HUNGARIAN UNIVERSITY OF AGRICULTURE AND LIFE SCIENCES

Effect of afforestation on soil nutrient supplying capacity and soil fauna in a former fertilization experimental area

PhD THESIS

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1. INTRODUCTION AND OBJECTIVES

Based on the past decades, the local negative effects of global climate change are becoming more perceptible. Thus the efforts to mitigate climate change have become one of the greatest challenges of our time. It is therefore essential to find solutions that can effectively reduce the increase in atmospheric CO_2 concentrations (Pan et al. 2011, Rogelj et al. 2018). Recognizing this, there is an increasing emphasis on the need to increase forest areas, especially on arable land that is unsuitable for agricultural cultivation or eroded as a result of intensive use. Afforestation of these low-quality agricultural areas can help improve their soil condition, increase biodiversity and offset adverse environmental impacts.

As afforestation is on the rise worldwide, knowledge of its long-term effects on soil fertility is essential. There has been a number of recent researches on the subject, but the results also vary significantly in terms of climatic elements, soil types, tree species planted and pre-planting land use (Cunningham et al. 2015).

An examination of the two areas that functioned as long-term field fertilization experiment at the „*Szárítópuszta*" experimental site in Gödöllő for 25 years and was then afforested in the mid-1990s provided an opportunity to clarify some insufficiencies and contradictions. Here, as a result of long-term fertilization with different intensities, the effect of afforestation of arable lands could be studied under five different soil conditions. The forest stands were 20–22 years old at the time of the studies (2017–2019), so by then they could have caused significant changes in soil properties. The fact that well-documented data about the experiment is available is a big advantage, so my results were well comparable with the soil conditions before afforestation occured. The two different forest stands made it possible to explore the differences between native and non-native species, as one stand consists of sessile oak (*Quercus petraea*) native to the area, while the other consists of exotic and invasive black locust (*Robinia pseudoacacia*).

In the course of my research, **the objectives** were to explore the changes and their causes in soil nutrient supply capacity and soil fauna after afforestation of field experimental area, analyzing the impacts of the two different forest stocks and the effects of different soil conditions caused by different fertilizer and lime treatment. I was looking for answers to how the developing two forest ecosystems affected some soil properties and how previously applied fertilizers affected tree growth and forest structure development.

My results help to understand the long-term effects of forest ecosystems planted onto previously intensively cultivated, poor-quality degraded soils on soil nutrient supply capacity and soil fauna.

The main **hypotheses** were the following:

1. In the experimental areas, the heavily degraded soil not only regenerated 20 years after afforestation, but a much more favorable soil conditions were developed compared to the soil condition before afforestation; humus content increased, deep nitrogen accumulation ceased, soil fauna heterogeneous and diverse, similar to typical forest ecosystems.

2. The area planted with native sessile oak is characterized by a much more favorable soil condition, both in terms of nutrient supply capacity and soil fauna, than the soil under the non-native black locust stand.

3. The previous higher amount of fertilization resulted stronger growth of tree stands and faster formation of the forest structure, which resulted in a more favorable soil condition on the plots with higher nutrient content during the 20 years of planting.

4. Previous liming had a positive effect on soil parameters, earthworm density and diversity, litter decomposition, tree growth and forest structure.

2. MATERIALS AND METHODS

During my doctoral research, investigations were occurred in two afforested fertilization long-term experiments at the MATE „*Szárítópuszta*" experimental site (T: sessile oak experimental site, A: black locust experimental site) and in five control habitats (SZ: cultivated arable land, FSZ: abandoned arable land, AK: black locust control, TK: sessile oak control, RT: relict forest). The areas are located in Gödöllő, Pest County, in the Gödöllő hills. The climate here is moderately cool, moderately dry continental; appropriate for sessile oak and Austrian oak (*Quercus cerris*) forests. The surrounding landscape is determined by intensively cultivated fields and forests in a similar extent, however, in most of the area the original vegetation corresponding to the climatic and edaphic conditions is the forest. The most common are various oak associations and artificial forests consisting mainly of black locust (Dövényi 2010).
The bedrock of the forested experimental areas (T, A) is sand mixed loess, on which a 60-90 cm thick **soil typed *Luvic Endocalcic Phaeozem*** (rust-brown forest soil) has formed, with a humus layer of 30-40 cm. The texture of the soil is sand, however, the amount of clay increases with depth. The topsoil is basically weakly acidic (pH_{KCl} = 5.0), carbonate-free, a significant lime content appears only below 60 cm. The topsoil layer (0-20 cm) has a low humus content (H = 1.5%), low phosphorus (AL-P_2O_5 = 30 $mg \cdot kg^{-1}$) and medium potassium content (AL-K_2O = 120 $mg \cdot kg^{-1}$). The soil can therefore be characterized by unfavorable nutrient supply capacity and water management properties.
Prior to afforestation, the Ca^{2+} and Mg^{2+} content of the soil, thus the pH value, decreased significantly as a result of long-term high-dose fertilization. However,

