an increased pressure on the soil manifested by deterioration of its quality, which subsequently reduces its ability to provide ESS (Makovníková et al., 2017).

In addition to providing food, the primary supply ESS also includes the use of land to grown biomass for energy purposes. The use of agricultural land for the cultivation of energy crops is integrated in processed outlooks and forecasts for the further development of agriculture and is also part of the conceptual, strategic and legislative instruments of the Slovak Republic and the EU (Straka, 2009; Povraz et al., 2010). Energy crops can be grown in Slovakia on areas less suitable and unsuitable for traditional agricultural activity, on contaminated soils, suitable only for production for non-food purposes and on devastated areas in industrial agglomerations (methodological guidance of the Ministry of Agriculture and Regional Development of Slovak Republic MP SR no. 3187/ 2007-430). The climatic conditions of Slovakia are most suitable for the cultivation of the following species of fast-growing trees (FGT): poplars, willows, alders, lindens, hazelnuts, rowanberries, birches, spruce trees (Jandačka & Malcho, 2007). When growing FGT, significant changes in soil properties can occur due to the influence of growing trees on the nutrient potential, on the water regime of the soil, a large mass of the root system is formed underground, compaction and changes in the physical properties of the soil may occur (Makovníková et al., 2020). Improper land management (failure to follow cultivation instructions) can also lead to soil degradation, a decrease in the total content of organic matter in the soil (McClean, 2012), a decrease in the nutrient potential of the soil, and thus a change in soil quality. When planting stands on contaminated sites, a positive trend can be observed in reducing the content of hazardous substances (Lone et al., 2008), when the phytoremediation ability of willow is manifested by accumulating these substances in the wood. The provision of ecosystem services largely depends on biophysical conditions and changes in land use in time and space; therefore, it is necessary to evaluate intensively managed methods of land use, which also include the cultivation of fast-growing trees on arable land (Burkhard et al., 2012; Frélichová et al., 2014). There is a research gap in the literature on the sustainable functioning of degraded agriculturally used soils from the point of view of the use of natural phytoremediation, which can be provided by the time-limited use of arable land for the cultivation of fast-growing woody plants.

The aim of the study was: 1) to evaluate the phytoremediation effect of planting the fast-growing trees on degraded arable land; 2) to apply a matrix system for evaluating ecosystem services to determine the change in the value of arable land before and after planting fast-growing trees.

2. Material and Method

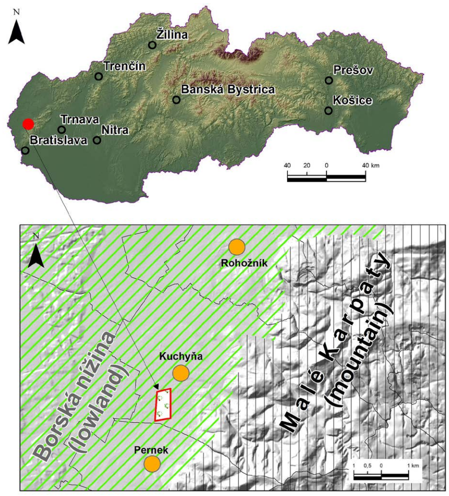
2.1. Study Area

The study site Kuchyňa, located in the area of the Záhorská low-land, which according to the Methodological Guideline of the Ministry of the Slovak Republic no. 3187/2007-430 belongs to soils suitable for growing fast-growing woody plants for energy purposes, were monitored from 2010 to 2018. In 2006, when establishing a stand of fast-growing willow for energy purposes (Salix viminalis), this location belonged with an area of 43 ha to soils unsuitable for agricultural production due to the above-limit contents of the risk elements Cd, Zn, Ni (**Figure 1**). In the years 2017-2018, the cultivation of FGT was completed, and in 2019 agricultural use was resumed (mixture, leguminous - cereal growth). We took soil and plant samples from 5 places, soil samples from a depth of 0 - 10 cm and 35 - 45 cm (Kolektív, 2011).

