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Original Research

The Sustainable Revitalization Potential of Agricultural Brownfield - a Case Study of East Slovakia

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Abstract

The interaction between soil quality and the potential of Paulownia cultivation in terms of revitalization of a specific agricultural brownfield located in the East Slovak region of the Slovak Republic is studied. At the same time, the qualitative indicators of soil and phytomass, including planted Paulownia seedlings, to further possible revitalization of agricultural brownfields in terms of the obtained soil quality data is presented. Based on the obtained qualitative data on the soil, originally occurring phytomass, summary findings and recommendations for revitalizing a particular agricultural brownfield in Paulownia are presented, as fast-growing trees are supporting not only the revitalization of a specific agricultural brownfield but also the climate change mitigation. At the same time, selected indicators of Paulownia's growth are used to potentially revitalize the agricultural brownfield with the aim of its practical use.

Keywords: agricultural brownfield, Paulownia, soil quality, heavy metal

Introduction

The theme of brownfields is now closely linked to the issue of sustainable development and spatial planning. Sustainable development is a development that respects the environment and is consistent with society's economic and social progress. Brownfield research is a discussed topic in current urban planning, land economy, and public policy. It is as well as an essential issue of concern in urban economic transformation and renewal in recent years [1]. These areas deserve the attention of the public and private sectors, and their systematic support will help the cultural, economic and social development of society [2]. Brownfields and their renewal promote the idea of sustainability. These areas with hidden development potential have a wide range of possibilities for revitalization, which also carries different risks [3, 4]. Scientists who focus on this research are primarily found in countries with higher urbanism and

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industrialization, such as the USA, China, and Germany [5, 6]. Development, sustainable development, pillars of sustainable development and other realities are directly or indirectly linked to the soil as a resource, space, and economic factor [7, 8]. The revitalization of brownfields is a logical step towards achieving the sustainability of the territory. Revitalization brings new activities and restores the previous. Revitalization reduces the pressure on the surrounding construction of areas not yet built and thus reduces the demands on transport and other urban infrastructure [9]. Some countries of the European Union have decided to re-establish their brownfields as a specific target. For example, the UK aims to locate 60 % of housing construction in the area of brownfields [10, 11]. These territories need to be dealt with systematically. We need multidisciplinary research through knowledge from different disciplines. Several scientific studies have been published on this subject, with around 800 scientific articles analyzed in 2000-2020, which analyzed sustainable development topics [12], biodiversity, heavy metals [13], and the environment [14]. Recent research has also revealed differences in research into brownfields between developed and developing countries. Research in developed countries focuses on renovation and ageing policies. This topic has an international context. Studies examine policy measures to overcome regulatory processes in the area under examination [15].

Paulownia is a fast-growing tree species commonly used to produce biomass for energetic purposes and has an excellent nutrient and water demand that may affect soil fertility and quality. Pizzol et al. introduced the "TBPT" model to help stakeholders find the best locations for renovation and revitalization [16]. A methodology for the efficiency of the use of brownfields is also developed in this area [17, 18]. The method of indexing these territories [19, 20] is also known. Scientists have also examined obstacles to revitalizing territories, including fear of accountability, regulation, and environmental purity standards [21, 22].

During the political-economic transformation in the 1990s, Slovakia's agriculture underwent significant structural changes, which resulted in a reduction in agricultural production and an overall decline [23, 24]. Agricultural brownfields on the ground of Slovakia were created as a result of the fundamental social and economic changes and transformation of the market economy after 1989 [25, 26], which caused the disappearance of specific farms and the reduction of agricultural land. Agricultural brownfields [27, 28] are one of the most common brownfields in the eastern EU region. The most frequently occurring agricultural brownfields in Slovakia are former areas of Agricultural Cooperatives. On these territories, there are storage halls, cattle stables, garages, small office areas, external silage areas, various paved areas and others [29]. In the way of pollution hazards, pollution of organic origin and gutter from agricultural machinery and heavy mechanization may occur. Agricultural brownfields are mostly part of villages and have meagre investment potential because their revitalization, complicated mainly by unadulterated property-legal relations of land, is unprofitable without financial subsidies.

In the coming years, there is a significant challenge for researchers based on identifying key research directions in the brownfields, their comprehensive evaluation, regeneration and sustainability. For this reason, the research aimed to propose and study the qualitative indicators of soil and phytomass, including Paulownia seedlings, and selected indicators of Paulownia seedling's growth and the revitalization of a specific brownfield in the eastern part of Slovakia.

Material and Methods

To examine the impact of soil quality of an agricultural brownfield on its revitalization by Paulownia cultivation, we selected a brownfield on the territory of a former Agricultural Cooperative in the East Slovak region. It was closed in 2010 and currently harms the landscape and aesthetics of the natural environment and determines the different types of diversionary activity [30].

Since the key determinant of the possibility of the revitalization of agricultural brownfields was considered the soil quality of the territory, the analysis was based on experimental evaluations of selected soil quality indicators and plant growing on unused agricultural land with an emphasis on soil reaction and heavy metal content. For these reasons, soil samples were taken at the following sites of the analyzed agricultural brownfield (Fig. 1):

- Site 1 – the upper border of the agricultural brownfield;
- Site 2 – the centre of the agricultural brownfield area;
- Site 3 – the lower border of the agricultural brownfield.

In all three localities described above, samples of wild plants were taken for the determination of heavy metals, and three experimental measurements and quantification of their average value were performed from each sample. At the same time, three identical seedlings of fast-growing Paulownia trees were planted. The growth was monitored for 12 weeks due to the time limit of their planting during the winter period when growth is minimized, as follows:

- Site 1 – Paulownia seedlings 1 – 3;
- Site 2 – Paulownia seedlings 4 – 6;
- Site 3 – Paulownia seedlings 7 – 9.