the concentration of fertilizer originated nutrients (N, P, K) increased greatly in the plowed layer (0-20 cm). In the case of AL-soluble phosphorus and potassium the enrichment was detectable to a depth of 60-80 cm. The mineral nitrogen ($NO_3^- + NH_4^+$) accumulated also in large amounts in the bedrock. The effects were most pronounced on plots treated with higher-dose of fertilizers. The soil humus content decreased on all plots as a result of intensive agricultural cultivation (Füleky and Debreceni 1991, Kovács and Füleky 1991).

During my doctoral research, the most important **fertility parameters of the soils** (K_A, humus content, pH_{H2O}, pH_{KCl}, $CaCO_3$, Ca^{2+}, Mg^{2+}, N_{min}, AL-P_2O_5, AL-K_2O) of the two afforested experiments and the the five control habitats (0-20 cm) were examined. The amount of fertilizer originated nutrients was also measured in the soil profile of the oak experiment (AL-P_2O_5 and AL- K_2O: 0-100 cm, $NH_4^+ + NO_3^-$: 0-300 cm). To demonstrate the effects of afforestation, previously unevaluated data were also processed and evaluated as a reference.

In the two experimental areas two generally accepted groups of **soil fauna** (Collembola, Lumbricidae) were examined and in the case of springtails the effect of afforestation was evaluated on the basis of the five control habitats. In addition to determination the species level and the average abundance (ind. m^{-2}), in the case of springtails the most important community characteristics (diversity, dominance structure, equality) were gave and the habitats were also evaluated using similarity indices. Earthworms were collected in two autumn and two spring periods (2018–2020), and from the obtained data abundance (ind. m^{-2}) and biomass mass ($g \cdot m^{-2}$) were calculated.

The **decomposition properties of litter** (*k*: decomposition coefficient, TH: number of days to reach 50% mass loss, N, P, K, Ca and Mg content) were also characterized in the experimental areas. For this, nylon bags (15x15 cm, 3-4 mm mesh size) filled with 10 g of dried litter from the respective plots were placed fixing to the soil surface, and then on days 28, 105, 168, 303, and 491 they were collected back.

The analysis of the **structural parameters of forest stands** also performed. The measured parameters were the canopy closure (Z_A, %), shrub layer cover (Z_B, %), number of trunks (N, ind. ha^{-1}), average distance between trees (a, m), stand basal area (G, $m^2 \cdot ha^{-1}$), average diameter at breast height (Dg, cm), average height (Hg, m) biological top height (Hf, m) and wood volumes (V, $m^3 \cdot ha^{-1}$). To characterize the black locust plantation, the data measured in 2015 was used (Harta et al. 2016).

In the afforested experiments (T, A), the fertilization levels (1: control, 2-5: increasing NPK fertilizer treatment) and the liming (Ø, M) were taken into account. Each treatment variant and control habitat was represented by three replicates. Analysis of variance (ANOVA), t-test, linear regression analysis, discriminant analysis (DA), hierarchical agglomerative cluster analysis (UPGMA), principal coordinate analysis (PCoA), and canonical correspondence analysis (CCA) were used to **evaluate the data**. Significance level was set at $p < 0.05$.

