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Afforestation of agricultural land affects soil structural stability and related preconditions to resist drought

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Abstract: Afforestation is important for the EU forest management strategy. Afforestation of abandoned and marginal arable land is a favourable non-agricultural land use option for climate change mitigation. It may prevent threats of drought or erosion e.g. by affecting the water balance in soil via increased structural stability. The structural stability control in afforested soil is related to i.a. organic matter content, nutrient content, soil reaction, planted tree species prosperity, and amelioration. A four-year field small-plot experiment on afforestation was carried out with Chernozem covered with deciduous (oak), coniferous (pine) or mixed planting, amended with 3 doses (no-application, 0.5 kg·m^{-2}, and 1.5 kg·m^{-2}) of alginite. In 2013 and 2016, soil reaction pH_{H_2O}, mean weight diameter (*MWD*), organic matter content (*LOI*) and total organic carbon (*TOC*) were determined and related to the soil structural stability to evaluate the soil precondition to sustain drought twice per vegetation period (spring and autumn). Afforestation significantly improved *MWD* compared to the field soil between 2013 and 2016 from 1.63 ± 0.04 mm to 1.85 ± 0.05 mm. Tree planting significantly neutralized the soil pH_{H_2O}, mixed planting appeared to improve *LOI* and *TOC*. Four-year afforestation led also to higher structural stability, less alkaline pH and deciduous tree-related increase in *LOI*, which may indicate better soil sustainability to drought.

Keywords: field experiment; tree planting; soil amendment; soil organic matter; soil organic carbon

Afforestation has recently represented one of the most significant induced changes in the land use of agricultural areas. For example, the European afforestation plan, in accordance with the EU strategy, intends to plant 3 billion additional trees by 2030, aiming to improve quantity and quality of EU forests and strengthen their protection, restoration and resilience potential. The afforestation of abandoned and marginal arable/agricultural soil has a potential of climate-

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change mitigation while restoring soil fertility (Fernández-Ondoño et al. 2010), promoting biodiversity, and enhancing other ecosystem services (Yang et al. 2020). It can also reverse degradation processes in soils and improve soil resilience to contemporarily increasing climatic and environmental threats, such as drought or erosion (Doelman et al. 2020). Drought mitigation and water cycling control (Schwärzel et al. 2020) are some of the key ecosystem services generated by afforestation (Di Sacco et al. 2021). However, large-scale tree-cover expansions may also produce an opposite effect on soil moisture, e.g. they may increase evaporation/transpiration, leading to reduced local water availability and streamflow through interception (Yao et al. 2016; Hoek van Dijke et al. 2022). Nevertheless, there are numerous beneficial impacts of afforestation on the water balance in soil (Cunningham et al. 2015; Buechel et al. 2022), one of which is an improved soil structural stability. Afforestation can improve the soil structure because forest soils exert higher aggregate stability due to larger inputs of leaf litter and reduced soil disturbance, lower bulk density (decreased soil compaction), and higher porosity than agricultural soils (Lichtfouse et al. 2011). Soil stable aggregates are formed by the combination of mineral particles with mainly organic bindings agents (Tisdall, Oades 1982; Bronick, Lal 2005), through different bonding mechanisms (Edwards, Bremner 1967; Tisdall, Oades 1982; Tisdall et al. 1997; Six et al. 2000) associated with plant roots, fungal hyphae, microbial or plant exudates, and humic material (Tisdall, Oades 1982; Chantigny et al. 1997; Tisdall et al. 1997; Christensen 2001). The complex dynamics of aggregation is the result of the interactions of many factors including mainly the soil and environmental aspects (soil texture, moisture, temperature, vegetation cover diversity, nutrient fluxes and availability, microbial activity) (Castro Filho et al. 2002). Microaggregation and biotransformation of the structural soil organic matter are controlled by the soil microbial activity (Pinheiro et al. 2004). Afforestation can greatly impact on soil organic matter (SOM) stabilization and soil aggregation by shifts in the soil carbon and nitrogen accumulation, which reflects changes in microbial biomass turnover (Wu et al. 2016). Apart from the aspect of soil microbial biomass, the community composition of the microbiome is an important determining driver of soil aggregation and its impact on soil quality as well (Trivedi et al. 2017). Distinct soil microbial communities accompany specific forest types (Hackl et al. 2005) and trees species (Ushio et al. 2008) and thus, specific afforestation of agricultural fields is likely to increase the heterogeneity of soil resources. Tree planting increases the species richness of soil assemblages (Bardgett et al. 2005), which are linked to plant community diversities through a range of interactions, including the exchange of carbon and nutrients (Schmid et al. 2021). The awareness is that distinct forest plants and soil organisms are capable of coping with more rapid shifts in soil moisture due to higher evaporation (Manrubia et al. 2019). It gives reasonable expectations to better sustain ranged shifts in water availability and preserve soil functioning under drought events. Complexity and specificity of the relationship between tree growth and resilience to drought defined variably for different tree species and forest stands are also important (Pardos et al. 2021). The ability of tree species to sustain stress under several drought events during their life and to recover may be crucial for long-term survival (DeSoto et al. 2020). Also some soil amendments regularly used for the reclamation of degraded or otherwise deteriorated soil (Whitbread-Abrutat 1997; Werden et al. 2017) may contribute to better afforestation efficiency to create sustained improvements in agricultural managed soils. Complete evaluation how several above-mentioned factors (time extend of soil management change, tree-specific effect, melioration by soil amendments) may impact on the succession of afforestation and alteration of soil properties has not been carried out in many studies (Haque et al. 2006; Wei et al. 2013; Holubík et al. 2014; Schwärzel et al. 2020) and thus, more research is still to do. Therefore, a field experiment was conducted to investigate variable impacts of arable soil afforestation with either monospecific plantations such as deciduous (oak), coniferous (pine) ones or mixed broadleaved (English oak, Northern red oak, Norway maple) plantation and the effect of alginite amendment on those soil properties that are related to the soil structural stability, an indicator of soil precondition to sustain drought. It was hypothesized that:

(1) Afforestation improves soil structural stability: this benefit is time-related (changing with afforestation succession within 4 years,

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and from spring to autumn), tree-specific, and amendment-related.

(2) Soil organic matter content (measured by loss-on-ignition) and its change during afforestation are positively related to soil structural stability and contribute to its improvement.

(3) Changes of other properties (pH, organic carbon) are tree-specific, annually and seasonally variable, alginite-dependent.

MATERIAL AND METHODS

Study site. The effect of afforestation was monitored in the field experiment on a model site at a locality of Předboj district (50°14'02''N; 14°28'09''E), near the village of Hovorčovice (Prague-East) in the Czech Republic (Central Europe), see Figure 1.

Figure 1. Site location of Chernozem – Předboj district (50°14'02''N; 14°28'09''E) near a village Hovorčovice (Prague-East) in the Czech Republic (Central Europe)

The model site had sandy loam texture of soil, the soil type was Leptic Chernozem (CH) (IUSS Working Group WRB. 2007). The bedrock of the soils was formed as Upper Proterozoic Eon (Barrandien group) from the alternation of oceanic basalt as siltstone sediments with the Quaternary loess admixture (CH). The local average annual temperature is 8–9 °C; average annual precipitation is 500–600 mm (expected precipitation for the vegetation dry season was 20–30% of this value). The forest stands (Polabí Natural Forest Area No. 17) were established at the altitude of 248 m a.s.l. on long-term arable sites. The crop rotation in the control field was oilseed rape – winter wheat – winter barley, under soil conventional tillage (without ploughing) and application of mineral N fertilization [200–300 kg(N)·ha^{-1} to cereals] in autumn. The model site was divided into the subplots as listed in Table 1.

Alginite (Vázsonyi Szövetkezeti Kft., Hungary) was used as an amelioration amendment: it is a unique (mined only in surface quarries in Hungary) organic-mineral fossil material, formed by weathering of deposited (3–5 million years ago) dead biomass of sea algae and volcanic dust in craters of volcanic lakes. Basic composition (according to the manufacturer) is dry matter 60% (w/w), humus ≤ 21%, $CaCO_3$ ≤ 31%.

The basic parameters of pH, content of soil nutrients and nutrient elements in afforested and non-afforested (field) sites (independently of the stand site composition) were determined before the experiment and are presented in Table 2.

Table 1. Chernozem (CH) sub-plots specified according to soil planting with trees, and melioration

Sub-plot	Area	Factor		Factor		Replicates
		tree species	abb.	alginite (kg·m^{-2})	abb.	
field	–	–	–	–	–	3
1A	20 m × 20 m	oak (*Quercus robur*)	1	0	A	3
1B	20 m × 20 m			0.5	B	3
1C	20 m × 20 m, 10 m × 10 m			1.5	C	3
2A	20 m × 20 m	pine (*Pinus sylvestris*)	2	0	A	3
2B	20 m × 20 m, 10 m × 10 m			0.5	B	3
2C	20 m × 20 m, 10 m × 10 m			1.5	C	3
3A	20 m × 20 m	mixed broadleaved species	3	0	A	3
3B	20 m × 20 m			0.5	B	3
3C	20 m × 20 m, 10 m × 10 m			1.5	C	3

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Table 2. Chernozem soil pH and basic chemical composition before experiment establishing (spring 2013)

Properties	Units	Mean ± SD	
		afforested	field
pH_{H_2O}	–	7.4 ± 0.4	7.7 ± 0.5
MWD	mm	1.6 ± 0.2	1.7 ± 0,2
LOI	%	8.5 ± 1.7	9.2 ± 2.2
TOC	%	2.5 ± 0.1	2.4 ± 0.2
$N_{Kjedahl}$	%	0.3 ± 0.0	0.3 ± 0.0
C : N ratio	–	9.1 ± 0.5	9.1 ± 0.6
Ca available	ppm	4 166 ± 983	4 036 ± 473
Mg available	ppm	211 ± 17	226 ± 44
K available	ppm	550 ± 79	427 ± 124
P available	ppm	278 ± 47	266 ± 58

MWD – mean weight diameter; *LOI* – loss-on-ignition soil organic matter; *TOC* – total organic carbon
The exchangeable pH_{KCl} and pH_{H_2O} were measured according to (ISO_10390 2005), oxidable carbon (C_{ox}) was determined in sulfochromic oxidation (ISO_14235 1998; ISO_15476 2009), nitrogen content ($N_{Kjeldahl}$) was analysed by modified Kjeldahl method (ISO_11261 1995), available macronutrients (P, K, Mg, Ca) was measured according to Mehlich 3 standard method (Mehlich 1984)