The heavy metal content was determined in different parts of plant samples and planted Paulownia as follows:

- Site 1 – beech leaf, grass, dandelion flower, cloverleaf;
- ite 2 – beech leaf, grass, dandelion flower, cloverleaf;
- Site 3 – leaf, root, bark of Paulownia.

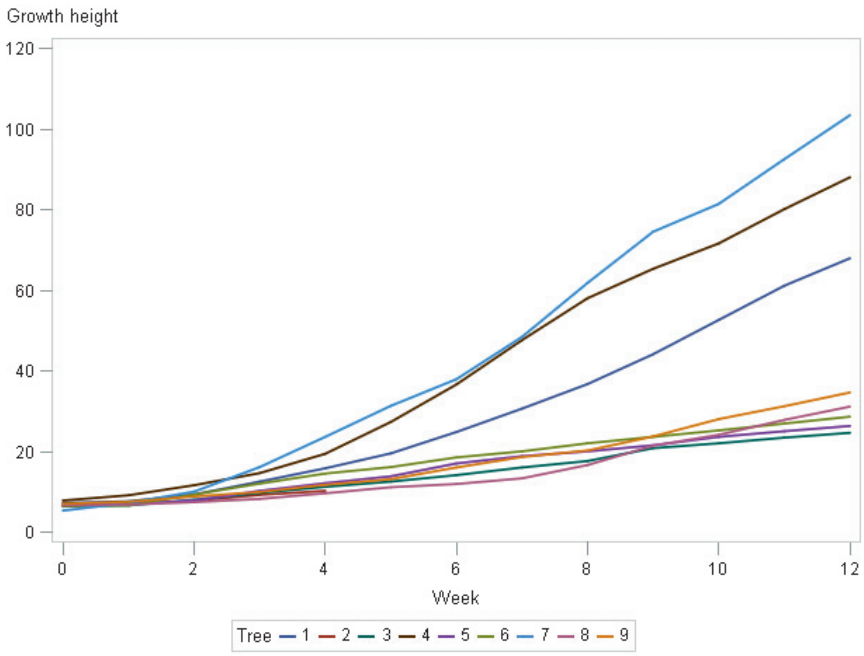

Fig. 1. Graphic representation of the growth of individual trees.

The soil pH was estimated in H_2O and KCl (1 mol.l-1) extracts (1:2.5, m/v) after agitation for one hour [31] (STN ISO 10390 Soil quality) using a pH meter (pH 70 portable). Pseudo-total heavy metal concentrations in soil samples (<0,125 mm) were determined by extraction in aqua regia (1:3 v:v conc. HNO_3:HCl) for 24 h and extraction under reflux [32, 33] (STN ISO 11466 Soil quality; ISO 20280:2007 Soil quality). Total heavy metal concentrations in soil samples (<2 mm) were determined by extraction in HNO_3 (2 mol.l-1) for two hours.

When determining heavy metals in the collected vegetal material, it was washed with 0.1 mol.l-1 HCl solution for 15 s and distilled water then for 10 s. The washed sample was oven-dried at 70ºC. 5 g of the prepared sample was burned in a muffle furnace at 500ºC, and 10 ml of 2M HNO_3 were added after cooling. After dissolving the ash, the sample was filtered and diluted to 50 ml with distilled water. AAS (iCE 3300, Thermo Fisher Scientific) analyzed the samples for heavy metal contents.

Results and Discussion

From laboratory experiments, the soil reaction was determined, the active soil reaction, pH/H_2O and soil exchange reaction, pH/KCl, were found to be in the range of 4.95-6.08, with the average pH determined as pH/H_2O was 5.89 and the average pH determined as pH/KCl was 5.60 (Table 1).

From the experimental results of the determination of the concentrations of heavy metals in HNO_3, the following facts were found (Table 2):

Table 1. Agricultural brownfield soil pH.

Method	Site 1	Site 2	Site 3
Active soil reaction (pH/H_2O)	5.64	5.96	6.08
Exchange soil reaction (pH/KCl)	4.95	5.89	5.95

– The agricultural brownfield soil did not contain As, Au, Ge, Ni, or Sn;
– Trace amounts were recorded in the case of Ag, Co, and Sb below 0.1 μm in all analyzed localities and the case of Cd in locality 1 - below 0.01 μm;
– The highest concentration in all analyzed localities was measured in the case of Fe, with the highest concentration in locality 1, the lowest in locality 3 and an average concentration of 0.256148 $mg.kg^{-1}$ and Al, with the highest concentration in locality 1, the lowest again in locality 3 and the average value 0.182611 $mg.kg^{-1}$;
– Compliance with the limit concentrations was found in all analyzed localities at As, Au, Cd, Cr, Cu, Ge and Ni;
– above-limit values were recorded in the localities at Ag, Al, Co, Fe, Mn and Sb. At the same time, the highest exceedance of the concentration was found in Fe with the highest exceedance in site 1 by more than 0.36 $mg.kg^{-1}$, the lowest exceedance in site 3 by more than 0.19 $mg.kg^{-1}$ and the average exceedance by 0.256148 $mg.kg^{-1}$, and conversely the lowest for Ag with the highest exceedance in site 2 by 0.14 $\mu g.kg^{-1}$, the lowest exceedance in site 1 by 0.012 $\mu g.kg^{-1}$ and the average exceedance by 0.090 $\mu g.kg^{-1}$.

Table 2. Content of heavy metals in agricultural brownfield soil analyzed using HNO_3 in mg.kg^{-1}.