3. RESULTS AND DISCUSSION

3.1. Soil nutrient supply capacity

In the 20-year-old forest stands (T, A) of the experimental areas, the **humus content** of the topsoil (0-20 cm) increased significantly compared to the level before afforestation. Values are slightly higher than in the control forests (TK, AK) and form transition between the values of arable land (SZ) and relict forest (RT). My results are in line with the findings that organic carbon content increases when afforestation has taken place in former arable land (Paul et al. 2002, Li et al. 2012). A Hungarian study also confirmed that the amount of carbon stored in the soil increases in both black locust and sessile oak plantations in a short time (Bidló et al. 2014). The different effect of afforestation with different tree species can also be seen from my results, the soil of the black locust stand has significantly higher humus content. Significant difference was not found between the average tree volumes of the two stands, but in the black locust plantation the rate of litter dcomposion was up to twice as fast based on the TH values. The higher humus content could also be caused by the much higher shrub cover; there was a close relationship between the shrub layer cover and the soil humus content. As a result of the previous liming, significant differences in the soil humus content were not found, but in the black locust plantation the average values of the limed plots were much higher. Shrub layer cover was significantly higher in both stands, as a result of liming. The humus content in the sessile oak plantation increased more substantially as a result of fertilization before afforestation, but only on the unlimed plots. On soils with higher nutrient content, the height and volume of each tree were higher at the trend level, but the number of trunks decreased significantly. This indicates initial rapid development, but later, as height growth slowed, the forest stands became homogenized.

After afforestation of arable land, most of the soil **N content** is translocated into the biomass, causing a significant decrease in the soil N content (Berthrong et al. 2009, Li et al. 2012). In this research it is also proved, thus the nitrogen supply capacity of the soil at the time of planting largely determined the intensity of the initial development of the trees. Soil N-supply values were much higher in the relict forest (RT) stand, suggesting that nitrogen accumulation is already beginning in the topsoil of old-growth forests. Nitrate accumulation in the deeper soil layer of the sessile oak plantation was completely ceased, but a small accumulation of ammonium-N was still detectable as a result of previous fertilization. Results also show that the plots with higher nutrient content had higher nitrate-N depletion and the soil N-content homogenized, suggests that trees used up soil supplies. As a result of the liming, the ratio of nitrate-N was higher, so the loss of N was stronger. Comparing the two stands, nitrate-N dominates in the black locust and NH_4^+ form in the sessile oak stand. It may be explained by that nitrifying bacteria are less effective in the lower pH range.

After afforestation, soils usually acidify mainly in the upper layers. The shift towards a lower **pH range** is also facilitated by the incorporation of Ca^{2+}, Mg^{2+}, and K^{+} basic cations into biomass (Jobbágy and Jackson 2003, Berthrong et al. 2009). In the sessile oak plantation, the pH_{KCl} values increased slightly compared to the level before afforestation, but the difference could not be proved. In the soils of black locust plantation the pH increased significantly on the other hand. The pH values were higher as a result of the previous liming in all cases, so the effect of the lime treatment was lasting. The tendency before afforestation that the pH was lower on the plots treated with higher N-fertilizer was only observed in the sessile oak plantation, the values of the black locust experiment were homogeneous when examining the effect of the fertilization factor. The pH values of the soil in the sessile oak plantation are also moving in the direction of balance, the lower pH_{KCl} values of the plots with higher nutrient content have increased, and the higher values of the control plots have decreased since afforestation. The results of my research thus confirm the theory that after afforestation the pH stabilizes, decreases in alkaline soils and increases in acidic soils (Hong et al. 2018). However, in the long term after afforestation soil acidification can be significant, as confirmed by the extremely low pH values of the upper soil layer (0-20 cm) of the old relict forest (RT).

There was a positive relationship between the changes in soil pH_{KCl} values and **calcium and magnesium content** after afforestation with sessile oak. The greater the loss of these two cations caused the less the pH increased. As the lowest loss in the Ca^{2+} and Mg^{2+} content was in the high nutrient plots, the pH increased the most here. This relationship is also confirmed by the significantly higher Ca and Mg content thus higher pH values of the soil of the black locust plantation. Moreover, the values of the black locust plantation exceeded the values of the oak plantation at all treatment levels. Due to previous liming, the values of Ca- and Mg-content were higher in both afforested stands. The relationship between Ca content and pH values of the soil is also confirmed by the results of the control habitats, as the lowest Ca content was measured in the relic forest (RT). Soil pH values and calcium content were also higher in black locust control forest (AK) compared to the sessile oak control forest (TK). One reason for this may be that in black locust forests, the rapidly degrading litter contains much higher amounts of calcium and magnesium than in the oak forests and these values were positively related to the degradation coefficient (*k*). The degradation coefficient (*k*) was also closely related to soil pH and Ca content. Higher shrub cover was also associated with higher soil pH values and Ca and Mg content in the experimental areas.

