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Afforestation of Abandoned Agricultural Land: Growth of Non-Native Tree Species and Soil Response in the Czech Republic

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Abstract

Non-Native Tree Species (NNTs) play crucial roles in global and European forests. However, in the Czech Republic, NNTs represent a tiny fraction of the forested areas due to limited research on their potential use. The country is actively afforesting abandoned agricultural lands; NNTs which are already tested and certified could enhance the country's forestry system. This study aimed to evaluate the initial growth of *Castanea sativa*, *Platanus acerifolia*, and *Corylus colurna* under three soil treatments on abandoned agricultural soil, evaluate the survival and mortality of the tree species, and further compare the soil dynamics among the three ecosystems to describe the initial state and short-term changes in the soil environment. The research plot was set in the Doubek area, 20 km East of Prague. Moreover, soil-improving materials, Humac (1.0 t·ha^{-1}) and Alginite (1.5 t·ha^{-1}), were established on the side of the control plot at the afforested part. The heights of plantations of tree species were measured from 2020 to 2024. Furthermore, 47 soil samples were collected at varying depths from three ecosystems (afforested soil, arable land, and old forest) in 2022. A single-factor ANOVA was run, followed by a post hoc test. The result shows that the Control-C plot (*Castanea Sativa* + *Platanus acerifolia* + *Corylus colurna* + agricultural soil without amendment) had the highest total growth (mean annual increment in the year 2024) for *Castanea sativa* (KS = 40.90 ± a21.61) and *Corylus colurna* (LS = 55.62 ± 59.68); Alginite-A (*Castanea Sativa* + *Platanus acerifolia* + *Corylus colurna* + Alginite) did best for *Platanus acerifolia* (PT = 39.85 ± 31.52); and Humac-B (*Castanea Sativa* + *Platanus acerifolia* + *Corylus colurna* + Humac) had the lowest growth. Soil dynamics among the three ecosystems showed that the old forest (plot two) significantly differs from arable soil (plot one), Humac and *Platanus* on afforested land (plot three), *Platanus* and Alginite on afforested land (plot four), and *Platanus* without amendment (plot five) in horizon three (the subsoil or horizon B) and in horizon four (the parent material horizon or horizon C). Results document the minor response of plantations to soil-improving matters at relatively rich sites, good growth of plantations, and initial changes in the soil characteristics in the control C plot. We recommend both sparing old forests and the afforestation of abandoned agricultural soils using a control treatment for improved tree growth and sustained soil quality. Further studies on the species' invasiveness are needed to understand them better.

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1. Introduction

Abandoned and marginal agricultural lands are a crucial challenge in numerous world regions. They are among Europe's predominant land-use change processes, where these lands are estimated to cover between 20,277 and 211,814 km^2 by 2040 [1]. Numerous benefits are identified for the afforestation of abandoned agricultural soils. These include increased/restored soil fertility, water regulation, erosion control, fungal biomass increase, greater decomposition ability, and carbon fixation [2]. Tree planting results in regaining microbial biomass, mediating the challenges after carbon sequestration [3–5]. It increases nutrient accessibility, like nitrogen and phosphorus, during mineralization through soil organic matter (SOM) decomposition [6]. Non-Native Tree Species have been spread throughout the world on abandoned agricultural soils and forestry systems for timber production, biodiversity promotion, ecosystem enhancement, and landscape beautification [7,8]. Contrary to the condition of agriculture, NNTs occupy a minor area in European forests and the Czech Republic [9]. This represents 8.54 million ha, approximately 4% of the forest cover in Europe [10], and 1.82% of the Czech Republic's forest [9]. Many NNTs were brought to Europe after the 16th century [11]. Some of the tree species have been promoted (through cultivation) across Europe, due to the goods and services they provide to societies [12]. After their first introduction, some of the NNTs have dispersed with little or no human interaction, benefiting from good soil and climatic conditions, dominant competition, and, in the end, becoming adapted or invasive in some scenarios [13]. Some of the NNTs in Europe are planted for timber, such as *Picea sitchensis*, *Eucalyptus globulus*, *Pseudotsuga menziesii*, and *Robinia pseudoacacia*, whereas some are used for ornamental reasons, such as *Quercus rubra* L., *Acacia dealbata*, and *Ailanthus altissima* [14–17]. Some researchers advocated that NNTs should be avoided in the massive tree-planting (3 billion trees) campaign of Vision 2030 in Europe to attain zero carbon emissions by 2050 [18]

Consequently, the advantages and disadvantages of valuable NNTs are a topic of academic discussion, due to possible negative impacts on the ecosystems that may occur from the spread of such species [19–22]. NNTs are progressively debated in a situation of world market change, the adverse effects of climate change on life, and insufficient managerial activities [23–25]. As a result, numerous legislative bodies have been established in European countries, focusing on regulating the development of NNTs, e.g., Regulation (EU) No 1143/2014 [26]. This regulation mandates several EU Member states to implement concrete management measures for invasive species on the EU watch lists [11,27]. This is in addition to the management recommendation of NNTs by many researchers, targeting the reduction of their possible negative impact [28]. On the other hand, there are ecosystem impacts usually associated with NNTs linked to soil or biodiversity, which are measurable and of research interest [29]. The impacts of NNTs on soil chemical properties may have permanent ecosystem outcomes, considering the role of soil as a foundation for environmental functioning. Common effects of NNTs on soil chemical properties are attributed to changes in nitrogen amount and some nutrients, organic-matter breakdown rate, pH, and organic carbon [30,31]. Depending on the viewpoint, soil changes caused by the NNTs may be perceived as either advantageous or harmful. For instance, soil nitrogen increments from leguminous species may be advantageous from the farmers' viewpoint, but harmful to conservationists [32]. In biodiversity, there is a concrete debate about the harmful impacts of NNTs because they decrease or change the species richness or diversity of indigenous taxa, including fauna and floral populations [33]. Allelochemical interference linked to NNTs is considered as the main mechanism that lowers the species richness of herbaceous plants under non-native, rather than native, tree species [34]. However, NNTs showed the highest percentage of regeneration compared to native species when used as a soil seed bank [35].

The tendency to use NNTs in the forestry system is debated in the Czech Republic, as well. For instance, *Pseudotsuga menziesii* (Douglas fir), an important species in Europe, is an established species through legislation (Decree No. 298/2018 Coll), forest management, and forest plan units, although it has some challenges with nature conservation experts [36,37]. Nevertheless, the story is different with particular coniferous and broadleaved trees; *Sequoiadendron giganteum* (giant sequoia), *Cedrus atlantica* (Atlas cedar), *Juglans nigra* (black walnut), *Quercus rubra* (Northern red oak), and *Metasequoia glyptostroboides* (Chinese redwood) and other potentially adaptable NNTs are under consideration, due to global warming [38]. In the context of the Czech Republic, NNTs can only be planted in research fields (plots) without administrative protocols. This is to understand their desirability and potentiality in the field (practical forestry). It is compulsory to test the tendencies of their existence (life), growth, development, and invasive ability [39]. In the Czech Republic, there is insufficient information on the performance of NNTs, particularly broadleaved species. There is also little information regarding using soil amendments (treatment) for NNTs' broadleaved trees on abandoned agricultural soils. Moreover, soil amendments like organic manure, farmyard manure, and green manure could affect seedling growth in abandoned agricultural soil [40]. Consequently, there is a need for intensive and comprehensive research.

This study aimed (i) to assess the initial growth of selected introduced broadleaved tree species, *Castanea sativa*, *Platanus acerifolia*, and *Corylus colurna*, with the application of two soil-improving materials, Humac and Alginite, on afforested agricultural land in the Doubek locality, Central Bohemia, the Czech Republic, and (ii) (another aim) to compare the upper soil state (horizon B) among forest site, arable soil, and the recently afforested agricultural soil. Humac was found to improve soil properties and all forms of observed nutrients, which increase crop yield [41]. Alginite is a component of certain kerogens, together with amorphous organic matter, commonly used in the adsorption, separation, and removal of cadmium ions in aqueous solutions. The Alginite from a central European geological maar in Hungary was used for the production of a new unconventional sorbent or mineral Sievers, for the removal of toxic metals in the soil [42]. In Slovakia, the soil shows high humus content (15.5%) and has a considerable number of macronutrients (K, Ca, Mg), and a high water-retention ability (110%); it is a useful natural sorbent agent, a growth enhancer with no side-effects on the environment, and a fertilizer [43]. Consequently, trying Humac and Alginate on Czech soil may yield similar positive results.