In the spring 2013, English oak (*Quercus robur*), Scots pine (*Pinus sylvestris*), and a line mixture of the broadleaved species English oak (*Quercus robur*), Northern red oak (*Quercus rubra*) and Norway maple (*Acer platanoides*) were planted using the dug-hole method with 1 m × 1 m spacing. The study site CH was designed as square variants of 23 plots (20 m × 20 m) and 4 smaller plots (10 m × 10 m) in the total area of 1 ha. Alginite was applied in the respective amount (no addition, 0.5 kg, and 1.5 kg per planting hole, mixed within the planting substrate) at the time of plantation. Considering the spacing 1 m × 1 m, the application doses were 0.5 kg·m^{-2} and 1.5 kg·m^{-2}. Soil sampling on plots was done in late spring and in autumn 2013, and in spring and in autumn 2016. The crop rotation for arable soil in the years 2013–2016 was winter wheat, oilseed rape, and winter wheat followed by sugar beet; under the fertilization scheme with no organic fertilizer. Before the sugar beet, ploughing was carried out to a depth of 22 cm, wheat and rape were only disked due to the dry weather.

The basic climatic conditions during the experiment (average precipitation, temperatures) were collected from a local weather station and are presented in Figure 2.

Soil sampling and analyses of soil properties. Soil samples were taken from the top 5–15 cm of soil (0–5 cm was omitted to avoid leaf litter) from each of afforested and control field variant on two dates (spring/autumn) during the veg-

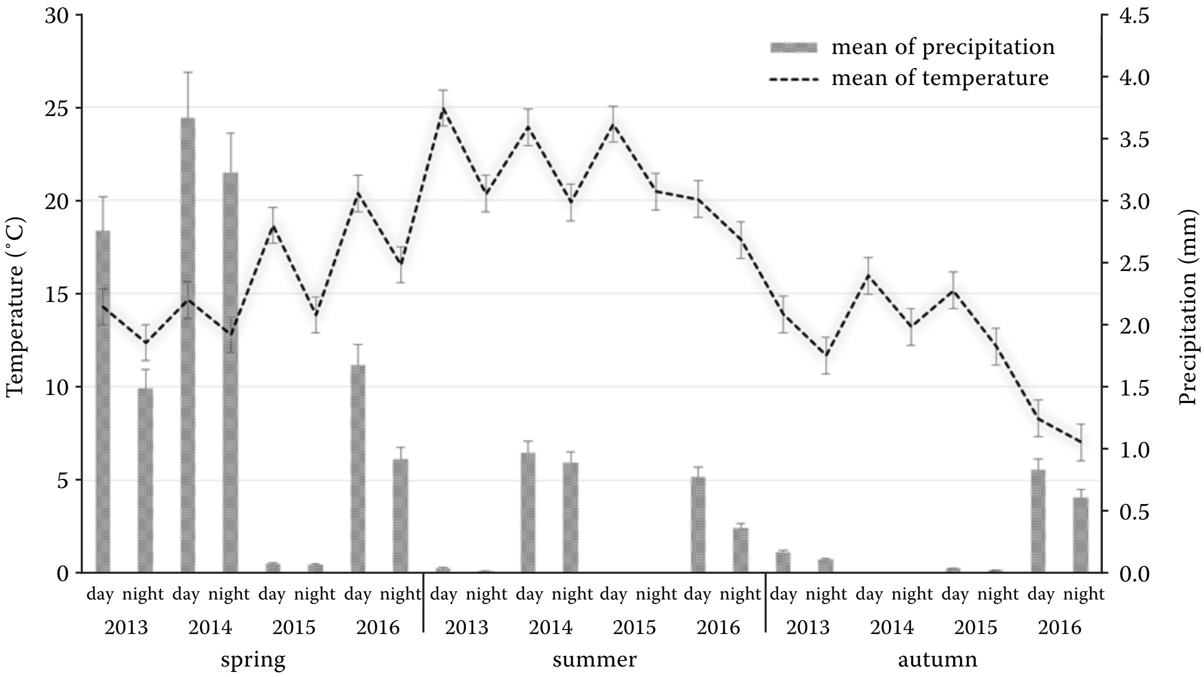

Figure 2. Air temperature and precipitation average values during the experimental period 2013–2016

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etation period. Four individual soil samples were taken per plot at each of the 4 time points (twice a year in the 1st and 4th year during a 4-year period) in experimental monitoring. Air-dried, pre-sieved (to 1–2 mm, Retsch Test Sieve, Retsch GmbH, Germany) samples, according to ISO_3310-1 2016, were used for the structural stability analysis, the mean weight diameter (*MWD*) was determined according to Mohanty et al. (2012) and Kemper and Rosenau (2018). Soil pH_{H_2O} was determined according to ISO_10390 2005, soil organic matter was measured by the loss-on-ignition method according to Nelson and Sommers (1996), soil total organic carbon was determined after dry combustion according to ISO_10694 1995.

