Soil and Atmospheric Microclimate Research in Poplar Forestry Intercropping System in Hungary

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Abstract – Climate change presents growing environmental, economic, and social problems for the industrializing and developing world. Applying new technologies and transitioning to a cleaner, more flexible economy are essential to solving these problems. These solutions focus on climate change mitigation and work toward a complete transformation in line with sustainable development goals. Agroforestry systems are used for climate change adaptation and to support biodiversity. They also help combat desertification and soil erosion. Practical experiences show that applying forestry alley cropping systems can contribute to the climate adaptation of young forest stocks. The present study examined a historical forestry intercropping method known as *Vákáncsos* following the effects of microclimate stress on poplar seedlings (*Populus × euramericana cv. I-214*). This study investigated the background of previous observations concerning the practice of using intermediate crops in forest conditions – and the favorable results from these – and compared the stress effects on seedlings. When assessing the microclimate of the system, we used the EC tester (EC–electrical conductivity) to measure soil temperature and conductivity. We employed an agrometeorological hand-held instrument to measure air temperature, humidity, and wind speed. The results show that the agroforestry system significantly reduces temperature extremes and provides more favorable humidity. The agroforestry system reduced soil temperature values by 1–14 C° in the warmest period of the year. Experience and measurements indicate that the applied agroforestry practice can increase stress tolerance, afforestation efficiency, land use maximization, and profitability. Applied agroforestry can also serve other purposes like ecosystem services and feeding. Forestry alley cropping systems can be combined with resource efficiency.

Agroforestry / maize hybrid – P9241 / *Populus* × *euramericana cv. I-214* / soil conductivity / soil temperature

Kivonat – Talaj mikroklíma kutatás magyarországi erdei köztes termesztéses rendszerben. A klímaváltozás a mai iparosodó és fejlődő világunkban a környezet, a gazdaság és a társadalom szempontjából is egyre nagyobb problémát jelent. A probléma megoldásához olyan technológiák alkalmazására van szükség, amelyek lehetővé teszik az áttérést a tisztább, rugalmasabban alkalmazkodó gazdaságra. Ezek a megoldások nem kizárólag az éghajlatváltozás mérséklésére fókuszálnak, hanem a fenntartható fejlődés céljaival összhangban álló teljes átalakulást szolgálják. Az agroerdészeti rendszereket a világ számos táján sikeresen alkalmazzák a klímaváltozáshoz való adaptáció céljából, az elsivatagosodás, talajerózió ellen és a biológiai sokféleség támogatására. A gyakorlati tapasztalatok azt mutatják, hogy a köztes termesztés erdészeti alkalmazása segítheti a fiatal erdőállományok klímaadaptációját. Célunk az erdei körülmények között a közteskultúrát alkalmazó gyakorlat hatására kialakuló kedvezőbb mikroklímára vonatkozó korábbi megfigyelések hátterének tudományos igényű feltárása és a csemetéket ért stresszhatások összehasonlító vizsgálata. A rendszer mikroklíma-vizsgálataihoz a talajhőmérséklet és -vezetőképesség mérésére alkalmas EC tesztert, valamint a

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léghőmérséklet, páratartalom és a szélsebesség mérésére szolgáló agrometeorológiai kézi műszert használtunk. Az eredmények azt mutatják, hogy az agrár-erdészeti rendszer szignifikánsan csökkenti a hőmérsékleti szélsőségeket és kedvezőbb páratartalmat biztosít. A talajhőmérsékleti értékeket 1-14 C°-kal csökkentette az agrár-erdészeti rendszer. A tapasztalatok és a mérések alapján elmondható, hogy az alkalmazott agroerdészeti gyakorlat növelheti az erdősítés stressztűrését és ezzel a hatékonyságát, javítja a területkihasználást és a jövedelmezőséget, emellett pedig egyéb célokat is szolgál (ökoszisztéma szolgáltatások, takarmányozás). Az erdősítésben alkalmazott köztesnövény-termesztés így erőforrás-hatékonysággal és jobb gazdasági megtérüléssel párosulhat.

agroerdészet / kukorica hybrid – P9241 / ***Populus* × *euramericana cv. I-214*** **/ talajhőmérséklet / vezetőképesség**

1 INTRODUCTION

1.1 Global presence of forestry alley cropping systems

Alley cropping is a plantation containing rows of trees and/or shrubs with agricultural or horticultural crops cultivated planted in between. Many parts of the world use alley cropping systems, but the number of systems that aim to increase the effectiveness of afforestation is limited. In these systems, alley cropping is used as one of the tools to mitigate the extremes of environmental impacts and compensate for human excesses (destruction of rainforests) by the local population.