The selected species, *Castanea sativa*, *Platanus acerifolia*, and *Corylus colurna* are noble hardwoods of economic importance originated from Southern Europe, which are considered from the perspectives of the climate change [44]. Trying their performance under Humac and Alginite in the experimental plot may give them the potential for integration into the Czech Republic forestry system, where afforestation is actively underway to combat climate change through biodiversity, among other factors. The research provides answers to the following questions: (i) Is there a difference in the tree species growth under control (Agricultural soil without amendment) and Alginate or Humac treatments? (ii) Is the survival of the tree species affected by the treatments? Is there a difference between the topsoil (horizon B) of the old forest (plot two), arable soil (plot one), Humac and *Platanus* on afforested land (plot three), *Platanus* and Alginite on afforested land (plot four), and *Platanus* without amendment (Plot Five)? The findings might provide valuable insights to support foresters, policymakers, and researchers in making informed decisions and interventions on improving forested agricultural land through tree species selection and soil quality enhancement.

2. Materials and Methods

2.1. Study Site

The research project was initiated in the autumn of 2019, and the research plot was established on private arable agricultural land in the locality of Doubek, 20 km east of Prague (50°116.511 N, 14°4353.920 E). The plot is fenced at 1.55 hectares, and the tree species were planted in autumn 2019 (Figure 1). The area's climate is moderately warm and humid, with mild winters; it is characterized by higher average temperatures in summer and dry periods, and its mean annual temperature (long-term) and precipitation are 9.8 °C and 550 mm, respectively [45]. The area is part of the Central Bohemian uplands, and the bedrock, formed by granite with loess enrichment, is fresh and loamy, with a tendency to drying and compaction. The soils are modal cambisols (Kam) with transition to luvic cambisols (KA1). The natural forest vegetation is determined as a medium-rich *Querceto-Fagetum* type. The soil type evaluation and tree species were conducted according to the published classification by Němeček et al. [46]. As it is the initial state, the arable soil is to be considered.

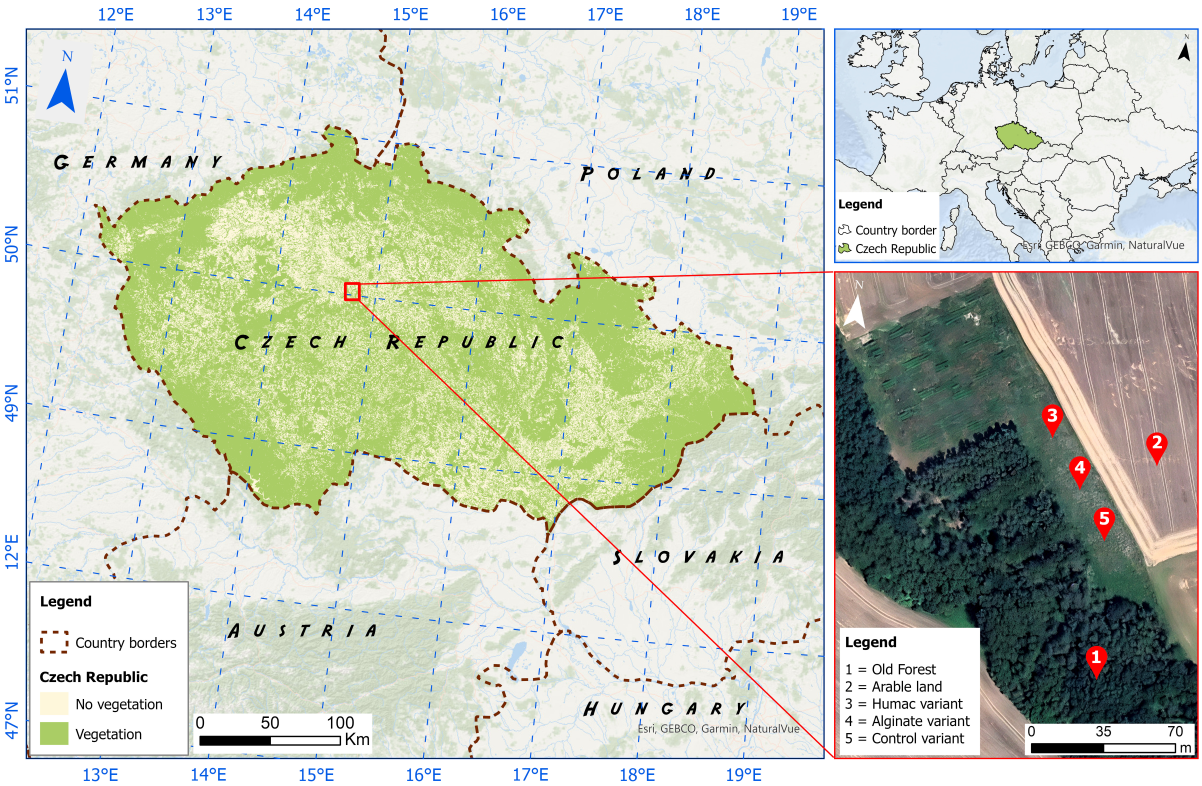

Figure 1. Research plot Doubek locality, Czech Republic: 1—Old forest, 2—Arable land, 3—Humac variant, 4—Alginite variant, 5—Control variant.

Planting

The planting was conducted in the autumn of 2019 in the arable soil, used for wheat and oil rape cultivation up until to this time, under conventional agriculture. Three introduced species, i.e., *Castanea sativa* (Sweet chestnut-KS), *Platanus acerifolia* (plane tree-PT), and *Corylus colurna* (Turkish hazel-LS), were planted at a spacing of 1.5 × 1.5 m. The areas were treated with 1.0 t/ha of Humac or 1.5 t/ha of Alginite materials. The application and incorporation of soil-improving materials into the surface soil layer were carried out using regular agricultural machinery and techniques before planting at both blocks. The general area layout is presented in Figure 1. The comprehensive description of the area is given by Gallo et al. [47]. The soil-improving materials were chosen based on the demand of the owner, supposing their testing in the given conditions.

2.2. Data Collection

The tree species data were collected every year, from 2020 to 2024, at the end of the vegetation seasons. The heights of the seedlings/individuals were measured by measuring poles. Individual tree quality was described using a simplified scale grading: 1—excellent, 2—slightly deformed, 3—forked, twisted, 4—dying, and dead.

The soil samples (47 samples) were collected in October 2022. They were taken at each subplot (1–5,) using an iron frame of 25 × 25 cm, and consisted of holorganic horizons—only under forest—and soil auger (mineral soil horizons, all plots). The following were used: agricultural land (arable land after wheat harvest plot 1), the old forest neighborhood to the fenced afforested area (subplot 2), plane tree + Humac, plane tree + Alginite, plane tree + control (in the fenced afforested former agricultural soil—plots 3–5, always in 4 replications. At arable-land and plane-tree plots, the horizons were sampled 0–10 and 10–20 cm; in the forest, horizons were 0–5, 5–10 cm (accordingly to visible pedogenetic horizons), and 10–20 cm. Moreover, the holorganic horizons (L + F + H) are also present in the forest.

The soil samples were transported to the laboratory, air-dried, and processed in the Research Institute of Soil Monitoring and Protection (VÚMOP), according to standard methods. The amount of surface humus layer was determined as dry matter at 105 °C, active (water) and exchange pH in 1 M KCl by the potentiometric method, and sorption complex characteristics by Kappen [48]: S—base content, T—cation exchange capacity, V—saturation of sorption complex by bases (V = S/T), content of total oxidizable carbon (humus) and nitrogen by Kjeldahl methods [49,50]. Total carbon content was multiplied by the mean coefficient (1.724) [51] to estimate the organic matter (OM) content, calculation of the C/N ratio, and content of available nutrients (P, K, Ca, Mg) by Zbíral method [52], exchangeable acidity, the content of exchangeable aluminum and hydrogen, and the content of total nutrients in holorganic horizons (N, P, K, Ca, Mg) after digestion with sulphuric acid and selenium as a catalyst; the repetition and widening of soil analyses are desirable [53].