Data and statistical analyses. The data obtained from determination of soil properties were compared after clustering according to factors whose effect on obtained values was evaluated: (*i*) tree species, (*ii*) year (2013, 2016), (*iii*) season (spring, autumn), (*iv*) amelioration (dose of alginite: zero, 0.5 $kg \cdot m^{-2}$, 1.5 $kg \cdot m^{-2}$). Effects of planted tree species or amelioration were calculated from the values of all samples, taken from the respective plots of each variant (plots 1, 2, or 3; A, B, or C; respectively) in 2013 and 2016. All data were tested for normality (Shapiro-Wilks test) and homogeneity of variance (Cochran test). The effects of different tree species, alginite amelioration, vegetation period and soil type on the *WSA* (water stable aggregates) were tested using one-way ANOVA of main effects with the post-hoc Tukey HSD (honest significant difference) test. The graphical representation of soil properties was expressed as means with standard deviation (SD). For advanced statistical modelling of the relationship between the soil properties and treatments the principal component analysis (PCA) was also applied. Eigenvalues were used for measuring the amount of variation retained by each principal component. These results were also graphically shown by the Rohlf biplot for standardized PCA. The Pearson correlation analysis was performed for measuring the linear dependence between soil properties. The Pearson correlation coefficient was interpreted as follows: $0.0 < r < 0.3$ (negligible correlation), $0.3 < r < 0.5$ (low correlation), $0.5 < r < 0.7$ (moderate correlation), $0.7 < r < 0.9$ (high correlation), and $0.9 < r < 1.0$ (very high correlation). All tests were carried out at a minimum significance level of 0.05 by the freely available software R (Version 3.6.1, 2019).

RESULTS

Soil pH and structural stability. The pH value was one of the key soil properties which likely change the subsequent afforestation in relation to trees, years, seasons and dose of alginite. This value is related to further physical and chemical properties which may affect the soil and plant ability to sustain drought. Soil pH_{H_2O} was not significantly affected by any of the tree species or variant (oak, pine, mixture) compared to bare-field soil within 4 years of experiment (Figure 3A). Nevertheless, in comparison with original pH_{H_2O} values (Table 2) afforestation (pine, oak, mixture: only –6.0%, –6.1%, –5.6% respectively) decreased soil pH_{H_2O} much less than the experimental management of field soil (–9.6% compared to the value in Table 2) during the whole monitored period. Further afforestation effect was apparent from a long-time change in average pH_{H_2O} values in 2013 (7.2 ± 0.06) and 2016 (7.32 ± 0.07), albeit this slightly alkalizing impact was not significant (Figure 3B). However, a significant effect of the season was revealed (Figure 3C), as spring samples had higher pH_{H_2O} values compared to autumn samples. The effect of alginite amendment was insignificant (Figure 3D), nevertheless an increasing dose (0 $kg \cdot m^{-2}$, 0.5 $kg \cdot m^{-2}$, and 1.5 $kg \cdot m^{-2}$) was coupled with rising values (7.11 ± 0.11, 7.28 ± 0.11, 7.36 ± 0.08), which was explainable due to the high content of calcium carbonate in alginite.

The mean weight diameter of soil aggregates (*MWD*) is a statistical index of aggregation. Albeit the tree-specific effect on *MWD* was not significant, the comparison of average values showed a trend of declining *MWD* from oak (1.83 ± 0.08 mm) to pine (1.79 ± 0.06 mm), through mixed planting (1.71 ± 0.07 mm) to the lowest value in field soil (1.63 ± 0.06 mm) (Figure 3E). A clear, significant increase of *MWD* in 2016 (1.85 ± 0.05 mm) compared to the value in 2013 (1.63 ± 0.04 mm) proved a positive effect of afforestation on soil structural stability (Figure 3F). No significant dependence of *MWD* on either season or amelioration was found (Figure 3G, H), however, average values of *MWD* differed between spring (1.79 ± 0.04 mm) and autumn (1.69 ± 0.06 mm), which assumed a trend of soil structural stability deterioration in the course of the vegetation period.

Soil organic matter and carbon. Soil organic matter (measured by loss-on-ignition, *LOI*) is also positively related to aggregation, and total or-