2.2. Matrix System

The assessment of ESS by a "matrix approach" is a practical approach that can be used to assess, map and value ecosystem services for their implementation in policy, institutional governance and sustainable ecosystem management (Kamlun et al., 2019; Burkhard et al., 2012; Jacobs et al., 2015). The Ecosystem Service Potential Matrix is essentially a lookup table that links land cover types to an ecosystem and its potential to provide ecosystem services. We evaluated the changes in potential of ESS over time of FGT using the modified matrix of authors Burkhard et al. (2014), Müller et al. (2020) and Černecký et al. (2020). A matrix with a score range from 0 to 100 proposed by Müller et al. (2020) was supplemented with values from the matrix of Burkhard et al. (2014) which were converted from a rating value 0 to 5 to point values ranging from 0 to 100 points. **Table 1** shows the point values of the potential of production (**Table 1(a)**) and regulatory ESS (**Table 1(b)**) for the ecosystem of arable soils and fast-growing trees FGT (the potential of ecosystem services represents the hypothetical maximum yield of selected ESS; Burghard et al., 2014).

Schematic evaluation of regulatory ecosystem services in model regions illustrates **Figure 2**. To determine the monetary price of natural capital for the



Willow growth in 2010

Willow growth after harvesting in 2014 Willow growth in 2018

Figure 1. Geographical location of model locality Kuchyňa.

Table 1. (a) Modified assessment matrix of production ecosystem services; (b) Modified assessment matrix of regulatory ecosystem services.

(a)

Provisioning services	Rating value of ecosystem services categories					
	1	2	3	4	5	6
Arable land	90	90	5	5	10	90
Fast-growing trees FGT	5	90	5	5	20	10

Explanation: 1. Food (biomass-nutrition), 2. biomass for energy purposes, 3. Livestock grazing, breeding, 4. Wood production, 5. Game hunting, 6. Folder for livestock and animals.

(b)

Regulating services	Rating value of ecosystem services categories							
	1	2	3	4	5	6	7	8
Arable land	40	20	20	20	30	30	30	30
Fast-growing trees	40	70	20	60	90	70	90	40

Explanation: 1. Local climate regulation, 2. Global climate regulation, 3. Air quality regulation, 4. Water regulation, 5. Erosion regulation, 6. Filtration/immobilization of risk elements, 7. Pollination, 8. Biodiversity protection.

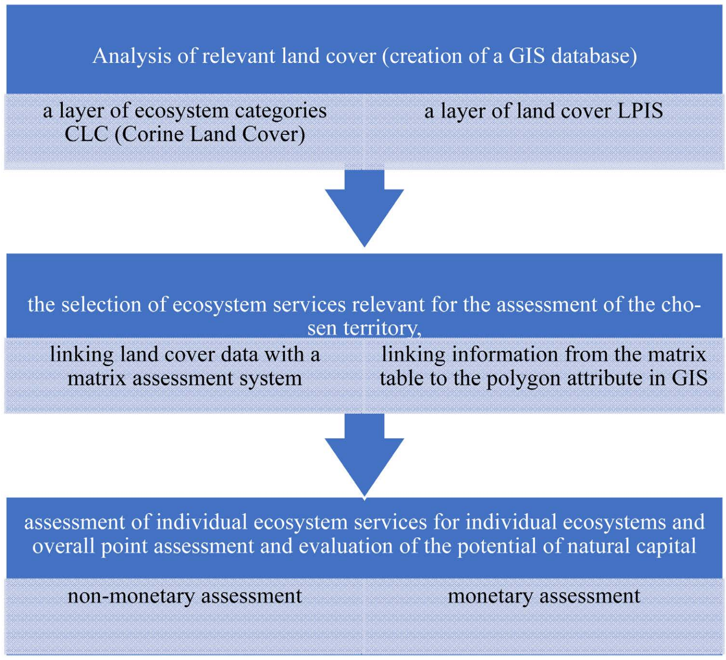


Figure 2. Scheme of evaluation of ecosystem services.

provision of ESS, we chose the value transfer method (Liu et al., 2010; Wilson & Hoehn, 2006; Burkhard & Maes, 2017; Černecký et al., 2020), based on which it is possible assign an economic value to the point values. Frélichová et al. (2014) stated the original value of 36.586 EUR per hectare; this value was adjusted for inflation in the Slovak Republic 3.2% in 2021. The value of score 1 was assigned an amount of EUR 40.70 per hectare. The monetary values of the potential of ecosystem services for individual ecosystems were subsequently calculated according to the point totals from the matrix.

2.3. Data Sources

The cartographic basis for the assessment of ecosystem services was the layer of land cover LPIS (Land Parcel Identification System) and the layer of the ecosystem category Corine Land Cover (CLC), Data from the Digital Soil Map of Slovakia and data of Soil Monitoring of Slovakia were used to evaluate soil properties changes.