2.3. Data Analysis

SPSS version 29.0.20 (20) was used for statistical analysis. The nature of the data obtained (normal distribution) was assessed. Having the normal distribution of the data confirmed, a single-factor analysis of variance (ANOVA) was run, followed by a post hoc test, according to Tukey. The significance level was chosen at the level (α = 0.05). The distinction of height (mean annual height was calculated by summing the height of all trees measured directly with measurement poles and divided by the total number of trees for each species) and increment (the year increment was calculated as the mean difference in height for each species with consecutive years: 2020 from 2021, 2021 from 2022, 2022 from 2023, and 2023 from 2024) between all three experimental variants (Humac, Alginite, and the control) were assessed. Distinction in individual years was assessed. Values that varied significantly were marked with different alphabets in the result tables (the same applied to the soil results). The number of lost seedlings was rated as mortality at the end of the 2023 growing season.

3. Results

3.1. The Results in the Doubek Locality

The comparison of three treatments, Alginite-A, Humac-B, and Control-C, on the growth (mean annual measurement) and three species, Castanea sativa-KS, *Platanus acerifolia*-PT, and *Corylus colurna*-LS, is shown in Table 1. Alginite-A indicates a stable increase in mean annual measurements in all three species. Humac-B indicates a similar pattern, but slightly lower values compared to those of Alginite-A. The Control-C indicates a persistent increase in measurements with height, and has medium values between Alginite-A and Humic-B. Among the species comparison, PT continuously shows the highest mean annual measurement throughout the three treatments, while LS indicates the lowest.

Table 1. The mean annual height of KS, PT, and LS in the Doubek locality (research plot).

Variant	Char.	Species (Mean ± Standard Deviation)		
		KS	PT	LS
Alginite-A	H_{20} cm	39.01 ± 19.15 a	58.84 ± 27.25 b	30.60 ± 19.32 c
Alginite-A	H_{21} cm	62.84 ± 38.64 a	132.10 ± 59.69 b	65.69 ± 40.29 c
Alginite-A	H_{22} cm	94.98 ± 55.01 a	166.72 ± 81.07 b	99.40 ± 59.34 c
Alginite-A	H_{23} cm	128.62 ± 70.88 a	206.57 ± 100.97 b	133.75 ± 75.03 c
Alginite-A	H_{24} cm	149.46 ± 84.35 a	223.36 ± 111.72 b	155.38 ± 110.05 a
Humac-B	H_{20} cm	36.14 ± 19.96 a	50.10 ± 23.30 b	25.46 ± 15.95 c
Humac-B	H_{21} cm	58.61 ± 35.89 a	98.28 ± 44.53 b	45.38 ± 32.46 a
Humac-B	H_{22} cm	84.85 ± 49.01 a	130.53 ± 58.21 b	74.19 ± 55.69 a
Humac-B	H_{23} cm	117.34 ± 64.21 a	159.90 ± 72.72 b	96.46 ± 73.23 a
Humac-B	H_{24} cm	138.15 ± 78.87 a	178.92 ± 82.01 b	118.22 ± 92.70 a
Control-C	H_{20} cm	40.42 ± 18.97 a	47.38 ± 26.88 b	34.19 ± 20.47 c
Control-C	H_{21} cm	64.60 ± 33.60 a	91.55 ± 52.83 b	59.31 ± 40.93 a
Control-C	H_{22} cm	102.49 ± 50.45 a	134.22 ± 77.97 b	93.04 ± 61.16 a
Control-C	H_{23} cm	143.39 ± 66.66 a	176.96 ± 105.12 b	148.65 ± 84.82 a
Control-C	H_{24} cm	175.47 ± 81.67 a	192.80 ± 117.26 b	184.25 ± 94.49 a

Notes: Char. = characteristics, KS = *Castanea sativa* (Sweet chestnut), PT = *Platanus* (Plane tree), LS = *Corylus colurna*, H = a height in the respective year. The same alphabet: statistically insignificant at 0.05. Different alphabets: statistically significant at 0.05.

The comparison of three treatments, Alginite-A, Humac-B, and the Control-C, on the mean annual increment and three species, *Castanea Sativa*-KS, *Platanus acerifolia*-PT, and *Corylus colurna*-LS, is shown in Table 2. Alginite-A indicates an irregular pattern, with the highest increment at I24 cm on KS. A decreasing increment was shown from I21 cm to I23 cm, this but increased at I24 cm on PT. A relatively stable increment in Alginite was shown on LS, with small fluctuations. Humac-B: KS indicates a relatively stable pattern with a slight increase at I24 cm. PT indicates a decreasing pattern from I21 cm to I23 cm, but this increased later, at I24 cm. Control-C indicates an increasing pattern of the highest increment on KS at L24 cm. Unstable increment was indicated on PT at I22 cm. An increasing increment pattern was shown to be the highest on LS. Overall, KS shows a general mean annual increment across all treatments. PT shows an irregular pattern of mean annual increment. LS indicates a stable mean annual increment across the three treatments.

The general comparison among the Alginite-A, Humac-B, and Control-C shows that control indicates the highest general growth for *Castanea sativa* (KS) and *Corylus colurna* (LS). Alginite-A does best for the *Platanus acerifolia* (PT), while Humac-B shows the lowest growth, generally, compared to the two treatments (Alginite-A and Control-C) (Tables 1 and 2).

Table 2. The mean annual increment of KS, PT, and LS in the Doubek locality (research plot).

Variant	Char.	Species (Mean ± Standard Deviation)		
		KS	PT	LS
Alginite-A	I_{21} cm	23.83 ± 25.08 a	73.26 ± 40.41 b	35.09 ± 30.02 c
Alginite-A	I_{22} cm	32.69 ± 23.21 a	37.24 ± 23.88 b	38.34 ± 31.01 b
Alginite-A	I_{23} cm	23.26 ± 32.87 a	16.52 ± 50.91 b	19.13 ± 53.64 b
Alginte-A	I_{24} cm	33.65 ± 26.41 a	39.85 ± 31.52 a	34.35 ± 29.33 a
Humac-B	I_{21} cm	22.46 ± 23.13 a	48.17 ± 30.24 b	19.92 ± 21.52 a
Humac-B	I_{22} cm	27.43 ± 23.35 a	32.25 ± 19.67 b	30.13 ± 31.64 a
Humac-B	I_{23} cm	23.31 ± 19.36 a	19.02 ± 26.21 b	19.31 ± 25.68 a
Humac-B	I_{24} cm	32.48 ± 24.45 a	29.37 ± 20.75 a	22.27 ± 32.81 a
Control-C	I_{21} cm	24.17 ± 20.60 a	44.17 ± 37.08 b	25.11 ± 26.09 a
Control-C	I_{22} cm	37.89 ± 24.12 a	44.77 ± 33.14 a	34.57 ± 29.27 a
Control-C	I_{23} cm	31.82 ± 19.51 a	15.42 ± 21.55 a	40.08 ± 49.48 a
Control-C	I_{24} cm	40.90 ± 21.61 a	42.75 ± 32.51 a	55.62 ± 59.68 a

Notes: Char. = characteristics, KS = *Castanea sativa* (Sweet chestnut), PT = *Platanus* (Plane tree), LS = *Corylus colurna*, I = height increment in the respective year. The same alphabet: statistically insignificant at 0.05. Different alphabets: statistically significant at 0.05.

3.2. Number of HealthySeedlings and Mortality in the Doubek Locality

The mortality of the tree species and the health condition at the end of the 2023 growing season in the Doubek locality research area were monitored. Table 2 shows statistical outcomes. The data indicate the healthy and mortality distribution for the tree species Castanea sativa -KS, Platanus acerifolia-PT, and Corylus colurna-LS throughout different years. The general results showed that most of the experimental trees were healthy, with a smaller fragment suffering death (mortality) (Table 3).

Table 3. Mortality and healthy state of tree species in the Doubek locality (research plot).

Tree Species	Healthy State/Mortality	Year 2020	2022	2023	Total
KS	Healthy state	278	21	30	329
	Mortality	53	2	2	57
Total		331	23	32	386
PT	Healthy state	276	41	11	328
	Mortality	50	9	3	62
Total		326	50	14	390
LS	Healthy state	71	23	11	105
	Mortality	16	4	5	25
Total		87	27	16	130
Total	Healthy state	625	85	52	762
	Mortality	119	15	10	144
Grand total	Healthy state + Mortality	744	100	62	906

Notes: KS = Castanea sativa, PT = Platanus acerifolia, and LS = Corylus colurna.