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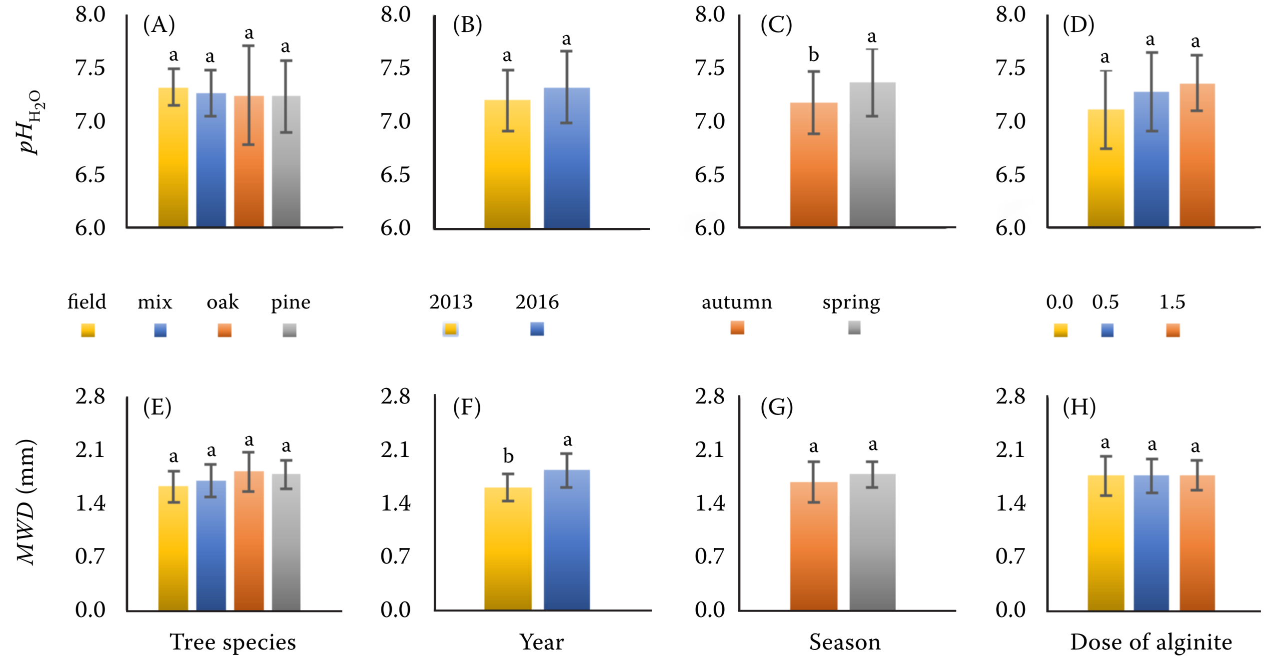

Figure 3. pH_{H_2O} and mean weight diameter (*MWD*) of chernozem in field plot experiment with lowland afforestation; mean values ± standard deviation (error bars) of respective soil properties in the afforested and field soil contrasted according to: (A, E) tree species of planted on the subplot (and unplanted variant = field); (B, F) year of measurement (2013 and 2016) (C, G) season (spring = May/June, autumn = Sept/Oct); (D, H) dose of alginite (0 kg·m^{-2}, 0.5 kg·m^{-2}, 1.5 kg·m^{-2}) used for melioration

Various letters indicate differences in values at statistical significance level $P \leq 0.05$

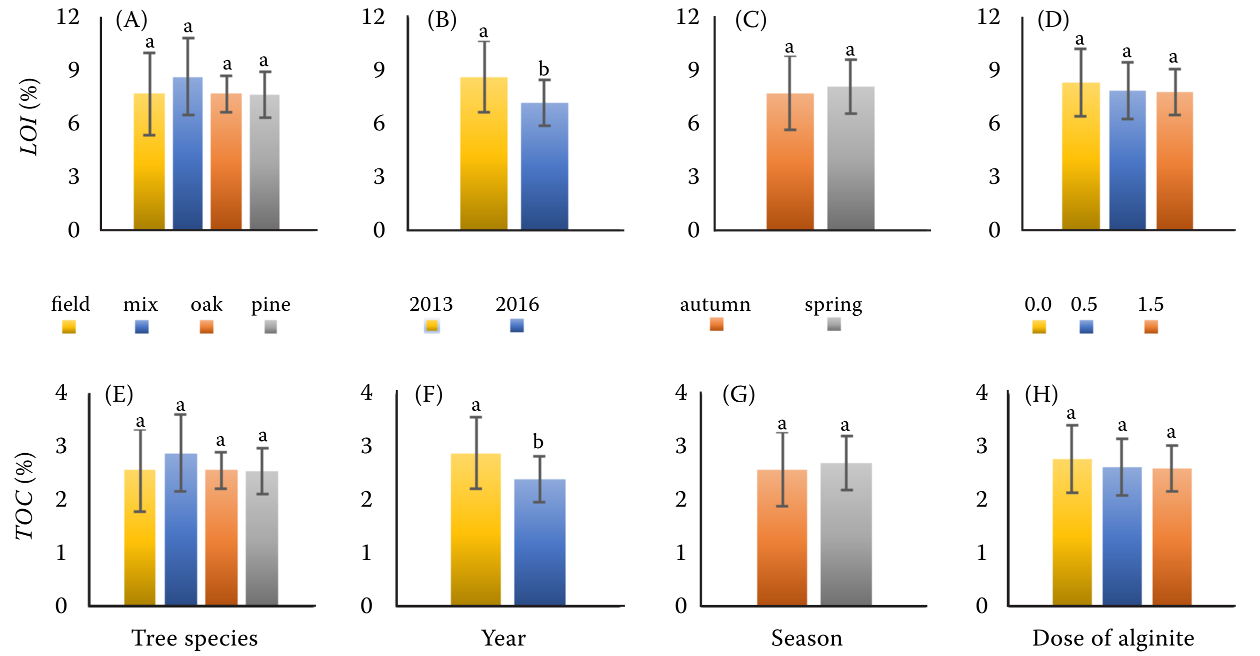

Figure 4. Loss-on-ignition soil organic matter (*LOI*) and total organic carbon (*TOC*) of chernozem in field plot experiment with lowland afforestation; mean values ± standard deviation (error bars) of respective soil properties in the afforested and field soil contrasted according to: (A, E) tree species of planted on the subplot (and unplanted variant = field); (B, F) year of measurement (2013 and 2016); (C, G) season (spring = May/June, autumn = Sept/Oct), (D, H) dose of alginite (0 kg·m^{-2}, 0.5 kg·m^{-2}, 1.5 kg·m^{-2}) used for melioration