3. Results and Discussion

During the monitoring of soil parameters when using the study site for FGT cultivation, we noted a slight decrease in the value of the active soil reaction, a negative trend in the content of accessible phosphorus and a positive trend in the development of the total content of risk elements in the soil. The indicators of soil quality at the beginning and at the end of the follow-up are shown in **Table 2**.

Willow belongs to potentially resistant crops due to the high content of risk elements in the soil, and at the same time it belongs to important phytoextractors

Table 2. Indicators of soil quality - location Kuchyňa.

Parameter/Year		Depth 0 - 10 cm		Depth 35 - 45 cm	
		2010	2018	2010	2018
pH in H_2O		5.81	5.58	5.80	5.52
pH in $CaCl_2$		5.23	5.10	5.31	5.20
Cox v %		2.318	2.35	1.958	2.09
Macronutrients in mg·kg^{-1}	P	73.70	63.04	43.50	47.880
	K	163.00	155.80	106.00	129.30
	Mg	92.70	105.08	119.00	117.34
Total content of risk elements in soil in mg·kg^{-1} (aqua regia)	Cd	1.016	0.443	0.822	0.340
	Zn	199.000	146.000	287.000	157.000
	Ni	51.500	39.600	69.600	44.400

used in the process of natural phytoremediation (Schmidt, 2003; Lamine & Saunders, 2022). Although the willow does not belong to the hyperaccumulators of risk elements, its advantage is a disproportionately larger biomass formation compared to phytoextractors such as the blue pennywort (Thlaspi (Noccaea) caerulescens) (Vaculík & Lux, 2018). The total content of cadmium, nickel and zinc in the monitored location was just below the limit value according to Decree 59/2013 of the Ministry of Agriculture of the Slovak Republic amending the Soil Act 220/2004 Coll. (Vyhláška č. 59/2013; Zákon o pôde č. 220, 2004), and the agricultural land could be reused for the production of crops and fodder.

During monitoring, the Cd content in the wood varied from 2730 to 9520 mg·kg^{-1}, the Zn content from 160.00 to 43.00 mg·kg^{-1}. The average value of the Cd bioaccumulation factor (the ratio of the total Cd content in the plant to the total Cd content in the soil) was 9.36 in the observed period (minimum 7.05 in 2010 and maximum 15.01 in 2015). The Zn bioaccumulation factor was significantly lower with an average value of 1.54 (minimum 0.41 in 2013 and maximum 2.63 in 2012). Willow is not one of the hyper-accumulators for Cd and Zn, but its bioremediation effect is enhanced by the high value of the annual biomass increase.

Quantification and evaluation of ESS represent one of the driving forces of the sustainable development of human activities in the context of natural capital (Wojtach, 2016). Only healthy soil can provide ESS to the full extent, it can reach maximum matrix point values (full potential of ESS). A contaminated site (degraded soil) has a reduced potential for crop and fodder production (1/3 of the full potential; Černecký et al., 2020) as well as a lower potential for regulatory ESS (in the case of climate regulation and air regulation by ½; filtration of hazardous substances, pollination and biodiversity protection by 1/3). The decrease in the total content of risk elements in the soil below the limit value increased the value of production and regulatory ESS at the study location Kuchyňa, when the degraded land type was changed back to arable land. We evaluated changes in the potential of production and regulatory ESS at the study location (Table 3(a) and Table 3(b)). We carried out the evaluation using a modified matrix of the potential of regulatory ESS (Table 1). Changes in the point value of ESS of arable land before cultivation of FGT (contaminated arable land) and after the end of cultivation of FGT (decontaminated arable land) as well as of the FGT ecosystem are shown in Table 3(a) and Table 3(b).

Table 3. (a) Changes in the point value (per ha) of production FGT of arable land before cultivation of FGT (contaminated arable land) and after the end of cultivation of FGT (decontaminated arable land) and FGT values; (b) Changes in the point value (per ha) of the regulatory ecosystem services of arable land before the cultivation of FGT (contaminated arable land) and after the end of FGT cultivation (decontaminated arable land) and the value of the potential of the regulatory ecosystem services of FGT.