Contrary to the trend of calcium and magnesium, the loss of **soluble potassium** was more significant in soils with higher nutrient reserves in the sessile oak plantation. After sessile oak planting, the relationship between the change in Ca and Mg content and pH and the change in soluble potassium content was negative. In the black locust plantation the average soluble K content were also much higher than in the sessile oak plantation. Based on these, the trees absorbed less calcium and magnesium from soils containing large amounts of soluble potassium, so the decrease in pH could be stopped and the values increased. A trend can be observed in the change in the amount of soluble potassium. Eleven years after black locust planting, the amount of AL-K_2O at a soil depth of 0–30 cm decreased significantly (Ockert 2006). At these values, now significantly higher values were obtained in black locust plantation, and the differences between treatments disappeared. The loss of soluble potassium in the entire 0-100 cm profile could be assumed based on the data measured in the 8-year-old black locust plantation. This indicates that although the potassium requirement of trees is significant, potassium as a fast-cycling element returns to the soil in a relatively short time and accumulates over time in the upper layer of forest soil. The highest soluble K concentration of the 0–20 cm soil layer was also found in the old relict forest (RT). This confirms the results of Jobbágy and Jackson (2004) that in forests, exchangeable K^+ of the soil is concentrated on the surface, as some of the potassium taken up by the trees from the deeper layers falls back to the surface with the litter. The higher humus content in the forest soil also increases the number of adsorption sites, so the binding of base cations taken up by the trees from the deeper layers and then mineralized from the litter may also be more efficient. Based on the results, the effect of previous fertilization on the accumulation of soluble K up to a depth of 80 cm could be verified in the sessile oak plantation. Clay content starts to increase at this depth (K_A), so it is likely that a stronger potassium binding is to be expected here. The depth displacement of K is therefore not to be expected, the reason for the loss in the deeper layers is mainly the translocation into the biomass.

After afforestation of arable land, both the total and **soluble P content** of the soil generally decrease (Chen et al. 2008, Deng et al. 2017, Li et al. 2019). This is confirmed by the results, because soluble phosphorus content in the topsoil (0–20 cm) was significantly reduced in both afforested experiments. This may have been mainly caused by plant uptake, as depth displacement of P is not been expected. However, large amounts of root fluid, enhanced microbial processes, and more favorable moisture conditions may promote an increase in soluble P content in the longer term (Chen et al. 2000, Zhao et al. 2007). This is confirmed by the results that soluble P content of the 0-60 cm soil layer in the sessile oak plantation increased significantly compared to the values before afforestation, even on the control plots. The significantly lower soluble P content of the black locust plantation can be caused by the higher pH and the fact that legume plants (Fabacea) have high demand of P. Although in the sessile oak experiment, soils with higher nutrient content showed a much larger decrease in soluble P content, which was more pronounced in the limed plots, the soluble P content of the larger treatments was still significantly higher than in the control (1) plots. Phosphorus can therefore remain in the soil for a long time and is a less limiting nutrient. Compared to other habitats, the soluble P content of the sessile oak experiment is extremely high in the soil of the highest fertilizer treatment, only the values of arable land and abandoned arable land are also high.