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ganic carbon (*TOC*) presents a substantial fraction of soil organic matter. The tree-specific effect on *LOI* and *TOC* was found insignificant, the average values were comparable between field soil and oak- and pine-planted variants, except for the variant with mixed planting, when the value (*LOI* 8.63 ± 0.65%, *TOC* 2.88 ± 0.22%) was nearly 13% higher (both *LOI* and *TOC*) as compared to other values (Figure 4A). *LOI* and *TOC* were significantly higher at the beginning of the experiment (2013; 8.62 ± 0.41%, 2.88 ± 0.14%) compared to its end (2016; 7.16 ± 0.27%, 2.39 ± 0.09%), although these changes were opposite to *MDW* (Figure 4B). Neither season (spring or autumn) nor amelioration with alginite impacted on the *LOI* significantly (Figure 4C, D), however differences in average values were apparent. These findings showed decreased *LOI* and *TOC* in the course of the vegetation period (spring to autumn – decrease from 8.07 ± 0.32% to 7.71 ± 0.43%, from 2.7 ± 0.11% to 2.58 ± 0.14%, respectively) and due to the increasing application dose of amendment (0 $kg{\cdot}m^{-2}$, 0.5 $kg{\cdot}m^{-2}$, and 1.5 $kg{\cdot}m^{-2}$: *LOI* 8.28 ± 0.57%, 7.86 ± 0.48%, 7.76 ± 0.4% and *TOC* 2.77 ± 0.19%, 2.63 ± 0.16%, 2.59 ± 0.13%, respectively).

DISCUSSION

Soil pH and structural stability. Afforestation is recognized as a land management practice contributing to soil and ecosystem conditions which alleviate drought [i.a. decrease in rainwater runoff via increased total evaporation (transpiration)], presumably leading to land cover-induced changes in precipitation (Meier et al. 2021). Changes induced by afforestation include shifts in various important soil quality indicators, such as soil pH. Several authors referred to the prevailing acidification effect of afforestation on various soil types (Kupka, Podrázský 2010; Podrázský et al. 2011; Labaz et al. 2022; Novák 2022). In contrast to the referred higher acidifying effect of afforested soil (compared to control agricultural soil), the results of this experiment showed no significantly diverse impacts of the planted tree species and field variants on pH_{H_2O}. However, the determined pH_{H_2O} values were decreased in comparison with the starting values in the soil of either afforested or control field subplots, while these findings proved afforestation-derived soil neutralization, such as reported by Hong et al. (2018). Nevertheless, neutralization revealed in the alkaline field control variant was even more distinctive. Surprisingly, the afforestation effect on soil pH_{H_2O} seemed to be the most significant after a change in agricultural practices, as the average values dropped the most in 2013 and they slightly rose up at the end of experiment (2016). Clustering of samples according to the season within a year revealed the only significant increase in pH_{H_2O} in spring compared to the autumn samples. It was assumed that the higher leaf fall in autumn enhanced decomposition coupled with intensive respiration in the leaf litter layer of soil. Increased CO_2 production and its solubilization in the litter layer and topsoil water contributed to soil neutralization. It was in line with the reported higher leaf litter-derived decomposition at near-neutral pH (Khalsa et al. 2016; Ferreira, Guérold 2017). On the contrary, the application of alginite amendment (at a dose of 0.5 $kg{\cdot}m^{-2}$ and 1.5 $kg{\cdot}m^{-2}$) tended to increase the soil pH, which was ascribed to the reported high absorption capacity (Szabó 2004; Tica et al. 2011) of organomineral materials for cations, i.e. Ca^{2+} or Mg^{2+} (alkalogenic ions). Moreover, the moisture stabilization ability of alginite (Gömöryová et al. 2009) could also contribute to decreased cation leaching. It was obvious from the results that during this afforestation experiment, no significant soil acidification occurred, and thus it led to the high synergy of pH with soil structural stability (*MWD*), shown on the PCA biplot (Figure 5A–D). Soil structural stability was reported to be the highest at neutral pH (and it decreased with alkaline pH), also coupled with increased saturated hydraulic conductivity (Ali et al. 2019), which is a prerequisite for high soil resilience to drought. Our observations verified our hypothesis 3.