Heavy metal	Site 1	Site 2	Site 3	Limit
Ag	0.0000135	0.0001415	0.000118	0
Al	0.181772	0.18702	0.17904	0
As	0	0	0	5
Au	0	0	0	0
Cd	0.0000085	0	0	0.3
Co	0.000829	0.000898	0.000799	0
Cr	0.0011065	0.001182	0.001101	10
Cu	0.0014935	0.0016055	0.001203	20
Fe	0.362779	0.2128725	0.192791	0
Ge	0	0	0	0
Mn	0.0534315	0.0579605	0.050027	0
Ni	0	0	0	10
Sb	0.000297	0.0000875	0.0000275	0
Sn	0	0	0	0
Zn	0.0030715	0.002617	0.001903	40

From the experimental results of the determination of the concentration of heavy metals by aqua regia, the following facts were found (Table 3):

– The agricultural brownfield soil did not contain As, Au, Cd, Ge, Ni, or Sn;
– Trace amounts below 0.1 μm were found only in the case of Ag in all analyzed sites;
– Trace amounts below 0.1 μm were found only in the case of Ag in all analyzed localities;
– The highest concentration in all analyzed localities was measured in the case of Fe with the highest concentration in site 1, the lowest in site 3 and the average concentration of 4.246482 mg.kg^{-1} and Al with the highest concentration in site 2,

Table 3. Content of heavy metals in agricultural brownfield soil analyzed using aqua regia in mg.kg^{-1}.

Heavy metal	Site 1	Site 2	Site 3	Limit
Ag	0.00027	0.000155	0.000093	0
Al	1.89196	2.2872	1.87201	0
As	0	0	0	25
Au	0	0	0	0
Cd	0	0	0	0.4
Co	0.005925	0.007045	0.004174	15
Cr	0.01323	0.00731	0.005822	70
Cu	0.011405	0.013785	0.010783	60
Fe	4.2206	4.510455	4.008391	0
Ge	0	0	0	0
Mn	0.41519	0.444335	0.39454	0
Ni	0	0	0	40
Sb	0.00189	0.00007	0.00005	0
Sn	0	0	0	0
Zn	0.02846	0.02659	0.02429	150

the lowest in locality 3 and the average value 2.017057 mg.kg^{-1};
- Compliance with the limit concentrations was found in all analyzed localities at As, Au, Cd, Co, Cr, Cu, Ge, Ni, Sn, and Zn;
- Above-limit values were recorded in all analyzed localities at Ag, Fe, Mn and Sb, while the highest exceedance of the concentration was found in Fe with the highest exceedance in site 2 by more than 4.51 mg.kg-^{1}, the lowest exceedance by almost 4.01 mg.kg^{-1} in site 3 and the average exceedance by 4.246482 mg.kg^{-1}, and conversely the lowest for Ag with the highest exceedance in site 1 by 0.27 μg.kg^{-1}, the lowest exceedance by 0.093 μg.kg^{-1} and the average exceedance by 0.172667 μg.kg^{-1}.

From the above-mentioned analyses of heavy metals using HNO_3 solution and aqua regia, it was found that there were no As, Au, Ge, Ni and Sn in any site, while exceeding was recorded in the cases of Ag, Al, Co, Fe, Mn, Sb, and in site 1 also Cd only when determined with HNO_3. In all sites, a slight exceedance of the elements Ag, Fe and Mn was found, the higher concentrations of which are not harmful to health if they do not enter the body regularly.

From laboratory experiments for the determination of heavy metals in phytomass samples, values that do not pose any environmental risk were measured, and the following facts were found in the analyzed phytomass samples (Table 4):
- The presence of As, Cd, Ge, Ni and Sn was not detected in any of the phytomass samples;
- No Au was detected in the grass sample from site 2 and the bark samples of Pau-lownia from site 3;
- No Sb was found in the grass sample from site 1, in the grass and dandelion sample from site 2 and in the leaf, and bark samples of Paulownia from site 3;
- Al was found only in a sample of dandelions from site 2.

For the needs of the above-analyzed selected qualitative indicators of agricultural brownfield soil, the growth trends of planted Paulownia seedlings in identical localities were determined, which included:
- Height of individual trees;
- The circumference of the trunk of individual trees just above the ground;
- Trunk circumference of individual tree species in the middle of tree species;
- The length of the leaf of each tree;
- The width of the leaf of each tree.

From the results of measurements of the height of individual trees, it was found that the development of the increase of the monitored indicator showed significant differences, while the highest height in the monitored period was reached by tree 7 from site 3, which reached 103.5 cm, and the lowest tree 3 from site 1, which reached only 24.7 cm, which was 78.8 cm less than tree 7 (Fig. 1).

Comparing the average growth of Paulownia seedlings according to individual localities of the analyzed agricultural brownfield, we could state that the highest average height was reached by woody plants

Table 4. Content of heavy metals in selected plants.

HM	Site 1				Site 2				**Site 3**		
	Beech leaf	Grass	Dandelion flower	Cloverleaf	Beech leaf	Grass	Dandelion flower	Cloverleaf	Paulownia leaf	Paulownia root	Paulownia bark
Ag	0.00038	0.00032	0	0.00006	0	0.00037	0.0001	0.00424	0.00019	0.0002	0.00133
Al	0	0	0	0	0	0	0	0.0364	0	0	0
As	0	0	0	0	0	0	0	0	0	0	0
Au	0.00026	0	0.0019	0.00059	0.00217	0.00608	0.00778	0.00326	0.006	0	0
Cd	0	0	0	0	0	0	0	0	0	0	0
Co	0.0042	0.00303	0.00738	0.00255	0.00374	0.00402	0.00351	0.00346	0.0045	0.00488	0.00354
Cr	0.01086	0.00951	0.0131	0.01006	0.00978	0.00996	0.01009	0.01045	0.00995	0.00987	0.01013
Cu	0.0091	0.03342	0.00449	0.00383	0.02014	0.00708	0.01285	0.0037	0.01111	0.00646	0.00625
Fe	0.0537	0.12493	0.35467	0.08377	0.15723	0.02239	0.62554	0.28185	0.17454	0.03915	0.21794
Ge	0	0	0	0	0	0	0	0	0	0	0
Mn	0.08123	0.02176	0.02606	0.01846	0.01474	0.01665	0.05049	0.0153	0.01948	0.0209	0.02808
Ni	0	0	0	0	0	0	0	0	0	0	0
Sb	0.00208	0.00654	0.00152	0	0	0	0.00417	0	0.00229	0	0
Sn	0	0	0	0	0	0	0	0	0	0	0
Zn	0.00641	0.02488	0.00507	0.00843	0.01824	0.0085	0.00951	0.00771	0.00632	0.00354	0.01052

planted in site 3. The average height of woody plants in this locality reached 56.47 cm in the last week of the analyzed period. From the obtained data we could further state that:

- The most significant difference in the growth of Paulownia seedlings was found between site 3 and site 2 and 1 between the 9th and 12th week;
- Paulownia seedlings in site 3 started to grow more significantly compared to the other two localities from the eighth week;
- In the first three weeks, we found only negligible differences in the growth of Paulownia seedlings between individual localities.

From the results of measurements of the trunk circumference of individual woody plants above the ground, it was found that the development of the increase of the monitored indicator showed significant differences. In contrast, the largest perimeter at the end of the monitored period was tree 7 from site 3, which reached a circumference of only 2.8 cm, a circumference 6.4 cm less compared to tree 7 (Fig. 2).

Based on the comparison of the average growth of the perimeter of the Paulownia seedling trunk just above the ground according to individual localities of the analyzed agricultural brownfield, it could be stated that the largest average perimeter was reached by trees planted in site 3. From the obtained data, we could further state that:

- The average increases in the perimeter of the Paulownia seedling trunk just above the ground showed only minimal differences between the sites;
- The difference between the average growth of the perimeter of the Paulownia seedlings between site 3 and site 1 was 0.2 cm;
- The difference between the average growth of the perimeter of the Paulownia seedlings between site 2 and site 1 was 0.87 cm;
- The average growth of the perimeter of the Paulownia seedlings between site 3 and site 2 was 1.07 cm.

From the results of measurements of the trunk circumference of individual trees in the middle of the tree, it was found that the development of the increase of the monitored indicator showed significant differences. In contrast, the largest circumference at the end of the monitored period reached tree 7 from locality 3 site 2, which reached a circumference of only 1.8 cm, which was 4.7 cm less in the middle of the tree compared to tree 7 (Fig. 3).

Based on the comparison of the average growth of the perimeter of the Paulownia seedling trunk in the middle of the tree according to individual localities of the analyzed agricultural brownfield, we could state that the largest average perimeter was reached by trees planted in site 3. 57 cm. From the obtained data we could further state that:

- Average increases in the perimeter of the Paulownia seedling trunk in the middle of woody plants between individual localities showed only minimal, resp. negligible differences by the fourth week of the analyzed period;
- The difference between the average growth of the perimeter of the Paulownia seedlings between site 3 and site 1 was 0.42 cm;
- The difference between the average growth of the perimeter of the Paulownia seedlings between site 2 and site 1 was 0.52 cm;

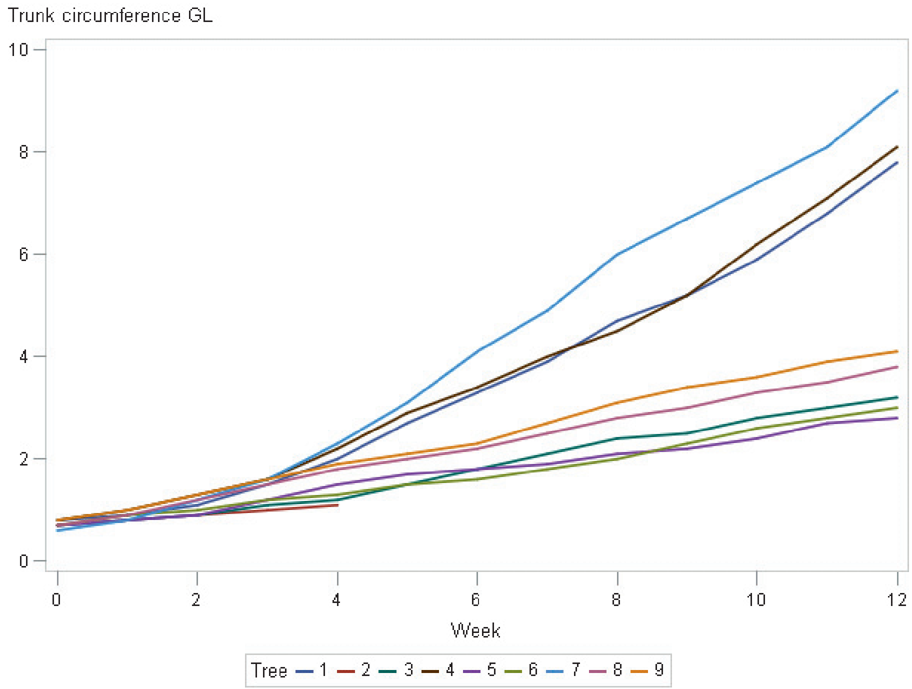

Fig. 2. Graphic representation of the growth of the trunk circumference of individual tree species above the ground.