3.2. Soil fauna

Based on the species composition, diversity and abundance of the springtail communities (Collembola), the two afforested experiments (T, A) form a transition between the arable lands (SZ, FSZ) and the control forests (AK, TK, RT). The lowest species richness, diversity and abundance were found in the arable land (SZ), proving the negative impact of intensive agricultural cultivation. Thus, several cosmopolitan species were found in the samples (e.g., *Brachystomella parvula, Ceratophysella succinea, Mesaphorura macrochaeta, Parisotoma notabilis, Entomobrya multifasciata, Folsomides parvulus* and *Lepidocyrtus cyaneus*) which are often found in intensively cultivated areas (Debeljak et al. 2007, Twardowski et al. 2016). These species can tolerate more unfavorable conditions, as indicated by the *CCA ordination*. A species-rich and abundant springtail community was found in the abandoned arable land, where the value of *Shannon diversity* even exceeded the values of the relict forest (RT). However, based on the intersection observed between the *Rényi diversity profiles* of the two habitats, the Collembola communities of open areas and forests cannot be compared solely on the basis of diversity. In addition to the species characteristic of open habitats, species *Hypogastrura vernalis, Entomobrya lanuginosa, Lepidocyrtus paradoxus* and *Isotoma viridis* were found in the abandoned arable land, which are more characteristic of grasslands (Ponge et al. 2003, Chauvat et al. 2007). The values of the springtail communities of the control forest stands (AK, TK, RT) and even of the afforested experimental areas (T, A) support the positive effect of afforestation of arable land. Abundance, species richness, and diversity values of the experimental areas, although lagging behind the control forest stands, the have much higher Collembola diversity compared to the surrounding arable land. Their springtail communities are still transient, dominated by open habitat species, and only a few species preferring forest condition have been found, such as *Neanura muscorum*, *Ceratophysella luteospina*, *Entomobrya muscorum*, *Folsomia quadrioculata*, *Isotomiella minor*, and *Megalothorax minimus* (Dányi és Traser 2008, Auclerc et al. 2009, Vanhée és Devigne 2018). The relatively high number of open habitat species found in the experiments (e.g., *Protaphorura campata, Entomobrya multifasciata, Lepidocyrtus cyaneus, Pseudosinella alba*) indicate the impact of the surrounding habitats. The relatively young age of the experimental stands is also reflected in the dominance structure of Collembola communities, as well indicated by the relatively high community dominance index (CDI) of the experiments compared to the old relict forest. Only occasional differences have been found caused by the previous fertilization in in the species number, diversity and dominance structure of the Collembola stocks in the experimental areas, mainly due to high doses. However, abundance increased at a trend level with each treatment in both experimetal stands, which may be related to higher phytomass production. The selection of planted tree species also has a significant long-term impact on the soil fauna; the biodiversity of non-native tree stands is generally poorer than that of native tree species (Traser and Csóka 2001, Traser 2003, Winkler and Tóth 2012). The higher organic matter content of the black locust plantation's soil is well reflected in the higher Collembola abundance compared to the sessile oak stand. However, the values of species richness, diversity, and evenness were higher in the native sessile oak stand. Presumably, the allelopathic effect of black locust may be responsible for the lower species richness and diversity of the black locust experiment, which is also indicated by the diversity profiles. In the black locust plantation the species showed a less uniform distribution, as shown by a higher CDI index compared to the sessile oak experiment. The high abundance of some eudominant species and the relatively low number of individuals of other species may reflect unfavorable conditions for certain groups. For all the habitats studied, the individual species are well separated along the pH gradient, from the alkalophil *Brachystomella parvula* to the weakly subneutral *Orchesella cincta* and *Lepidocyrtus cyaneus* species to the acidophil *Tomocerus vulgaris*, based on the *CCA biplot*.

In our studies, a total of five earthworm species were found in the two afforested experiments (T, A) from three ecological types (Brown et al. 2004). Among epigeic species *Lumbricus rubellus* was found, but only in the oak stand. Species of this ecological type live on the soil surface, most often in the litter. The rapidly decomposing litter layer of black locust is thus less suitable for this species as a habitat, while the sessile oak has a thick, hardly decomposed litter layer. The endogeic species live and feed in the mineral soil, making their horizontal tunnels here. In our experimental areas this ecological type represented the largest number of species. The species detected were *Aporrectodea rosea*, *Aporrectodea caliginosa* and *Allolobophora chlorotica*. Only one species, the *Lumbricus terrestris* represented the surface-feeding but deep vertical tunnels-making anecic species, which was found in relatively large numbers in both experiments. The small number of detected species and the dominance of endogeic species show the effect of intensive cultivation before afforestation, while the relatively large number of anecic *Lumbricus terrestris* indicates the positive effect of afforestation. Statistically significant differences were not detected for any of the examined factors, but black locust plantation was generally characterized by greater abundance and biomass than all sampling. Previous liming increased abundance too, which was even more pronounced in the black locust stand. Of the fertilizer treatments, in general, the largest number of individuals and biomass were found in plots treated with medium-dose fertilization before afforestation. The higher values expressed as a trend can be explained by the more favorable soil moisture condition, higher organic matter content and favorable pH. A positive relationship was found between the abundance and the humus content of the soil, as well as between the N content of the litter and the abundance and biomass. This demonstrates that earthworms are extremely effective in decomposing the litter layer of forest soils, thus can accumulate soil organic matter (Alban and Berry 1994).