It has been reported that the afforestation of field (or generally non-forest) soil increases soil porosity, capillarity, but it decreases bulk density, which leads to better hydrological properties of soil (e.g. water-holding capacity), soil air capacity, and soil stability (Sparling et al. 1994; Podrázský et al. 2015; Kalhoro et al. 2017). Albeit *MWD* was not significantly altered by the tree-specific effect during four years of afforestation succession, *MWD* average values were descending from oak to pine, line mixture of broadleaved trees and the lowest values were observed in the field variant (Figure 3E). Therefore, at least a weak positive effect of tree planting on soil stability and *MWD* was revealed. Significant

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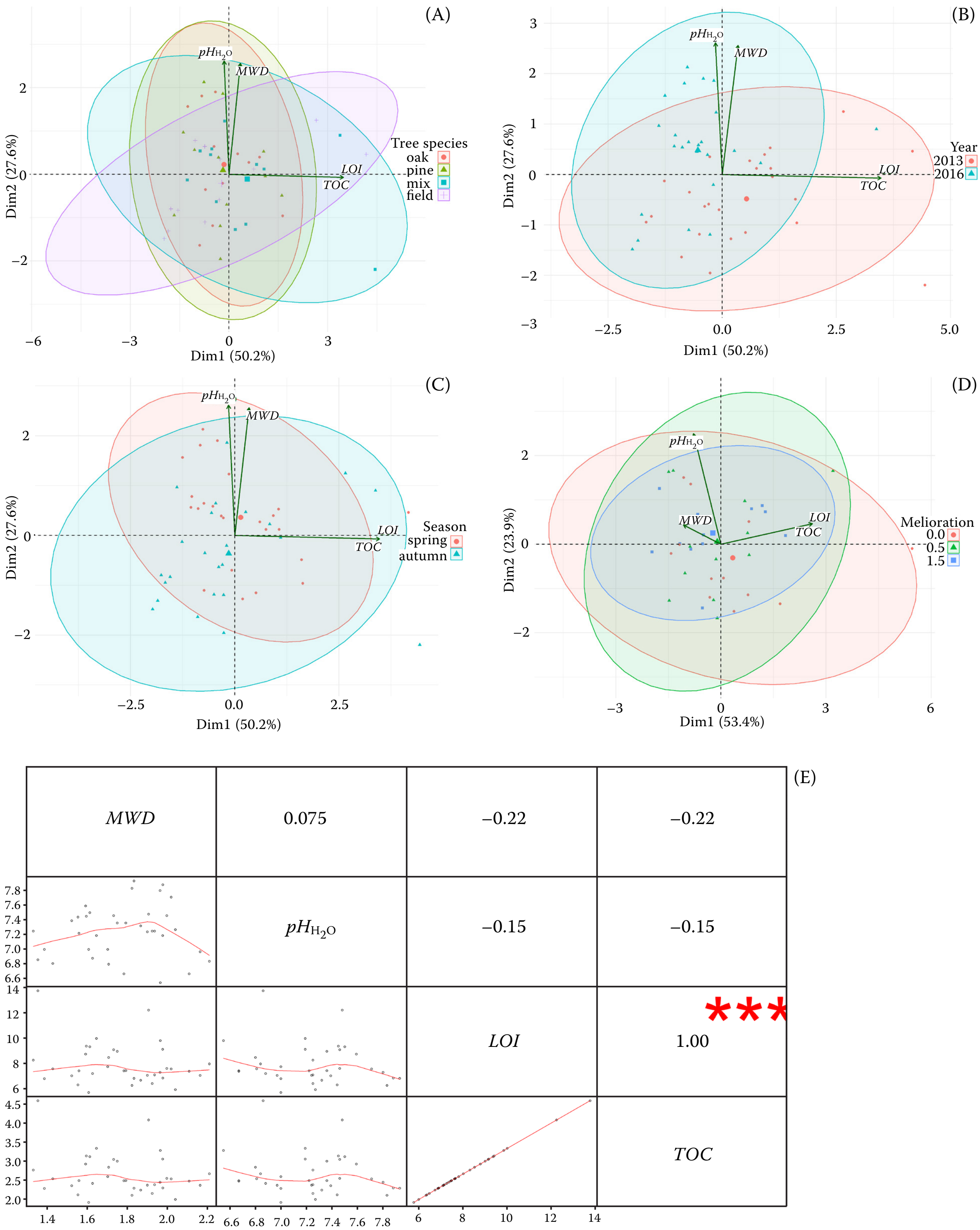

Figure 5. (A–D) Rohlf's PCA biplot analysis and (E) Pearson's correlation analysis of variables in field plot experiment with lowland afforestation; statistically analyzed mutual relationship between values of variables were clustered according to factors: (A) tree species of planted on the subplot (and unplanted variant = field) (B) year of measurement (2013 and 2016) (C) season (spring = May/June, autumn = Sept/Oct), (D) dose of alginite (0 kg·m^{-2}, 0.5 kg·m^{-2}, 1.5 kg·m^{-2}) used for melioration

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long-term improvement in soil stability (1.63 ± 0.04 in 2013 and 1.85 ± 0.05 in 2016, Figure 3F), which corresponded to previous findings (Liu et al. 2019; Bai et al. 2020; Wang et al. 2021), verified our hypothesis 1. Afforested soil, in contrast to the field, is characterized by improved hydrological properties such as hydraulic conductivity, micro- and macroporosity, which are also related to the mean weight diameter (a soil stability indicator) (Nemati et al. 2002). However, the other two tested factors – season and amelioration – contributed to only insignificant changes in *MWD* values (Figure 3G, H). The presumable decrease in *MWD* between spring and autumn could be caused by a decrease in organic matter content (indicated by *LOI*, Figure 4C), which was assumed to be lowered due to enhancement of microbial (degradation) activity in the leaf litter layer and topsoil (and coupled with pH decrease). A trend of slightly destabilization impact of alginite on the soil structure could be ascribed to its sorption capacity, which might have bound Ca^{2+} or Mg^{2+} ions which strengthen the soil structure when interacting with other components of SOM. The calcium role in soil aggregation is known on the basis of studies which found a beneficial effect of liming on structurally degraded soils (Haynes, Naidu 1998).