(a)

Provisioning services	Capacity score		
	Contaminated arable land	Arable land after planting willow	Fast-growing trees
Food (biomass -nutrition)	30	90	5
Biomass for energy purposes	90	90	90
Livestock grazing, breeding	5	5	5
Wood production	5	5	5
Game hunting	5	10	20
Folder for livestock and animals	30	90	10
Point value	**165**	**290**	**135**

(b)

Regulating services	Capacity score		
	Contaminated arable land	Arable land after planting willow	Fast-growing trees
Local climate regulation	20	40	70
Global climate regulation	10	20	40
Air quality regulation	10	20	20
Water regulation	20	20	60
Erosion regulation	30	30	90
Filtration/imobilisation of risk elements	10	30	70
Pollination	10	30	90
Biodiversity protection	10	30	40
Point value	**122**	**220**	**480**

Table 4. Changes in the price of ecosystem services of arable land before FGT cultivation (contaminated arable land) and after FGT cultivation (decontaminated arable land) and FGT monetary values.

Ecosystem services		Contaminated arable land	Arable land after planting willow	Fast-growing trees
Provisioing	price per ha in euros	6715	11,803	5494
	price for 43 ha in euros	288,766	507,529	236,263
Regulating	price per ha in euros	4965	8954	19,536
	price for 43 ha in euros	213,512	385,022	840,048

The cultivation of FGT on agricultural land itself can contribute to the reduction of greenhouse gases by carbon sequestration, thereby positively influencing the regulatory ESS, the regulation of the local climate (Aengenheyster et al., 2018), through the process of phytoremediation/phytoextraction, it restores the potential of filtering hazardous substances and contributes to reducing the degree of degradation soil, contributes to the regulation of the water regime, as well as prevents the release of contaminated or less productive arable soils. However, the planting of monocultures can reduce the biodiversity of the area (Chobotová, 2010). When following the recommended management for planting FGT, there is no excessive draining of nutrients from the soil, especially phosphorus, but if not followed, there may be a decrease in the content of accessible nutrients as well as a decrease in the content of organic carbon in the soil (McClean & Gary, 2012).

Changes in ecosystem conditions caused by land use change (such as energy crops) may affect the ability of an ecosystem to provide services of sufficient quality and quantity (Erhard et al., 2016). The value of the productive ESS of the arable land ecosystem increased by 125 points per ha and the regulatory ones by 98 points per ha after FGT cultivation. The changes in the ESS price of arable land before FGT cultivation (contaminated arable land) and after FGT cultivation (decontaminated arable land) and FGT ecosystem values are shown in **Table 4**. After the end of FGT cultivation, the value of ESS of 43 ha of arable land ecosystem increased by 390,272 Euros.

4. Conclusion

The decline of natural resources and the deteriorating quality of the environment causes constant pressure on ecosystems. The growing demands of satisfying social needs call for a sustainable way of managing the landscape, which requires the introduction of tools for the evaluation and assessment of ESS. Combining economic and ecological approaches in the form of the concept of ESS represents such an alternative. When changing the use of agricultural land from arable land to land for FGT cultivation and back to arable land, we can evaluate two levels. First level are changes in soil indicators after the end of FGT cultivation, phytoremediation of the given site and its return to its original use. The second level is the impact of FGT cultivation on soil properties. In the course of monitoring the use of agricultural land for the cultivation of energy crops in Kuchyňa, we observe a slight decrease in the value of active soil reaction, a more significant negative trend in the content of accessible phosphorus and a positive trend in the development of the total content of risk elements in the soil. Cultivation of FGT also has a positive effect on the regulatory ESS, as the total point value of regulatory services of the FGT ecosystem is significantly higher than arable land for all monitored services.

Phytoremediation represents a progressive type of bioremediation procedures, and since plants play the main role in these procedures, they are sometimes also referred to as green phyto-technologies. The phytoremediation ability of willow with regard to risk elements was manifested by an increase in the value and price of production and regulatory ESS at the monitored location Kuchyňa in Slovakia. The price of natural phytoremediation of fast-growing willow on the given area (with a bonus from the sale of FGT for energy processing) was EUR 218762.5 for production services and EUR 171509.8 for regulatory services.

In the future, the task should be standardization of ESS assessment systems for individual ecosystems as well as groups of ESS, to monitor changes in the potential of ESS, and to maintain the highest possible value of natural assets at the regional and national level within sustainable land management.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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