4. CONCLUSION AND RECOMMENDATIONS

While afforestation of degraded or low-quality arable land is on the rise worldwide, on its necessity and usefulness opinions are divided. Based on the results of my Phd research, favorable changes have taken place in the nutrient supply capacity of the soil and in the soil fauna after the afforestation of previously intensively cultivated arable lands. Forest vegetation therefore has a positive effect on the soil condition of agricultural areas and contributes to the optimization of soil nutrient turnover by stimulating soil life.

Based on the results, both the native sessile oak and the non-native black locust forest have changed the soil condition in 20 years, but in different ways. Black locust used up soil nutrients, homogenized the soil, and significantly increased humus content and pH. In the sessile oak stand, different soil properties developed caused by fertilization and liming before afforestation were still perceptible. However, while for P and K content it was pronounced, the nitrogen content was greatly reduced in all treatments and the differences developed before afforestation disappeared. Thus, the N content of the soil became a limiting factor within a few years after afforestation. Black locust, as a legume, has symbiotic nitrogen-fixing rhizobia, which has helped increase the amount of available N and thus more efficient nutrient utilization. As a result of the higher amount of nutrients, a more favorable soil condition was developed, and homogenization of the soil was more efficiently. Soil acidification and leaching of base cations were also reduced in plots with higher nutrient content. On soils with more favorable nutrient supply, the growth of both tree species was stronger, but this could only be justified to a small extent after 20 years. Without forestry treatment, the intraspecific competition of sessile oak was stronger on plots with more favorable nutrient supply, verifyed by significantly lower trunk numbers and larger tree volumes.

The soil fauna of the former intensively cultivated field experiments reacted positively to afforestation and indicated well the changes in soil properties. Although the studied parameters of the springtail communities lagged behind the control forest stands, higher species richness, diversity and abundance were observed compared to the arable land. The effect of tree species selection was shown in the studied experiments. Although higher springtail density was found in the black locust plantation, the species richness, diversity and evenness were higher in the case of native sessile oak experiment. Based on earthworms, although there was no significant difference between the stands consist of two different tree species, the abundance and biomass were slightly higher in the black locust plantation at each sampling.

Based on the results, my **recommendations** are as following:

1. The conversion of degraded arable land into forests as a possible form of agricultural cultivation should be encouraged. This is especially necessary in Hungary in hilly areas at risk of erosion due to sudden heavy rainfall, where the tillage solutions prescribed in legal regulations (eg. contour tillage) and cultivation technology methods (exclusion of row crops, continuous soil cover) do not lead to results. At the same time, the results of our studies on abandoned arable land (FSZ) (humus content, springtail diversity) support that grassland (meadow, pasture) can also be a potential option from the point of view of soil protection.

2. During recultivation, planting with black locust can have significant positive effects in the short term (rapid growth, increasing the soil humus content) however a high utilization of soil nutrients must be taken into account. However, black locust enriches the soil with nitrogen, thus helps weeds, its stands are ecologically only degraded habitats, and due to its invasive properties it can spread from the place of planting. Black locust cannot be planted in protected nature areas and Natura 2000 areas.

3. In order to preserve and increase soil biodiversity, it is worthwhile to convert a reasonable part of these black locust plantations into native stands over time. During the conversion, the continuous forest stock, so the soil coverage must be ensured. Efforts should be made to maintain shrub layers. However, it should be noted that due to the high regeneration potential of black locust, the environmentally friendly replacement of its population is currently not fully solved.

4. When planting sessile oak, the N content of the soil must be taken into account, as it can be a limiting factor, even in the presence of other nutrients in more favorable quantities. Before afforestation of degraded or eroded arable land, it is worth considering the optimization of soil nutrients (NPK).

5. Soil protection, forestry and nature conservation considerations should also be taken into account and considered when selecting tree species for afforestation.