3.3. Dynamics of Soil Properties in the Doubek Locality (Research Plot)

The different soil characteristics evaluated throughout plots one to five and horizon number three and four (because horizons one and two are only on one, plot two-old forest) on the Doubek locality showed that old forest (plot two) has significant differences compared to arable soil (plot one), Humac-B and Platanus (plot three), Alginite-A and Platanus (plot four) and the Control-C; Platanus without amendment (plot five). The differences in the soil characteristics among the five plots showed that the old forest (plot two) has different properties from the other plots (Table 4).

Table 4. Different characteristics of soil properties on particular plots at the Doubek locality. Data from holorganic horizons (1, 2) not indicated (present only at forest (plot 2)).

Characteristics	Unit	Horizon	pl 1	pl 2	pl 3	pl 4	pl 5
pH/H_2O		3	5.60 a	4.87 b	5.83 c	5.91 c	5.84 c
		4	5.64 a	5.08 b	5.72 a	5.76 a	5.71 a
pH/KCl		3	4.54 a	3.57 b	4.74 a	4.80 a	4.68 a
		4	4.67 a	3.76 b	4.75 a	4.63 a	4.63 a
S	mval/100 g	3	9.77 a	5.81 b	10.67 a	10.68 a	11.88 a
		4	9.74 a	4.89 b	9.99 a	10.01 a	11.26 a
T − S	mval/100 g	3	2.60 a	7.33 b	2.18 a	2.11 a	2.06 a
		4	2.25 a	5.21 b	2.04 a	2.20 a	1.95 a
T	mval/100 g	3	12.38 a	12.94 a	12.84 a	12.79 a	13.94 a
		4	11.98 a	10.10 a	12.02 a	12.20 a	13.22 a
V	%	3	78.99 a	42.73 b	82.93 a	83.43 a	85.07 a
		4	81.29 a	47.74 b	83.17 a	81.99 a	85.13 a
Titration acidity	mval/kg	3	2.26 a	27.27 b	1.97 a	1.93 a	1.77 a
		4	2.06 a	24.27 b	2.00 a	1.99 a	1.82 a
H^+	mval/kg	3	1.59 a	1.68 a	1.38 ab	1.28 b	1.34 b
		4	1.52 a	1.70 b	1.43 a	1.41 a	1.38 a
AL^{3+}	mval/kg	3	0.67 a	25.29 b	0.59 a	0.64 a	0.43 a
		4	0.54 a	22.57 b	0.58 a	0.58 a	0.48 a
Humus content	%	3	2.50 a	4.90 b	2.69 a	2.34 a	2.83 a
		4	2.63 a	2.98 a	2.20 a	1.97 a	2.05 a
Cox	%	3	1.45 a	2.84 b	1.56 a	1.35 a	1.65 a
		4	1.53 a	1.73 a	1.28 a	1.14 a	1.19 a
combustible l	%	3	4.81 a	7.09 b	5.02 a	4.86 a	5.26 a
		4	4.84 ab	5.51 b	4.49 a	4.36 a	4.63 a
	%	3	0.143 a	0.150 a	0.146 a	0.109 a	0.096 a
total N		4	0.121 a	0.122 a	0.135 a	0.120 a	0.119 a
P	mg/kg	3	36.0 a	21.67 a	3.50 a	37.08 a	36.25 a
		4	37.25 a	14.00 b	2.75 a	41.25 a	32.25 a
K	mg/kg	3	203.75 a	157.67 a	253.75 a	343.00 b	390.20 b
		4	182.75 a	142.75 a	184.00 a	180.50 a	185.75 a
Ca	mg/kg	3	1084.8 a	478.0 b	1183.3 a	1083.5 a	1197.3 a
		4	1163.0 a	469.3 b	1185.5 a	1089.3 a	1266.8 a
Mg	mg/kg	3	114.0 a	75.0 b	120.75 a	129.5 a	121.0 a
		4	122.8 a	70.3 b	110.5 a	105.5 a	114.0 a

Notes: Plots: 1 = arable land; 2 = old forest; 3 = Humac + *Platanus*; 4 = Alginite + *Platanus*; 5 = control, no amendment + *Platanus*; Horizons: 3 = Ah, 4 = B (upper 10 cm); Characteristics: S = base content exchange capacity (ekv. BC); T-S = hydrolytical acidity; T − S = cation exchange capacity (ekv. CEC); H^+ = exchangeable hydrogen ion content; AL^{3+} = exchangeable aluminum ion content; Cox = oxydable carbon content; P, K, Ca, Mg = plant available-nutrient contents. The different alphabets show statistically significant results at 0.05; otherwise, they show statistically insignificant results.

For active (water) and exchange pH (pH/H_2O) in 1M KCL, horizons three and four showed more significant differences between the old forest (plot two) and the four other plots. Significant differences in horizons three and four were recorded in complex characteristics: S-saturation base content, T-S-total soluble salts, and V-base saturation between the old forest (plot two) and the other plots. Furthermore, significant differences were observed in the titrable acidity between the old forest (plot two) and the others in horizons three and four, respectively. Only horizon three showed significant differences between plots four and five and the rest of the plots in H^+. For Al^{3+}, significant differences were observed between horizons three and four of plot two and the rest. Humus in horizon three of plot two showed significant differences from the other plots. For organic carbon, the same horizon three showed a significant difference between plot two and the others.

For the contents of combustible humus, plot two showed a significant difference compared to the four others.

For the content of available nutrients (P, K, Ca, Mg), Potassium (K) in horizon three showed a significant difference in Alginite and Platanus (plot four) and in control (plot five) compared to arable soil (plot one) and old forest (plot two), and Humac with Platanus (plot three). However, calcium (Ca) and magnesium (Mg), on both horizons three and four, showed significant differences between the old forest (plot two) and the others.

4. Discussion

Regarding the general growth comparison among the three treatments (Alginite-A, Humac-B, and Control-C) on the tree species, *Castanea sativa* (KS), *Platanus acerifolia* (PT), and *Corylus colurna* (LS), there is a significant difference in growth in individual species (Table 1). There are also significant differences between soil-improving treatments within species. This is because KS and LS show the highest growth in the control, consistent with Podrázský et al. [44], who reported the best performance of some introduced tree species under control treatment in the Czech Republic. This may be due to the period of the abandoned agricultural soil, among other drivers, which influences the growth, as reported by Perdersen et al. [54], in Denmark. This could be due to the quick recovery of higher macro-porosity and lower bulk density (physical properties) of soil after abandonment, as reported by Piche and Kelting [55], in the eastern United States. In China, it was found out that there is a relationship between soil properties on abandoned afforested agricultural soil as years increase, which has a positive effect on tree height and diameter of crown [56]. Adapting the introduced tree species to the new locality may also play a role, as naturalization or invasiveness is normal in some NNTs, as reported by Vaceket al. [39]. Similar invasiveness of NNTs was reported in Austria, many countries in Central Europe, and the European Alpine area [57,58]. Nevertheless, *Castanea sativa* (KS) in Europe is among the tree species affected by ink diseases, due to biological conquering fueled by humans [59,60]. We also found that Alginite was particularly effective for the PT species. This shows a significant difference between soil-improving treatments within species, contrary to Podrázský et al. [44], who reported insignificant Alginite on the PT growth in 2023. This new development may be due to the slow mineralization of the Alginite, which is a common characteristic reported in reviews around the world of organic amendments in soils [61]. Organic fertilizer becomes typically more effective with an increase in years, unlike inorganic fertilizer, which has an immediate effect [62]. Among the three treatments, we found Humac to be the least effective on the replications' growth and development. This is probably due to the slower decomposition of Humac, especially in temperate regions [63].

Not much effect regarding mortality was found among the three treatments in the research plot (Table 3). This probably means that the two amendments (Alginite-A and Humac-B), just like the control treatment, do not affect the health or death of the seedlings, as reported by Podrázský et al. [44]. It could be due to the adaptability of the newly introduced tree species (KS, PT, and LS) to the temperate Czech soil [64]. This would enhance mixed forestry in the Czech soil, where non-native tree species are scarce, as reported by Wagner et al. [65]. This is essential, as mixed forests enhance ecological stability, improve biodiversity, forest sustainability, resilience, redundancy of function, and complementary approaches, and improve soil biological and chemical quality in tree growth, especially on abandoned agricultural soils [66].