Agroforestry systems created in this form in tropical-subtropical forest areas significantly improve the survival rate of tree individuals. In Africa, afforestation combined with intercropping aims primarily at food production and plays an essential role in soil improvement and erosion protection (Gichuru – Kang 1989, Kang et al. 1995, Watson 2014). The primary goal in South America and China is to replant and conserve forests, while agroforestry systems also provide food for local farmers and their families (Chamshama et al. 1994, Haggar et al. 2003, Fan A-nan et al. 2006, Suoza et al. 2010, Muwamba et al. 2015).

In Kenya and Sudan, the taungya management of agroforestry systems is established for successful industrial plantation and engages in the surrounding forest ecosystem. The shamba system is a well-known agroforestry system in Kenya (KFMP 1994). It includes ligneous vegetation combined with horticultural or agricultural intercrops managed by entrepreneurial mind farmers in forestland for 3–4 years. The area between the trees is made available for the farmers in exchange for free labor, which includes planting and caring for tree seedlings (Mburu 1981, Oduol 1987). After clearcutting, the farmers in taungya systems grow food crops (mainly corn, beans, potatoes, cabbage, and carrots) for one cropping period and then plant tree seedlings with intercrops for 3–4 years, followed by sole ligneous vegetation due to canopy closures (Wanyeki 1981).

1.2 Forestry alley cropping systems in Hungary

Forestry alley cropping has a long tradition in Hungary – especially in the eastern regions in the Great Plain – and was known as *Vákáncsos* historically. The Hungarian word *vákáncs* comes from the Latin word vacans. This word appeared on authentic instruments in Debrecen at around 1820. The name referred to abandoned and degraded forest areas. Hungary's state-owned forests were ruthlessly destroyed until the mid-1800s, which finally led to the need to compensate for the growing volume of deforestation in the eastern counties. Cost-effective reforestation was promoted as a solution. To moderate rising unemployment and accelerate afforestation at the same time, Debrecen's city management granted the designated afforestation areas to unemployed people possessing an entrepreneurial spirit (Miklós 1974). Hence, people living there took the name *Vákáncsos* from the area called "Vákáncs". They lived in the clearcutting areas and grew agricultural crops among the tree seedlings during their stay. After 3–5 years – depending on the tree species – they moved to another designated forest parcel (Balogh 1935). Though the Vákáncsos lifestyle is a thing of the past, the technology used has survived. Forestry professionals and forest land tenants in Hungary still employ the method, but the practice is not widespread. The overall aims include maximum area utilization, tree seedling protection, successful afforestation, and wild fodder provision. Although forestry alley cropping still exists in Europe, the technical sophistication of this method in some places has remained at the initial level.

1.3 The impact of climate change on domestic forests of Hungary

Climate change is a growing problem in our developing world, both naturally and socio-economically (Richard et al. 2000, Ramsfield et al. 2016, Isabel et al. 2019). Weather extremes, which are becoming more and more common both in Hungary and internationally, have a significant impact on the climate of a forest area which, being a production factor, has a strong influence on the forest ecosystem. From 1960 to about 1970, Hungary developed a forest climate classification system based on the forest aridity index (FAI) and Kaminszki's results (Führer 2018). The changes in aridity in recent decades have prompted the expansion of the classifications from four to five in number (Steppe), i.e. Hungarian forests now have five classes:

- Beech with *Fagus sylatica L.*
- Pannonic woods with *Quercus petraea (Matt.) Liebl.* and *Carpinus betulus L.*
- Pannonian-Balkanic turkey oak –sessile oak with *Quercus cerris* and *Quercus petraea (Matt.) Liebl.*
- Forest-steppe
- Steppe