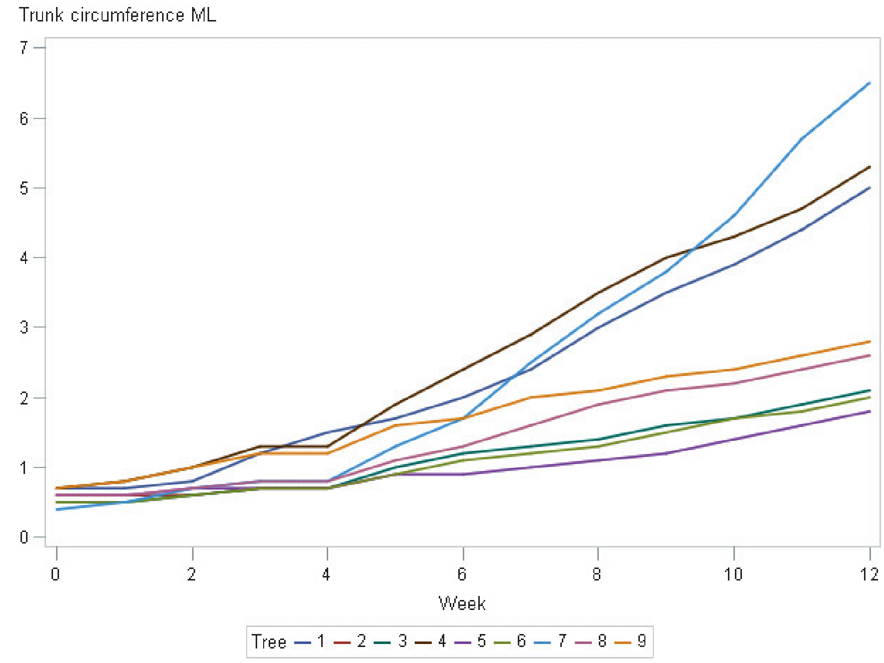

Fig. 3. Graphic representation of the growth of the trunk circumference in the middle of the tree individually.

– The difference between the average growth of the perimeter of the Paulownia seedlings between site 3 and site 2 was 0.94 cm.

From the results of measuring the leaf length of individual trees, it was found that the development of the increase of the monitored indicator showed significant differences, while the largest length at the end of the period was tree 7 from site 3, which had a leaf length of 31 cm and the smallest tree 3 from site 1, which reached the length of only 13.3 cm, which was a leaf length of 17.7 cm less compared to woody plant 7 (Fig. 4).

Comparing the average increase in the leaf length of Paulownia seedlings according to individual localities of the analyzed agricultural brownfield, we could state that the largest average leaf length was reached by trees

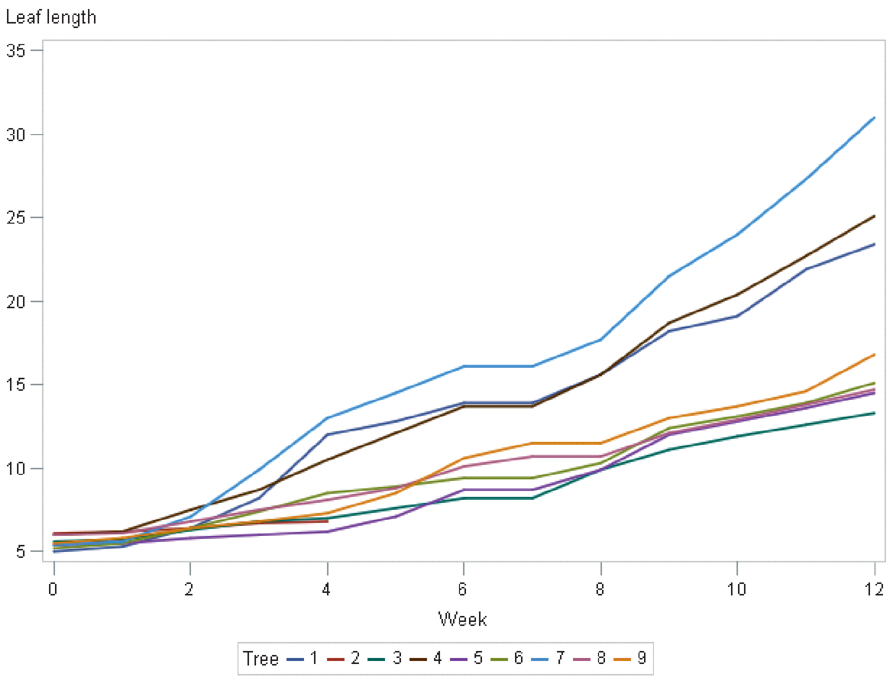

Fig. 4. Graphic representation of the growth of the leaf length of individual woody plants.

planted in site 3. The average leaf length in this locality reached 20.83 cm in the last week of the analyzed period. From the obtained data we could further state that:

- The average increases in the leaf length of Paulownia seedlings between individual localities showed only minimal differences by the second week of the analysis period;
- The most considerable difference between the average leaf length growth of Paulownia was found between site 3 and site 1, which was 2.48 cm;
- The difference between the average growth of the perimeter of the Paulownia seedlings between site 3 and site 2 was 2.6 cm;
- The slightest difference between the average increase in leaf length of Paulownia was found between site 3 and site 2, which showed a value of 0.03 cm.

From the results of measurements of the leaf width of individual trees, it was found that the development of the increase of the monitored indicator showed significant differences, while the largest width at the end of the monitored period was reached by tree 7 from site 3, which had a leaf length of 30.5 cm and the smallest tree 3 from site 1. which reached a width of only 11.7 cm, which was 18.8 cm less in width than tree 7 (Fig. 5).

Based on comparing the average leaf width growth of Paulownia seedlings according to individual localities of the analyzed agricultural brownfield, it was possible to state that the largest average leaf width was reached by trees planted in site 3. The average leaf length in this locality reached 18.95 cm in the last week of the analyzed period. From the obtained data, we could further state that:

- The average increases in the leaf width of Paulownia seedlings between the individual localities showed only minimal differences during the analyzed period;
- The most significant differences between the average growth of the leaf width of Paulownia were found between the individual localities between the 9th and 12th week;
- The difference between the average increase in the leaf width of Paulownia between site 3 and site 1 at the end of the reference period was 2.05 cm;
- The difference between the average increase in the leaf width of Paulownia between site 3 and site 2 at the end of the monitored period was 1.35 cm.