However, we found irregular growth patterns, especially in the mean annual increment of the two soil amendments, stagnation, and negative growth (Table 2). This is more significantly pronounced in Humac treatment, especially in PT and LS. This may be due to the mean annual increase in each tree volume; it changes with varying growth phases in a tree's life cycle [67]. The mean annual increment is usually highest in the medium years of trees, and hence decreases slowly with an increase in age [68]. The mean annual increment is the crest typically used in tracing the biological maturity of a tree and its ripeness for logging [69]. It may be due to the relative fertility of the former land use (abandoned agricultural soil), which makes those in the control treatment appear not much affected [70], or the soil amendments, coupled with climate fluctuation, in Central Europe [71]. This may change, as found in central Italy, because the addition of soil amendments and tree planting increase soil quality over a longer period, which in turn improves tree growth [66].

Concerning different characteristics of soil properties in the Doubek locality (Table 4), on active (water) and exchange pH (pH/H_2O) in 1M KCL, horizons three and four showed more significant differences between the old forest (plot two) and the four other plots. Soil pH may respond quickly in the old forest compared to the arable soil (plot one), plot three (Humac and Platanus on afforested land), plot four (Platanus and Alginite on afforested land), and plot five (Platanus without amendment). This is due to the substitution in the base cation pattern and the incorporation of plant remnants [72], which leads to a more unusual pile of soil organic matter [73]. Consequently, the significant differences between plot two and the others are probably a result of more excellent base cation absorption (by trees) [72]. This may result from higher organic remnant downfall and decomposition [74]. Soil pH was lower in plot two in our study, consistent with Hong et al. [72] and Berthrong et al. [74], who reported lower pH with higher C in continuous forested land than in agricultural soils. In addition, the significant differences in pH/KCL (acidity/extractable and water-soluble Al in soil) align with the findings of Dlouhá et al. [75], who reported decreased pH values with increased Aluminum concentration in old forests. Accordingly, the more significant part of KCl-extractable Al exists in the Al^{3+} form [75]. Furthermore, significant differences in base saturation (v), exchangeable sodium (S), total soluble salt (TSS), and percentage base saturation (V%) were observed between plot two and the other four plots, in horizons three and four. The same information was observed between plot two and the rest on the titer acidity and exchangeable hydrogen (H+). This may be related to the old-forest stand age; however, similar soil dynamics may be recorded in the amended afforested agricultural soils [40], as observed in a 34-year-old afforested agricultural soil enriched with organic matter. Soil pH is recognized for identifying dynamics between forest and afforested agricultural soil [76]. This study also observed significant differences in Humus, organic carbon (C) content (Cox% %), and combustible I (a portion of the organic matter that can be burnt or oxidized at high temperature), mainly on horizon three between plot two and the other four plots. This is probably due to disturbances linked to agricultural fields during tillage, unlike the old forest, which hardly encountered such incidences [77–80]. Soil organic carbon stock was found to increase (up to 30 years and above) after the afforestation of former agricultural soils [81,82]. However, soil organic carbon stock was claimed to be unchanged after 30 years of afforestation on a pasture [83] in Swiss alpine areas. This is contrary to the Czech Republic chernozem area, which recorded an increase in SOC after more than 50 years [84].

Lastly, we observed significant differences between plot two and the other four, with Phosphorus (P) only on horizon four. The higher amount of P in the old forest was probably due to higher soil organic matter, mostly from litter fall, compared to the agricultural soil, afforested agricultural soils with amendments, and the control [85]. Another study suggested that P increases with age, following afforestation of abandoned agricultural soils [86]. Agricultural soil was found to have the least P content compared to other ecosystems; it is possibly a result of P absorption by the arable crops [87]. P increase in the forest ecosystem or afforested agricultural soil is also associated with the composition of the tree species; pine-dominated stands increase level of P more than other species [88]. In our study, Potassium (K) in horizon three significantly differed on Alginite and *Platanus* (plot four) and the control *Platanus* without amendment (plot five). This is likely due to its possible constituents in the Alginite amendments (plot four) or its application during fertilization in the arable field (plot five), especially for wheat cultivation, as in our study area. This is consistent with Zörb et al. [89], who reported the mean soil reserve K as generally large, necessitating its supply as soluble fertilizer. K-absence could affect photosynthates and sugar accumulation on leaves, which not just yield production, but also quality indices, as in wheat, grape, and potato [89]. Calcium (Ca) and Magnesium (Mg) in horizons three and four significantly differed in plot two from other ecosystems in our study (Table 4). This is probably due to the same fate as mentioned above in the litter fall accumulation of the old forest, especially from coniferous trees like Douglas fir, as reported by Novák et al. [36].

5. Conclusions and Recommendations

This study explored how three non-native tree species—Sweet Chestnut (*Castanea sativa*), Plane Tree (*Platanus acerifolia*), and Turkish Hazel (*Corylus colurna*)—responded to different soil treatments in abandoned agricultural soil in Central Bohemia, Czechia (Doubek locality). We tested two organic soil amendments, Humac-B and Alginite-A, alongside a Control-C treatment, to assess their impact on tree growth. The control treatment showed the best overall performance, but it is too early to determine its superiority, as forestry research takes decades. We recommend afforestation of abandoned agricultural soil using a control treatment for better tree growth. Tree mortality rates remained unchanged across treatments, suggesting all three species adapted well. After finding these species non-invasive, we encourage their integration into Czech forests to boost biodiversity, stability, and resilience. This finding, that is, using control treatment and invasive-free non-native tree species on abandoned agricultural soils, could be used in forestry systems for afforestation of abandoned agricultural lands at the international level, especially in the current situation of rapid climate change, where resilient forests are needed which could be achieved through mixed forestry, among other factors.

For soil and ecosystem comparisons, we analyzed three ecosystems: an old forest with diverse tree species, arable soil previously used for wheat cultivation, and afforested agricultural soil treated with amendments using *Platanus acerifolia.* Results showed significant differences in horizons three (upper soil or B horizon) and four (C-horizon) of the old forest, reinforcing the importance of preserving natural forests and afforesting marginal agricultural lands to maintain soil health amid climate challenges. This study found that potassium (K) levels differed notably between certain plots (four and five). We suspect these variations may be linked to previous fertilization practices or the presence of K in Alginite treatment. More studies are needed to pinpoint the exact cause. Due to resource limitations, we could not replicate treatments across additional plots, but we recommend further trials with Sweet Chestnut and Turkish Hazel to better understand species adaptability and long-term soil dynamics.