Soil organic matter and carbon. A very strong significant positive correlation of *LOI* and *TOC* ($r = 1.0$, $P \leq 0.001$) was found via Pearson's correlation (Figure 5E) and corroborated by mutual synergy on the PCA biplot (Figure 5A–D). These findings were in line with the observed similarity of trends and rates of changes of these properties. Albeit *LOI* and *TOC* values were insignificantly different between various tree-specific variants (Figure 4A), the highest average values were found in the soil under mixed planting. Insignificant differences were reported in the ability of deciduous and coniferous trees to accumulate and protect SOM, with an advantage to deciduous trees (Nickels, Prescott 2021). However, *LOI* was indeed significantly decreased during afforestation succession (from 2013 to 2016) when this trend was in contrast to the reported increase in organic matter (carbon) content during succession in land afforestation (Wang et al. 2020, 2021). Similarly, the apparent seasonal trend (from spring to autumn) of decreasing both *LOI* and *TOC* assumed that an increased organic matter input to the leaf litter layer induced the activity of microbial decomposers. These decomposers, after the consumption of labile carbon sources from leaf fall-derived organic matter, contributed to the partial consumption of less recalcitrant, degradable fractions of SOM in topsoil. Nevertheless, this loss of SOM was not coupled with deterioration of soil stability, which was in contrast with the observed direct relation between increased organic carbon content in soil aggregates and their stability (Wei et al. 2013). Thus, hypothesis 2 was not verified. Despite it was assumed that afforestation and tree planting resulted in the enhanced microbial activity at the end of vegetation season due to the higher organic matter input via increased leaf fall: these presumptions were in line with the referred significance of changes in land management or various planted tree species during afforestation for the activity of soil microbiome (Kaptanoğlu Berber et al. 2014; Huang et al. 2022). A possible explanation for the undisturbed soil structure together with the long-term loss of SOM could be that permanent microbial degradation enhancement with the external organic matter input via leaf fall induced repeatedly only the degradation of labile TOC fractions (due to permanent high supply from fresh leaf litter) and the content of recalcitrant carbon fractions, crucial for soil stabilization, remained unchanged. Furthermore, the presumed afforestation-derived increase in microbial activity was referred to be coupled with increased microbial biodiversity as well (Kara et al. 2016; Huang et al. 2022). Some authors reported the dependence of the soil structural stability on the microbiome diversity (Tardy et al. 2014; Lan et al. 2022). Therefore, in spite of a negative impact of afforestation on SOM content in soil, a putative indirect relation between *LOI*, *TOC* and microbial decomposition activity in soil may explain the improved soil structure indicated by *MWD*, which (possibly) presents a higher restraint of drought. The benefit of amelioration with alginite for *LOI* and *TOC* was not proved, on the contrary, the insignificant decrease in the determined values with increasing dose (0 $kg \cdot m^{-2}$, 0.5 $kg \cdot m^{-2}$, and 1.5 $kg \cdot m^{-2}$) made a possible contribution of this amendment to soil stabilization doubtful, more likely exerting an adverse effect on soil aggregation. Nevertheless, these revealed moderate changes of soil characteristics at the study site might have corresponded with the only limited reaction of plantations to soil amendment. Some authors reported significantly lower mortality in the

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first years after planting and higher increment in the first year of growth (Podrázský et al. 2014), while no relevant differences were registered later (Cukor et al. 2017).

CONCLUSION

The effect of lowland afforestation (and the effect of alginite amendment, season and year) on the soil properties of formerly arable field Chernozem was evaluated and it showed significant changes (related to the afforestation succession and season of soil sampling) in pH_{H_2O}, mean weight diameter (*MWD*), soil organic matter determined as *LOI*, and total organic carbon (*TOC*). Afforestation significantly improved the soil structural stability (*MWD*) between the 1st and 4th year of experiment, but *LOI* and *TOC* significantly decreased within this period. The tree-specific effect on *MWD*, *LOI*, and *TOC* was insignificant but apparent, and assumed advantageous effects of English oak (*Quercus robur*) on *MWD* and English oak (*Quercus robur*) + Northern red oak (*Quercus rubra*) + Norway maple (*Acer platanoides*) mix on *LOI* and *TOC*. The apparent trend of declining values of *pH*, *MWD*, *LOI* and *TOC* in the course of vegetation period (from spring to autumn) was significant only for pH_{H_2O}. The application of alginite seemed to be less beneficial to soil properties, as an adverse trend of slight soil alkalization, structural destabilization, and *LOI* and *TOC* decrease was assumed with the increasing dose of this amendment. The changes in all monitored properties were assessed in terms of the influence on the structural stability of soil and its resistance to the impacts of drought. Higher structural stability, near-neutral pH and mixed planting-related higher SOM were considered as improvements in physicochemical and hydrological state of soil for better sustainability to drought.

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