5. NEW SCIENTIFIC RESULTS

With my results, on the soil type *Luvic Endocalcic Phaeozem* (rust-brown forest soil) under field conditions in Hungary was demonstrated the following.

1. **Soil degraded as a result of intensive agricultural use was regenerated 20 years after afforestation, its fertility improved**, and a more favorable condition was developed compared to the soil condition before afforestation.

- The strongly reduced ***humus content*** in the topsoil (0-20 cm) due to the intensive agricultural use has significantly increased during 20 years (average before afforestation: 1.17%, average of afforested experimental areas: 2.35%).
- The strongly decreased ***pH*** in the topsoil (0-20 cm) as a result of intensive agricultural use, did not decrease further during 20 years, but even increased (average before afforestation: pH_{KCl} = 4.90, average of afforested experimental areas: pH_{KCl} = 5.72).
- ***Nitrogen accumulation*** was eliminated from the soil profile in the afforested experimental areas, the trees made efficient use of the available nitrogen surplus, even from the deeper soil layers.
- The ***soil fauna*** of the afforested experiments (Collembola, Lumbricidae) is species-rich, abundant and diverse, forming a transition between the forest ecosystems characteristic of the region and the soil fauna of the agricultural areas.

2. **The soil under the native sessile oak stand can be characterized by greatly different soil conditions**, both in terms of nutrient supply capacity and soil fauna, than the soil under the non-native black locust stand.

- The ***humus content*** of the soil (0-20 cm) of the black locust stand significantly exceeded the values measured in the soil of the sessile oak stand (T: 1.73%, A: 2.96%).
- The ***pH values*** (T: pH_{KCl} = 5.12, A: pH_{KCl} = 6.31), the ***Ca^{2+} content*** (T: 384 $mg \cdot kg^{-1}$, A: 963 $mg \cdot kg^{-1}$) and the ***Mg^{2+} content*** (T: 94 $mg \cdot kg^{-1}$, A: 108 $mg \cdot kg^{-1}$) of the soil (0-20 cm) in the black locust stand significantly exceeded the values measured in the soil of the sessile oak stand.
- The ***soluble phosphorus content*** in the soil (0-20 cm) of the black locust stand was greatly reduced (average before afforestation: 200 $mg \cdot kg^{-1}$, A: 42 $mg \cdot kg^{-1}$).
- During 20 years, the ***soluble phosphorus content*** in the 0-20 cm soil layer in the sessile oak stand decreased, but the soluble P content of the deeper soil layers (20-100 cm) increased for all treatments, mainly in the soil layer 40-60 cm.
- ***Collembola*** abundance values were much higher in the black locust stand; however, diversity and equability were higher in the native sessile oak stand.

3. **The large amount of fertilization before afforestation resulted in a stronger growth of tree stands and faster formation of the forest structure**, so in connection with this, the plots with higher nutrient content had a more favorable soil condition after 20 years.

- In the case of a larger decrease of the ***soluble potassium*** content in the soil (0-20 cm) of the oak stand (1: -32 mg kg^{-1}, 5: -177 mg kg^{-1}) the decrease of ***Ca^{2+} content*** (1: -1263 mg kg^{-1}, 5: -138 mg kg^{-1}) and ***Mg^{2+} content*** (1: 68 mg kg^{-1}, 5: -20 mg kg^{-1}) were less pronounced, the pH values increased better (1: pH_{KCl} = -0. 60, 5: pH_{KCl} = 0.77).

4. **Liming before afforestation had a positive effect on shrub layer cover and the formation of a complex forest structure**, and in this context on soil parameters**.**

- As a result of liming before afforestation, shrub layer cover increased significantly in both experimental stands (Ø: 21%, M: 42%), which was strongly positively related to the humus content (r = 70 ***), ***Ca^{2+} content*** (r = 50 ***), ***Mg^{2+} content*** (r = 57 ***) and pH_{KCl} values (r = 45**) of the soil (0-20 cm).

6. PUBLICATIONS IN THE TOPIC OF THIS WORK

Articles in a periodic
Article in a foreign language, with IF

Harta I., Simon B., Vinogradov Sz., Winkler D. (2020): Collembola communities and soil condition in forest plantations established in an intensively managed agricultural area. In: *Journal of Forestry Research*, 1-14. DOI: 10.1007/s11676-020-01238-z

Article in a foreign language, without IF

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