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References

1. Van Der Zanden, E.H.; Verburg, P.H.; Schulp, C.J.E.; Verkerk, P.J. Trade-offs of European agricultural abandonment. *Land Use Policy* **2017**, *62*, 290–301. [CrossRef]
2. Farooqi, T.J.A.; Portela, R.; Xu, Z.; Pan, S.; Irfan, M.; Ali, A. Advancing forest hydrological research: Exploring global research trends and future directions through scientometric analysis. *J. For. Res.* **2024**, *35*, 128. [CrossRef]
3. Wang, Y.; Chen, L.; Xiang, W.; Ouyang, S.; Zhang, T.; Zhang, X.; Zeng, Y.; Hu, Y.; Luo, G.; Kuzyakov, Y. Forest conversion to plantations: A meta-analysis of consequences for soil and microbial properties and functions. *Glob. Change Biol.* **2021**, *27*, 5643–5656. [CrossRef] [PubMed]
4. Baldrian, P.; López-Mondéjar, R.; Kohout, P. Forest microbiome and global change. *Nat. Rev. Microbiol.* **2023**, *21*, 487–501. [CrossRef] [PubMed]
5. Gu, X.; Jia, H.; Wang, X.; Jiang, Y.; Li, J.; He, X. Differential aluminum tolerance and absorption characteristics in Pinus massoniana seedlings colonized with ectomycorrhizal fungi of *Lactarius deliciosus* and *Pisolithus tinctorius*. *J. For. Res.* **2023**, *34*, 1523–1533. [CrossRef]
6. Mueller, K.E.; Hobbie, S.E.; Oleksyn, J.; Reich, P.B.; Eissenstat, D.M. Do evergreen and deciduous trees have different effects on net N mineralization in soil? *Ecology* **2012**, *93*, 1463–1472. [CrossRef]
7. Konijnendijk, C.C. Evidence-based guidelines for greener, healthier, more resilient neighbourhoods: Introducing the 3–30–300 rule. *J. For. Res.* **2023**, *34*, 821–830. [CrossRef]
8. Nyssen, B.; Ouden, J.D.; Bindewald, A.; Brancalion, P.; Kremer, K.; Lapin, K.; Raats, L.; Schatzdorfer, E.; Stanturf, J.; Verheyen, K.; et al. Established Invasive Tree Species Offer Opportunities for Forest Resilience to Climate Change. *Curr. For. Rep.* **2024**, *10*, 456–486. [CrossRef]
9. Novotný, S.; Gallo, J.; Baláš, M.; Kuneš, I.; Fuchs, Z.; Brabec, P. Silvicultural potential of the main introduced tree species in the Czech Republic—Review. *Cent. Eur. For. J.* **2023**, *69*, 188–200. [CrossRef]
10. Wohlgemuth, T.; Gossner, M.M.; Campagnaro, T.; Marchante, H.; van Loo, M.; Vacchiano, G.; Castro-Diez, P.; Dobrowolska, D.; Gazda, A.; La Porta, N.; et al. Impact of non-native tree species in Europe on soil properties and biodiversity: A review. *NeoBiota* **2022**, *78*, 45–69. [CrossRef]
11. Brundu, G.; Pauchard, A.; Pyšek, P.; Pergl, J.; Bindewald, A.M.; Brunori, A.; Canavan, S.; Campagnaro, T.; Celesti-Grapow, L.; Dechoum, M.d.S.; et al. Global guidelines for the sustainable use of non-native trees to prevent tree invasions and mitigate their negative impacts. *NeoBiota* **2020**, *61*, 65–116. [CrossRef]
12. Castro-Diez, P.; Fierro-Brunnenmeister, N.; Gonzalez-Munoz, N.; Gallardo, A. Effects of exotic and native tree leaf litter on soil properties of two contrasting sites in the Iberian Peninsula. *Plant Soil* **2012**, *350*, 179–191. [CrossRef]
13. Elina, O.; Tarja, S.; Luisa, G.; Francesco, P.; Kaisa, N.; Helena, R.; Matti, R.; Alberto, S.; Juha, M. High-acclimation capacity for growth and role of soil fertility after long-range transfer of *Betula pendula* and *B. pubescens* Between Finland and Italy. *J. For. Res.* **2025**, *36*, 38. [CrossRef]
14. Nicolescu, V.-N.; Rédei, K.; Mason, W.L.; Vor, T.; Pöetzelsberger, E.; Bastien, J.-C.; Brus, R.; Benčať, T.; Đodan, M.; Cvjetkovic, B.; et al. Ecology, growth and management of black locust (*Robinia pseudoacacia* L.), a non-native species integrated into European forests. *J. For. Res.* **2020**, *31*, 1081–1101. [CrossRef]
15. Puchałka, R.; Dyderski, M.K.; Vítková, M.; Sádlo, J.; Klisz, M.; Netsvetov, M.; Prokopuk, Y.; Matisons, R.; Mionskowski, M.; Wojda, T.; et al. Black locust (*Robinia pseudoacacia* L.) range contraction and expansion in Europe under changing climate. *Glob. Change Biol.* **2021**, *27*, 1587–1600. [CrossRef] [PubMed]
16. Øyen, B.-H.; Nygaard, P.H. Impact of Sitka spruce on biodiversity in NW Europe with a special focus on Norway—Evidence, perceptions and regulations. *Scand. J. For. Res.* **2020**, *35*, 117–133. [CrossRef]

17. Nosko, P.; Moreau, K.; Kuehne, C.; Major, K.C.; Bauhus, J. Does a shift in shade tolerance as suggested by seedling morphology explain differences in regeneration success of northern red oak in native and introduced ranges? *J. For. Res.* **2022**, *33*, 949–962. [CrossRef]
18. Abeli, T.; Di Giulio, A. Risks of massive tree planting in Europe should be considered by the EU Forestry Strategy 2030. *Restor. Ecol.* **2023**, *31*, e13834. [CrossRef]
19. Wagner, V.; Večeřa, M.; Jiménez-Alfaro, B.; Pergl, J.; Lenoir, J.; Svenning, J.; Pyšek, P.; Agrillo, E.; Biurrun, I.; Campos, J.A.; et al. Alien plant invasion hotspots and invasion debt in European woodlands. *J. Veg. Sci.* **2021**, *32*, e13014. [CrossRef]
20. Bezabih Beyene, B.; Li, J.; Yuan, J.; Dong, Y.; Liu, D.; Chen, Z.; Kim, J.; Kang, H.; Freeman, C.; Ding, W. Non-native plant invasion can accelerate global climate change by increasing wetland methane and terrestrial nitrous oxide emissions. *Glob. Change Biol.* **2022**, *28*, 5453–5468. [CrossRef]
21. Shovon, T.A.; Auge, H.; Haase, J.; Nock, C.A. Positive effects of tree species diversity on productivity switch to negative after severe drought mortality in a temperate forest experiment. *Glob. Change Biol.* **2024**, *30*, e17252. [CrossRef] [PubMed]
22. Nag, S.; Sangha, K.S.; Dhillon, G.P.S. Differences in gall development by invasive pest Eucalyptus gall wasp (*Leptocybe invasa*) in susceptible and resistant Eucalyptus clones. *J. For. Res.* **2025**, *36*, 23. [CrossRef]
23. Wohlgemuth, T.; Moser, B.; Pötzelsberger, E.; Rigling, A.; Gossner, M.M. Über die Invasivität der Douglasie und ihre Auswirkungen auf Boden und Biodiversität. *Schweiz. Z. Fur Forstwes.* **2021**, *172*, 118–127. [CrossRef]
24. Frigo, D.; Eggertsson, Ó.; Prendin, A.L.; Dibona, R.; Unterholzner, L.; Carrer, M. Growth form and leaf habit drive contrasting effects of Arctic amplification in long-lived woody species. *Glob. Change Biol.* **2023**, *29*, 5896–5907. [CrossRef] [PubMed]
25. Lázaro-Lobo, A.; Ruiz-Benito, P.; Cruz-Alonso, V.; Castro-Díez, P. Quantifying carbon storage and sequestration by native and non-native forests under contrasting climate types. *Glob. Change Biol.* **2023**, *29*, 4530–4542. [CrossRef]
26. Pötzelsberger, E.; Lapin, K.; Brundu, G.; Adriaens, T.; Andonovski, V.; Andrašev, S.; Bastien, J.-C.; Brus, R.; Čurović, M.; Čurović, Ž.; et al. Mapping the patchy legislative landscape of non-native tree species in Europe. *For. Int. J. For. Res.* **2020**, *93*, 567–586. [CrossRef]
27. Booy, O.; Robertson, P.A.; Moore, N.; Ward, J.; Roy, H.E.; Adriaens, T.; Shaw, R.; Van Valkenburg, J.; Wyn, G.; Bertolino, S.; et al. Using structured eradication feasibility assessment to prioritize the management of new and emerging invasive alien species in Europe. *Glob. Change Biol.* **2020**, *26*, 6235–6250. [CrossRef]
28. Campagnaro, T.; Brundu, G.; Sitzia, T. Five major invasive alien tree species in European Union forest habitat types of the Alpine and Continental biogeographical regions. *J. Nat. Conserv.* **2018**, *43*, 227–238. [CrossRef]
29. Hulme, P.E.; Pyšek, P.; Jarošík, V.; Pergl, J.; Schaffner, U.; Vilà, M. Bias and error in understanding plant invasion impacts. *Trends Ecol. Evol.* **2013**, *28*, 212–218. [CrossRef]
30. Medina-Villar, S.; Rodríguez-Echeverría, S.; Lorenzo, P.; Alonso, A.; Pérez-Corona, E.; Castro-Díez, P. Impacts of the alien trees *Ailanthus altissima* (Mill.) Swingle and *Robinia pseudoacacia* L. on soil nutrients and microbial communities. *Soil Biol. Biochem.* **2016**, *96*, 65–73. [CrossRef]
31. Cremer, M.; Prietzel, J. Soil acidity and exchangeable base cation stocks Under pure and mixed stands of European beech, Douglas fir and Norway spruce. *Plant Soil* **2017**, *415*, 393–405. [CrossRef]
32. Yuan, Y.; Zhao, Z.; Niu, S.; Li, X.; Wang, Y.; Bai, Z. Reclamation promotes the succession of the soil and vegetation in opencast coal mine: A case study from *Robinia pseudoacacia* reclaimed forests, Pingshuo mine, China. *CATENA* **2018**, *165*, 72–79. [CrossRef]
33. Krevš, A.; Kučinskiene, A. Influence of invasive *Acer negundo* leaf litter on benthic microbial abundance and activity in the littoral zone of a temperate river in Lithuania. *Knowl. Manag. Aquat. Ecosyst.* **2017**, *26*. [CrossRef]
34. Vallé, C.; Le Viol, I.; Nabias, J.; Princé, K.; Gosselin, F. Tree species identity shapes the relationship between canopy cover and herb-layer species in temperate forests. *J. Ecol.* **2025**, *113*, 582–597. [CrossRef]
35. Skowronek, S.; Terwei, A.; Zerbe, S.; Mölder, I.; Annighöfer, P.; Kawaletz, H.; Ammer, C.; Heilmeier, H. Regeneration Potential of Floodplain Forests Under the Influence of Nonnative Tree Species: Soil Seed Bank Analysis in Northern Italy. *Restor. Ecol.* **2014**, *22*, 22–30. [CrossRef]
36. Novák, J.; Kacálek, D.; Dušek, D. Litterfall nutrient return in thinned young stands with Douglas fir. *Cent. Eur. For. J.* **2020**, *66*, 78–84. [CrossRef]
37. Nicolescu, V.-N.; Mason, W.L.; Bastien, J.-C.; Vor, T.; Petkova, K.; Podrázský, V.; Đodan, M.; Perić, S.; La Porta, N.; Brus, R.; et al. Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in Europe: An overview of management practices. *J. For. Res.* **2023**, *34*, 871–888. [CrossRef]
38. Podrázský, V.; Vacek, Z.; Vacek, S.; Vítámvás, J.; Gallo, J.; Prokůpková, A.; D'Andrea, G. Production potential and structural variability of pine stands in the Czech Republic: Scots pine (*Pinus sylvestris* L.) vs. introduced pines—Case study and problem review. *J. For. Sci.* **2020**, *66*, 197–207. [CrossRef]