From the measured values of all five analyzed indicators, i.e. tree height, trunk circumference just above the ground and in the middle of the tree, and length and width of Paulownia leaves, we summarised the development of their minimum, average and maximum values in all three monitored localities of agricultural brownfield in Nižná Myšľa, from which we found that (Table 5):

- The analyzed minimum, average and maximum values showed significant differences according to the compared sites;
- The most significant differences in the analyzed indicators were recorded between site 3 and site 1;
- According to the results of the monitored indicators, site 3 in the area of agricultural brownfield is the most suitable for Paulownia cultivation;
- Site 1 is, according to the monitored indicators and their minimum, average and maximum values in the

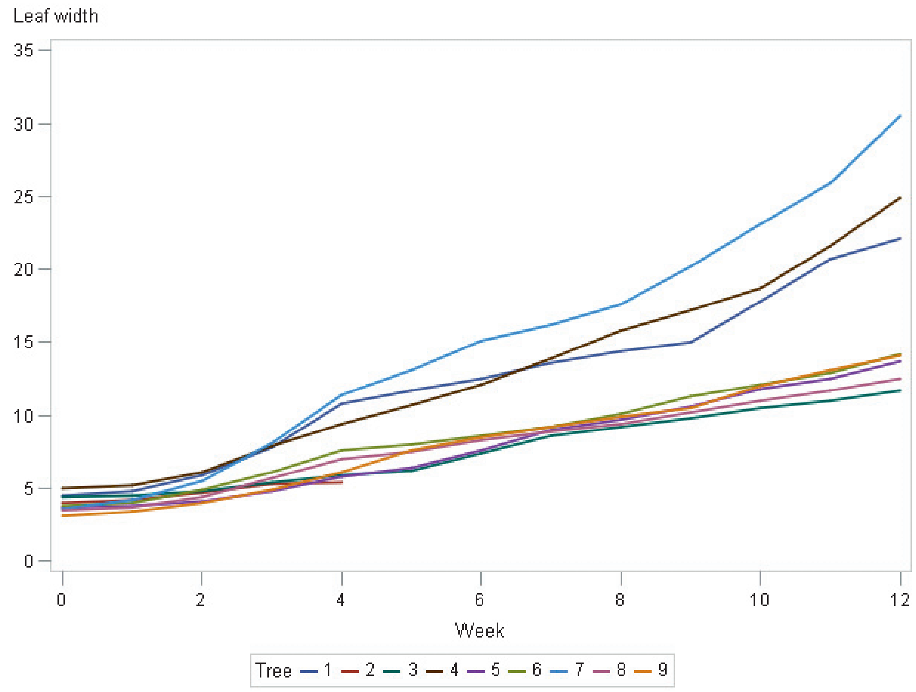

Fig. 5. Graphic representation of the growth of the leaf width of trees.

Table 5. Descriptive statistics values of the monitored indicators.

Site=1

Variable	Mean	Std Dev	Variance	Minimum	Maximum	N	Lower 95% CL for Mean	Upper 95% CL for Mean
Growth height	20.21	16.43	269.98	6.50	68.00	31	14.18	26.24
Trunk circumference GL	2.42	1.91	3.64	0.70	7.80	31	1.72	3.12
Trunk circumference ML	1.59	1.21	1.47	0.50	5.00	31	1.14	2.03
Leaf length	10.39	5.07	25.75	5.00	23.40	31	8.53	12.25
Leaf width	9.18	4.98	24.75	4.00	22.10	31	7.36	11.01

Site=2

Variable	Mean	Std Dev	Variance	Minimum	Maximum	N	Lower 95% CL for Mean	Upper 95% CL for Mean
Growth height	25.14	20.78	431.71	6.50	88.10	39	18.40	31.87
Trunk circumference GL	2.40	1.74	3.03	0.70	8.10	39	1.84	2.97
Trunk circumference ML	1.58	1.22	1.50	0.50	5.30	39	1.19	1.98
Leaf length	10.84	4.91	24.15	5.20	25.10	39	9.24	12.43
Leaf width	9.87	5.04	25.43	3.70	24.90	39	8.23	11.50

Site=3

Variable	Mean	Std Dev	Variance	Minimum	Maximum	N	Lower 95% CL for Mean	Upper 95% CL for Mean
Growth height	26.24	24.74	612.04	5.40	103.50	39	18.22	34.26
Trunk circumference GL	3.00	2.09	4.37	0.60	9.20	39	2.32	3.68
Trunk circumference ML	1.89	1.38	1.91	0.40	6.50	39	1.44	2.34
Leaf length	12.04	6.04	36.50	5.40	31.00	39	10.08	14.00
Leaf width	10.38	6.38	40.65	3.10	30.50	39	8.31	12.44

analyzed period, the least suitable for the needs of Paulownia cultivation.

We have summarized the values f selected indicators in Table 5.

An improvement in soil biochemical quality was found in soils affected by Paulownia growth. In contaminated soils, heavy metal concentrations in leaves were in the normal range for plants [34]. The accumulation of Cd, Cu, Pb and Zn by Paulownia and their mobilization in soil was studied in addition to EDTA, tartrate and glutamate, and there was no significant difference in metal accumulation in plants, but metal bioavailability in soil was higher in EDTA than in tartrate and glutamate treated [35]. The high concentrations of Zn in Paulownia significantly affect its anatomy and physiology; the plant growth and leaf gas exchange were reduced, and the damages to the cell functionality (negatively affected photosynthetic performance) led to significant growth inhibition [36].