Global warming has caused the emergence and territorial spread of the steppe climate class. Climate predictions for the 21st century show rising average temperatures and decreased rainfall in the main growing period of ligneous vegetation (May–August), being most critical in July–August in Hungary. These changes are projected to lead to a significant increase in the less profitable forest-steppe areas (up to 30%) by 2050 (Gálos – Führer, 2018). According to some estimates, the spread of the forest-steppe area will cause the beech climate in Hungary to disappear (Führer 2011). The issue is serious as it pertains to the tolerance of tree species (Szép 2010) and, thereby, the necessity of a shift in forest management. The inadequate conditions give rise to biotic pests that weaken resistance and, thus, reduce the assimilating surface and decrease the survival rate of trees. At the same time, the biomass yield of stands also decreases (Führer 2018), which is accompanied by a deterioration in wood quality (early-late wood) (Szép 2010).

Preventing this process is often only possible by using species that are better adapted to the changes expected in the long term. Practices that aid in climate adaptation can complement this measure. In non-protected forest areas, forestry alley cropping systems can be used as an effective tool for successful afforestation and to create the optimal conditions that support improved adaptation in vulnerable young stocks.

1.4 The benefits and disadvantages of forestry alley cropping systems

Depending on tree species, intercropping systems are used in the initial years of afforestation, before the crown gradually intensifies the competition between trees and intermediate plants. However, this also hinders the proper care of the tree stand. The cultivation of intercrop species is limited to 1–4 years, depending on the species. The length of intermediate cultivation can be increased by changing the crop species according to the growing intensity of the trees as needed, but this will not necessarily have the same positive effect on tree development in later years. Concerning crop yields, it is not worthwhile to apply this practice beyond a single growing season when associating a fast-growing tree species with a light-intensive intercrop because the stand canopy closes quickly, causing a drastic decline in the yield of the complementary crop. With slower-growing tree species – such as areas afforested with domestic oaks, where the row spacing is at least three meters – it is possible to apply a form of intermediate cultivation adapted to the given area for up to three growing seasons. Nineteenth-century documents attest that intermediate crops were used in the same field for up to five consecutive years (Miklós 1974). Research results in Hungary and other countries demonstrate that this form of agroforestry affects the microclimate of young forest stock. It helps tree seedlings survive during the initial, critical years, develops healthy and more resilient young forests, and, thus, supports the climate adaptation process in the forestry sector (Dalland et al. 1993, Quinkenstein et al. 2009, Nair 2013, Vityi et al. 2016, Vityi – Kovács 2018; Kovács et al. 2019, Xu et al. 2019).

One of the biggest disadvantages of the technology is the limited possibilities for mechanization, which can even deter entrepreneurial farmers from applying it. The selection of crop components is based on the forest site type of the forest area, the purpose of utilization, and the forest site characteristics. Even if these factors narrow the range of cultivable crops, the system to be developed will at the same time compensate for this by adapting to the climate. Temperate areas are in a more difficult position than warmer zones when it comes to choosing plant combinations because the environmental effects of warmer regions allow for a larger number of species and variety choices (e.g. non-frost sensitive species); therefore, agroforestry systems are much more diverse there. In the flat regions of Central Europe, the main tree species combined with agricultural crops are poplar (*Populus spp.*), black locust, (*Robinia pseudoacacia L.*) and in some cases oak (*Quercus spp.*) (Eichhorn et al. 2016, Paris – Dalla Valle 2017, Paris et al. 2018, Kay et al. 2019).

1.5 Purpose of the research

Intercropping is currently used for reforestation in the territories of several forestry enterprises in Hungary. The experience gained so far is related to the increase in the effectiveness of reforestation, the improvement of the health status and survival rate of the seedlings, and the observation of some other positive effects, which were explained by the presence of the crop. However, no research explaining such favorable experiences has been completed in Hungary to date, and only a few results related to the topic – focusing mostly on soil improvement aspects – can be found in the international literature. Therefore, the main goal of this research is to examine what environmental changes occur in a forest system combined with intercropping and which factors may play a role in these changes. The studies focused primarily on measuring changes in the microclimate of the system. The research examined the following hypotheses:

i) due to the higher vegetation cover, the agroforestry system (AF) reduces air temperature and soil temperature extremes compared to the control area of non-intercropped trees (CO);

ii) the intermediate crop increases the surface roughness, which significantly modifies the wind speed;

iii) the agroforestry system (AF) produces better soil moisture indices in the upper 10 cm of the soil and

iv) a more ideal humidity in the agroforestry system (AF) is likely due to the larger assimilating surface.