39. Vacek, Z.; Vacek, S.; Eşen, D.; Yildiz, O.; Král, J.; Gallo, J. Effect of Invasive *Rhododendron ponticum* L. on Natural Regeneration and Structure of Fagus orientalis Lipsky Forests in the Black Sea Region. *Forests* **2020**, *11*, 603. [CrossRef]
40. Sławski, M.; Tarabuła, T.; Sławska, M. Does the enrichment of post-arable soil with organic matter stimulate forest ecosystem restoration—A view from the perspective of three decades after the afforestation of farmland. *For. Ecol. Manag.* **2020**, *478*, 118525. [CrossRef]
41. Tóth, S.; Rysak, W.; Soltysová, B.; Karahuta, J. Effect of Soil Conditioner Based on Humic Acids Humac Agro on Soil and Yield And Sugar Content of Sugar Beet in Context of Selected Indicators of Agriculture System Sustainability. *Listy Cukrov. A Reparske* **2015**, *131*, 53.
42. Frišták, V.; Pipíška, M.; Nováková, M.; Lesný, J.; Packová, A. Sorption separation of cadmium from aqueous solutions by alginite material: Kinetic and equilibrium study. *Desalination Water Treat.* **2015**, *56*, 379–387. [CrossRef]
43. Pichler, V.; Gregor, J.; Bublinec, E.; Vass, D. Ecological-productive properties of Slovak alginite. *Ekol.-Bratisl.* **2001**, *20*, 278–284.
44. Podrázský, V.; Gallo, J.; Baláš, M.; Kuneš, I.; Tama, A.Y.; Šulitka, M. Initial growth of native and introduced hardwoods at the afforested agricultural lands—Preliminary results. In Proceedings of the 11th Hardwood Conference Proceedings, Columbia, MO, USA, 23–26 March 1997; p. 102.
45. Vondráková, A.; Vávra, A.; Voženílek, V. Climatic regions of the Czech Republic. *J. Maps* **2013**, *9*, 425–430. [CrossRef]
46. Němeček, J.; Mühlhanselová, M.; Macků, J.; Vokoun, J.; Vavříček, D.; Novák, P. *Taxonomic Classification System of Soils in the Czech Republic*, 2nd ed.; Česká Zemědělská Univerzita Praha: Prague, Czech Republic, 2011; p. 94.
47. Gallo, J.; Záruba, J.; Podrázský, V. Výzkumná plocha Doubek—Introdukované Dřeviny na Zemědělské Půdě. In *Nové Poznatky ve Výzkumu Introdukovaných Dřevin*; Czech Forestry Society, z. s.: Prague, Czech Republic, 2022; ISBN 978-80-02-02981-6.
48. Kappen, H. *Die Bodenazidität: Nach Agrikulturchemischen Gesichtspunkten Dargestellt*; Springer: Berlin/Heidelberg, Germany, 1929.
49. Ciavatta, C.; Antisari, L.V.; Sequi, P. Determination of organic carbon in soils and fertilizers. *Commun. Soil Sci. Plant Anal.* **1989**, *20*, 759–773. [CrossRef]
50. Kirk, P.L. Kjeldahl Method for Total Nitrogen. *Anal. Chem.* **1950**, *22*, 354–358. [CrossRef]
51. Nelson, D.W.; Sommers, L.E. Total Carbon, Organic Carbon, and Organic Matter. In *Methods of Soil Analysis: Part 3 Chemical Methods*; SSSA Book Series; Sparks, D.L., Page, A.L., Helmke, P.A., Loeppert, R.H., Soltanpour, P.N., Tabatabai, M.A., Johnston, C.T., Sumner, M.E., Tabatabai, C.T., Johnston, M.E., Eds.; Soil Science Society of America; American Society of Agronomy: Madison, WI, USA, 2018; pp. 961–1010. ISBN 978-0-89118-866-7.
52. Zbíral, J. Determination of plant-available micronutrients by the Mehlich 3 soil extractant—A proposal of critical values. *Plant Soil Environ.* **2016**, *62*, 527–531. [CrossRef]
53. Zbíral, J. *Comparison of Extraction Procedures for the Determination of Basic Nutrients in Soils in the Czech Republic*; Central Institute for Supervising and Testing in Agriculture: Brno, Czech Republic, 2001.
54. Pedersen, N.K.; Schmidt, I.K.; Kepfer-Rojas, S. Drivers of tree colonization, species richness, and structural variation during the initial three decades of natural forest colonization in abandoned agricultural soils. *For. Ecol. Manag.* **2023**, *543*, 121138. [CrossRef]
55. Piché, N.; Kelting, D.L. Recovery of soil productivity with forest succession on abandoned agricultural land. *Restor. Ecol.* **2015**, *23*, 645–654. [CrossRef]
56. Yao, W.; Nan, F.; Li, Y.; Li, Y.; Liang, P.; Zhao, C. Effects of Different Afforestation Years on Soil Properties and Quality. *Forests* **2023**, *14*, 329. [CrossRef]
57. Karrer, G.; Bassler-Binder, G.; Willner, W. Assessment of Drought-Tolerant Provenances of Austria's Indigenous Tree Species. *Sustainability* **2022**, *14*, 2861. [CrossRef]
58. Hazarika, R.; Lapin, K.; Bindewald, A.; Vaz, A.S.; Marinšek, A.; La Porta, N.; Detry, P.; Berger, F.; Barič, D.; Simčič, A.; et al. Balancing Risks and Benefits: Stakeholder Perspective on Managing Non-Native Tree Species in the European Alpine Space. *Mitig. Adapt. Strat. Glob. Change* **2024**, *29*, 55. [CrossRef]
59. Webb, J.; Goodenough, A.E. Applying palaeoecological analogues to contemporary challenges: Community-level effects of canopy gaps caused by systematic decline of a prevalent tree species. *J. For. Res.* **2024**, *35*, 132. [CrossRef]
60. Heinz, M.; Prospero, S. A modeling approach to determine substitutive tree species for sweet chestnut in stands affected by ink disease. *J. For. Res.* **2025**, *36*, 24. [CrossRef]
61. Priya, E.; Sarkar, S.; Maji, P.K. A review on slow-release fertilizer: Nutrient release mechanism and agricultural sustainability. *J. Environ. Chem. Eng.* **2024**, *12*, 113211. [CrossRef]
62. Singh Brar, B.; Singh, J.; Singh, G.; Kaur, G. Effects of Long Term Application of Inorganic and Organic Fertilizers on Soil Organic Carbon and Physical Properties in Maize–Wheat Rotation. *Agronomy* **2015**, *5*, 220–238. [CrossRef]
63. Meynier, S.; Brun, J.-J. Humus forms pathways in low-elevation cold scree slopes: Tangel or Mor? *Appl. Soil Ecol.* **2018**, *123*, 572–580. [CrossRef]