The effect of roadside pond sediments applied to soil on heavy metal uptake by different parts of Indian mustard demonstrated that the limits of the metal content in mustard leaves and seeds were not exceeded, and the accumulation of metals was proportionally lesser in grains than in shoots and roots [37]. Other plant species are efficient in bioremediation of Pb and Zn-contaminated soils – Sapium sebiferum, Salix matsudana, Hibiscus cannabinus, Corchorus capsularis, Ricinus communis, and Populus nigra [38] (Tang et al., 2019). Deciduous street trees are effective in bioremediation soils contaminated by Cd – Populus tomentosa, Sophora japonica and Catalpa speciosa – and Pb – Catalpa speciosa, Junglas regia and Paulownia tomentosa [39].

Conclusions

The issue of brownfields, especially the agricultural ones, is an area that requires special attention. For this reason, this issue is addressed as agricultural brownfields are among the most common types of brownfields in the Slovak Republic. In light of this fact, experiments on the soil and phytomass quality and the growth of Paulownia seedlings in three sites were carried out. From the analysis of the mentioned selected qualitative indicators, it was possible to state:

Soil pH ranged from 4.95 (at site 1 for pH/KCl determination to 6.08 at site 3 for pH/H_2O determination), with the average pH determined as pH/H_2O being 5.89 and the average pH determined as the pH/KCl was 5.60, in general, it is suitable for the cultivation of Paulownia, as the recommended soil reaction for the growth of fast-growing trees is in the range of 5.5-9;

The content of heavy metals determined the development of Paulownia growth, which was also confirmed by the development of growth of height, length and width of leaf and trunk circumference of these fast-growing trees, as the highest increases of these indicators were recorded in site 3, where the lowest heavy metal content was among all three analyzed sites in addition to the trace values of Ag and Al, and vice versa, the lowest increments were recorded in locality 1, where we recorded the highest content of heavy metals;

Since all the monitored woody plants had the same conditions and the same care, the composition of the soil could have a significant effect on their growth.

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Conflict of Interest

The authors declare no conflict of interest.

References

1. MARTINÁT S., NAVRÁTIL J., HOLLANDER J.B., TROJAN J., KLAPKA P., KLUSÁČEK P., KALOK D. Re-reuse of regenerated brownfields: Lessons from an Eastern European post-industrial city. Journal of Cleaner Production, **188**, 536, **2018**.
2. ZHANG X., SONG Y., WANG S., QIAN S. Exploring Research Trends and Building a Multidisciplinary Framework Related to Brownfield: A Visual Analysis Using CiteSpace. Complexity, **2021**, 1, **2021**.
3. TUREČKOVÁ K., NEVIMA J., ŠKRABAL J., MARTINÁT S. Uncovering Patterns of Location of Brownfields to Facilitate Their Regeneration: Some Remarks from the Czech Republic. Sustainability, **10**(6), 1984, **2018**.
4. LESAGE P., EKVALL T., DESCHÊNES L., SAMSON R. Environmental assessment of brownfield rehabilitation using two different life cycle inventory models: Part 2: Case study. The International Journal of Life Cycle Assessment, **12** (**7**), 497, **2007**.
5. KLUSÁČEK P., ALEXANDRESCU F., OSMAN R., MALÝ J., KUNC J., DVOŘÁK P., FRANTÁL B., HAVLÍČEK M., KREJČÍ T., MARTINÁT S., SKOKANOVÁ H., TROJAN J. Good governance as a strategic choice in brownfield regeneration: Regional dynamics from the Czech Republic. Land Use Policy, **73**, 29, **2018**.
6. BOENTE C., SIERRA C., RODRÍGUEZ-VALDÉS E., MENÉNDEZ-AGUADO J.M., GALLEGO J.R. Soil washing optimization by means of attributive analysis: Case study for the removal of potentially toxic elements from soil contaminated with pyrite ash. Journal of Cleaner Production, **142**, 2693, **2017**.
7. RAHBARIANYAZD R. Regeneration as a Tool for Enhancing Vitality of Urban Spaces. Civil Engineering and Architecture, **8** (5), 908, **2020**.
8. HAN Q., ZHU Y., KE G., LIN H. A Two-Stage Decision Framework for Resolving Brownfield Conflicts. International Journal of Environmental Research and Public Health, **16** (6), 1039, **2019**.
9. BATES A.J., SADLER J.P., GRESWELL R.B., MACKAY R. Effects of recycled aggregate growth substrate on green roof vegetation development: A six year experiment. Landscape and Urban Planning, **135**, 22, **2015**.
10. HEATHERINGTON C., JORGENSEN A., WALKER S. Understanding landscape change in a former brownfield site. Landscape Research, **44** (1), 19, **2019**.
11. DIXON T., OTSUKA N., ABE H. Critical Success Factors in Urban Brownfield Regeneration: An Analysis of 'Hardcore' Sites in Manchester and Osaka during the Economic Recession (2009-10). Environment and Planning A: Economy and Space, **43** (4), 961, **2011**.
12. LONGO A., CAMPBELL D. The Determinants of Brownfields Redevelopment in England. Environmental and Resource Economics, **67** (2), 261, **2017**.
13. DAHLIN C., WILLIAMSON C., COLLINS W.K., DAHLIN D. Sequential Extraction Versus Comprehensive Characterization of Heavy Metal Species in Brownfield Soils. Environmental Forensics, **3** (2), 191, **2002**.
14. SUN L., GENG Y., SARKIS J., YANG M., XI F., ZHANG Y., XUE B., LUO Q., REN W., BAO T. Measurement of polycyclic aromatic hydrocarbons (PAHs) in a Chinese brownfield redevelopment site: The case of Shenyang. Ecological Engineering, **53**, 115, **2013**.
15. DE SOUSA C.A. Brownfield redevelopment in Toronto: an examination of past trends and future prospects. Land Use Policy, **19** (4), 297, **2002**.
16. PIZZOL L., ZABEO A., KLUSÁČEK P., GIUBILATO E., CRITTO A., FRANTÁL B., MARTINÁT S., KUNC J., OSMAN R., BARTKE S. Timbre Brownfield Prioritization Tool to support effective brownfield regeneration. Journal of Environmental Management, **166**, 178, **2016**.
17. RIZZO E., PESCE M., PIZZOL L., ALEXANDRESCU F.M., GIUBILATO E., CRITTO A., MARCOMINI A., BARTKE S. Brownfield regeneration in Europe: Identifying stakeholder perceptions, concerns, attitudes and information needs. Land Use Policy, **48**, 437, **2015**.
18. CHENG F., GEERTMAN S., KUFFER M., ZHAN Q. An integrative methodology to improve brownfield redevelopment planning in Chinese cities: A case study of Futian, Shenzhen. Computers, Environment and Urban Systems, **35** (5), 388, **2011**.
19. CHRYSOCHOOU M., BROWN K., DAHAL G., GRANDA-CARVAJAL C., SEGERSON K., GARRICK N., BAGTZOGLOU A. A GIS and indexing scheme to screen brownfields for area-wide redevelopment planning. Landscape and Urban Planning, **105** (3), 187, **2012**.
20. THORNTON G., FRANZ M., EDWARDS D., PAHLEN G., NATHANAIL P. The challenge of sustainability: incentives for brownfield regeneration in Europe. Environmental Science & Policy, **10** (2), 116, **2007**.
21. BENDOR T.K., METCALF S.S., PAICH M. The Dynamics of Brownfield Redevelopment. Sustainability, **3** (6), 914, **2011**.
22. CHEN, I. -CHUN, MA H. Using risk maps to link land value damage and risk as basis of flexible risk management for brownfield redevelopment. Chemosphere, **90** (**7**), 2101, **2013**.
23. FRANTÁL B., KUNC J., NOVÁKOVÁ E., KLUSÁČEK P., MARTINÁT S., OSMAN R. Location Matters! Exploring Brownfields Regeneration in a Spatial Context (A Case Study of the South Moravian Region, Czech Republic). Moravian Geographical Reports, **21** (2), 5, **2013**.
24. SQUIRES G., HUTCHISON N. Barriers to affordable housing on brownfield sites. Land Use Policy, **102**, 105276, **2021**.
25. NAVRÁTIL J., KREJČÍ T., MARTINÁT S., FRAZIER R.J., KLUSÁČEK P., PÍCHA K., ŠKRABAL J., OSMAN