64. Alizoti, P.; Bastien, J.-C.; Chakraborty, D.; Klisz, M.M.; Kroon, J.; Neophytou, C.; Schueler, S.; Loo, M.V.; Westergren, M.; Konnert, M.; et al. Non-Native Forest Tree Species in Europe: The Question of Seed Origin in Afforestation. *Forests* **2022**, *13*, 273. [CrossRef]
65. Wagner, V.; Chytrý, M.; Jiménez-Alfaro, B.; Pergl, J.; Hennekens, S.; Biurrun, I.; Knollová, I.; Berg, C.; Vassilev, K.; Rodwell, J.S.; et al. Alien plant invasions in European woodlands. *Divers. Distrib.* **2017**, *23*, 969–981. [CrossRef]
66. Danise, T.; Andriuzzi, W.S.; Battipaglia, G.; Certini, G.; Guggenberger, G.; Innangi, M.; Mastrolonardo, G.; Niccoli, F.; Pelleri, F.; Fioretto, A. Mixed-Species Plantation Effects on Soil Biological and Chemical Quality and Tree Growth of A Former Agricultural Land. *Forests* **2021**, *12*, 842. [CrossRef]
67. Pallett, R.N. Evidence-based global yield benchmarks in unthinned industrial plantation eucalypts. *South. For. A J. For. Sci.* **2024**, *86*, 153–168. [CrossRef]
68. Brichta, J.; Vacek, S.; Vacek, Z.; Cukor, J.; Mikeska, M.; Bílek, L.; Šimůnek, V.; Gallo, J.; Brabec, P. Importance and potential of Scots pine (*Pinus sylvestris* L.) in 21st century. *Cent. Eur. For. J.* **2023**, *69*, 3–20. [CrossRef]
69. Journé, V.; Bogdziewicz, M.; Courbaud, B.; Kunstler, G.; Qiu, T.; Acuña, M.A.; Ascoli, D.; Bergeron, Y.; Berveiller, D.; Boivin, T.; et al. The Relationship Between Maturation Size and Maximum Tree Size From Tropical to Boreal Climates. *Ecol. Lett.* **2024**, *27*, e14500. [CrossRef] [PubMed]
70. Levers, C.; Schneider, M.; Prishchepov, A.V.; Estel, S.; Kuemmerle, T. Spatial variation in determinants of agricultural land abandonment in Europe. *Sci. Total Environ.* **2018**, *644*, 95–111. [CrossRef] [PubMed]
71. Matula, R.; Knířová, S.; Vítámvás, J.; Šrámek, M.; Kníř, T.; Ulbrichová, I.; Svoboda, M.; Plichta, R. Shifts in intra-annual growth dynamics drive a decline in productivity of temperate trees in Central European forest under warmer climate. *Sci. Total Environ.* **2023**, *905*, 166906. [CrossRef]
72. Hong, S.; Piao, S.; Chen, A.; Liu, Y.; Liu, L.; Peng, S.; Sardans, J.; Sun, Y.; Peñuelas, J.; Zeng, H. Afforestation neutralizes soil pH. *Nat. Commun.* **2018**, *9*, 520. [CrossRef]
73. Laganière, J.; Angers, D.A.; Paré, D. Carbon accumulation in agricultural soils after afforestation: A meta-analysis. *Glob. Change Biol.* **2010**, *16*, 439–453. [CrossRef]
74. Berthrong, S.T.; Jobbágy, E.G.; Jackson, R.B. A global meta-analysis of soil exchangeable cations, pH, carbon, and nitrogen with afforestation. *Ecol. Appl.* **2009**, *19*, 2228–2241. [CrossRef]
75. Dlouhá, Š.; Borůvka, L.; Pavlů, L.; Tejnecký, V.; Drábek, O. Comparison of Al speciation and other soil characteristics Between meadow, young forest and old forest stands. *J. Inorg. Biochem.* **2009**, *103*, 1459–1464. [CrossRef]
76. Harta, I.; Simon, B.; Vinogradov, S.; Winkler, D. Collembola communities and soil conditions in forest plantations established in an intensively managed agricultural area. *J. For. Res.* **2021**, *32*, 1819–1832. [CrossRef]
77. Mayer, M.; Prescott, C.E.; Abaker, W.E.A.; Augusto, L.; Cécillon, L.; Ferreira, G.W.D.; James, J.; Jandl, R.; Katzensteiner, K.; Laclau, J.-P.; et al. Tamm Review: Influence of forest management activities on soil organic carbon stocks: A knowledge synthesis. *For. Ecol. Manag.* **2020**, *466*, 118127. [CrossRef]
78. Świtoniak, M. Assessment of soil organic carbon stocks differentiation in humus horizons of clay-illuvial soils within young morainic landscapes, northern Poland. *Soil Sci. Ann.* **2023**, *74*, 1–14. [CrossRef]
79. Armolaitis, K.; Aleinikovienė, J.; Lubytė, J.; Žėkaitė, V.; Garbaravičius, P. Stability of soil organic carbon in agro and forest ecosystems on Arenosol. *Zemdirb.-Agric.* **2013**, *100*, 227–234. [CrossRef]
80. Sheng, H.; Zhou, P.; Zhang, Y.; Kuzyakov, Y.; Zhou, Q.; Ge, T.; Wang, C. Loss of labile organic carbon from subsoil due to land-use changes in subtropical China. *Soil Biol. Biochem.* **2015**, *88*, 148–157. [CrossRef]
81. Kukuļs, I.; Kļaviņš, M.; Nikodemus, O.; Kasparinskis, R.; Brūmelis, G. Changes in soil organic matter and soil humic substances following the afforestation of former agricultural lands in the boreal-nemoral ecotone (Latvia). *Geoderma Reg.* **2019**, *16*, e00213. [CrossRef]
82. Varnagirytė-Kabašinskienė, I.; Žemaitis, P.; Armolaitis, K.; Stakėnas, V.; Urbaitis, G. Soil Organic Carbon Stocks in Afforested Agricultural Land in Lithuanian Hemiboreal Forest Zone. *Forests* **2021**, *12*, 1562. [CrossRef]
83. Speckert, T.C.; Suremann, J.; Gavazov, K.; Santos, M.J.; Hagedorn, F.; Wiesenberg, G.L.B. Soil organic carbon stocks did not change after 130 years of afforestation on a former Swiss Alpine pasture. *Soil* **2023**, *9*, 609–621. [CrossRef]
84. Juřicová, A.; Chuman, T.; Žížala, D. Soil organic carbon content and stock change after half a century of intensive cultivation in a chernozem area. *Catena* **2022**, *211*, 105950. [CrossRef]
85. Zhu, X.; Fang, X.; Wang, L.; Xiang, W.; Alharbi, H.A.; Lei, P.; Kuzyakov, Y. Regulation of soil phosphorus availability and composition during forest succession in subtropics. *For. Ecol. Manag.* **2021**, *502*, 119706. [CrossRef]
86. Chen, H.; Zhang, S.; Ma, C.; Xiang, Y.; Wu, J. Restoring farmland to forest increases phosphorus limitation based on microbial and soil C:N:P stoichiometry-a synthesis across China. *For. Ecol. Manag.* **2024**, *556*, 121745. [CrossRef]
87. Hammad, H.M.; Fasihuddin Nauman, H.M.; Abbas, F.; Ahmad, A.; Bakhat, H.F.; Saeed, S.; Shah, G.M.; Ahmad, A.; Cerdà, A. Carbon sequestration potential and soil characteristics of various land use systems in arid region. *J. Environ. Manag.* **2020**, *264*, 110254. [CrossRef] [PubMed]

88. Spohn, M.; Stendahl, J. Carbon, nitrogen, and phosphorus stoichiometry of organic matter in Swedish forest soils and its relationship with climate, tree species, and soil texture. *Biogeosciences* **2022**, *19*, 2171–2186. [CrossRef]
89. Zörb, C.; Senbayram, M.; Peiter, E. Potassium in agriculture—Status and perspectives. *J. Plant Physiol.* **2014**, *171*, 656–669. [CrossRef] [PubMed]