R. Variation in brownfield reuse of derelict agricultural premises in diverse rural spaces. Journal of Rural Studies, **87**, 124, **2021**.
26. AHMAD N., ZHU Y., ULLAH Z., IQBAL M., HUSSAIN K., AHMED R.I. Sustainable solutions to facilitate brownfield redevelopment projects in emerging countries – Pakistani scenario. Land Use Policy, **109**, 105727, **2021**.
27. BAKALÁR T., PAVOLOVÁ H., WEISS E. Benefits of RES Use in Brownfields Reuse in Slovak Municipalities. Advanced Materials Research, **1001**, 15, **2014**.
28. HAMMOND E.B., COULON F., HALLETT S.H., THOMAS R., HARDY D., KINGDON A., BERIRO D.J. A critical review of decision support systems for brownfield redevelopment. Science of The Total Environment, **785**, 147132, **2021**.
29. PAVOLOVÁ H., CSIKÓSOVÁ A., BAKALÁR T. Development of Košice Region by Implementation of Environmental Projects in the Field of Water Management - Case Study. Ekologia, **33** (4), **2014**.
30. HAMMOND E.B., COULON F., HALLETT S.H., THOMAS R., HARDY D., KINGDON A., BERIRO D.J. A critical review of decision support systems for brownfield redevelopment. Science of The Total Environment, **785**, 147132, **2021**.
31. ISO 10390:2005 Soil quality – Determination of pH.
32. STN ISO 11466 (465121) Soil quality. Extraction of trace elements soluble in aqua regia.
33. ISO 10390:2021 Soil, treated biowaste and sludge – Determination of pH.
34. MADEJÓN P., XIONG J., CABRERA F., MADEJÓN E. Quality of trace element contaminated soils amended with compost under fast growing tree Paulownia fortunei plantation. Journal of Environmental Management, **144**, 176, **2014**.
35. DOUMETT S., LAMPERI L., CHECCHINI L., AZZARELLO E., MUGNAI S., MANCUSO S., PETRUZELLI G., DEL BUBBA M. Heavy metal distribution between contaminated soil and Paulownia tomentosa, in a pilot-scale assisted phytoremediation study: Influence of different complexing agents. Chemosphere, **72** (10), 1481, **2008**.
36. AZZARELLO E., PANDOLFI C., GIORDANO C., ROSSI, M., MUGNAI S., MANCUSO S. Ultramorphological and physiological modifications induced by high zinc levels in Paulownia tomentosa. Environmental and Experimental Botany, **81**, 11, **2012**.
37. KARAK T., BHATTACHARYYA P., KUMAR PAUL R., DAS D.K. Metal accumulation, biochemical response and yield of Indian mustard grown in soil amended with rural roadside pond sediment. Ecotoxicology and Environmental Safety, **92**, 161, **2013**.
38. TANG C., CHEN Y., ZHANG Q., LI J., ZHANG F., LIU Z. Effects of peat on plant growth and lead and zinc phytostabilization from lead-zinc mine tailing in southern China: Screening plant species resisting and accumulating metals. Ecotoxicology and Environmental Safety, **176**, 42, **2019**.
39. LIU Y.-J., ZHU Y.-G., DING H. Lead and cadmium in leaves of deciduous trees in Beijing, China: Development of a metal accumulation index (MAI). Environmental Pollution, **145** (2), 387, **2007**.