We have taken measurements in two locations in Hungary thus far – at Hajdúhadház (eastern Hungary, Great Hungarian Plain) and Kapuvár (western Hungary, Little Hungarian Plain). Preliminary experiments at Hajdúhadház Forest Management Unit served as the basis of the ongoing experiments at Kapuvár Forest Management Unit. This paper presents the portion of the research methods and results related to the microclimate studies completed at Kapuvár in 2020.

2 MATERIALS AND METHODS

2.1 Design of experimental area

Picture 1. Poplar alley cropping system at Kapuvár in 2020 (Klaudia Kovács)

The Kapuvári Forest Management Unit of Kisalföldi Erdőgazdaság Zrt. provided the possibilities for further field investigations planned by expanding the range of previously applied test methods. The new study area was established in 2020. *Table 1* shows the parameters for the AF and CO systems. Hybrid poplar long cuttings (2 m) with bare root (*Populus × euramericana cv. I-214*) were planted with a distance of two meters between stems and a row spacing of four meters. Maize was used as intercrop since it has been used for decades in poplar afforestation in Hungary. P9241 Optimum® AQUAmax® - FAO 340 maize hybrid was sown in four rows with a row spacing of 75 cm in the hybrid poplar plantation (*Picture 1*, *Figure 1*). This variety tolerates extreme weather effects and has a good yield and fast water release, ensuring quicker harvesting (keeping game damage prevention in mind). In order to achieve a good yield, the areas are selected each year to develop an agroforestry system that is unflooded at any time of the year.

Two adjacent areas were selected for the design of the mixed system and control system. The site characteristic similarities of the two plots were expected based on the comparison of the documents describing the forest subcompartment. However, the size of the area made soil sampling necessary, which may indicate possible inhomogeneity or any imparity in the soil. Sub-sampling points were selected in each plot along the diagonals where aggregate samples were made from the upper 15 cm layers of the soil. Each aggregate sample weighed 0.5 kg taken from a minimum of 20 sampling points. In addition, spot samples were taken at 3-3 points from a depth of 60 cm. In the laboratory test pH (H_2O) and pH (KCl), liquid limit (KA), total carbonate content ($CaCO_3$%), fine organic matter content (%), easily soluble phosphorus (P_2O_5 mg / 100 g) and potassium (K_2O mg / 100 g) were determined (90/2008. (VII. 18.) FVM regulation). Mechanical weed control was applied in both parcels in addition to the use of a brush cutter in the tree rows and two times harrowing in the control plot in early spring.

Table 1. The main features of the experimental area

Main features	Agroforestry	Control
Köppen-Geiger climate classification	Cfb	Cfb
Hydrology	Wet until surface	Wet until surface
Type of soil	Flat bog	Flat bog
Surface soil	Moderately deep	Moderately deep
Tree species	Hybrid poplar	Hybrid poplar
Coordinates	47°41’33.0”N, 17°02’06.0” E	47°41’32.4”N, 17°02’0.4.0”E
Forest subcomponent	Kapuvár 21 /C2	Kapuvár 21 /C2
Forestry region	Fertő-Hanság basin	Fertő-Hanság basin
Natura 2000	Not included	Not included
Owner	Hungarian State	Hungarian State
Primer function	Wood producer	Wood producer
Next forest management plan	2026	2026
Type of protection	No	No
Fire risk	Low	Low
Area	~1,0 ha	~1,0 ha
Cultivation	hybrid poplar, corn	hybrid poplar
Number of cutting	1320 pieces/hectare	1320 pieces/hectare
Sowing density	~80 000 seed/hectare	-
Distance of rows (cm)	~90 -75-75-75- ~90	400
Planting distance (cm)	200	200
Tree rows orientation	northwestern-southeastern	northwestern-southeastern
Gradient	plain	Plain
Irrigation	Drainage canal	Drainage canal
Game control	Wildlife fence	Wildlife fence
Plant protection	-	-
Period	1 year	1 year

[*] C- warm temperature, f-fully humid, b- warm summer

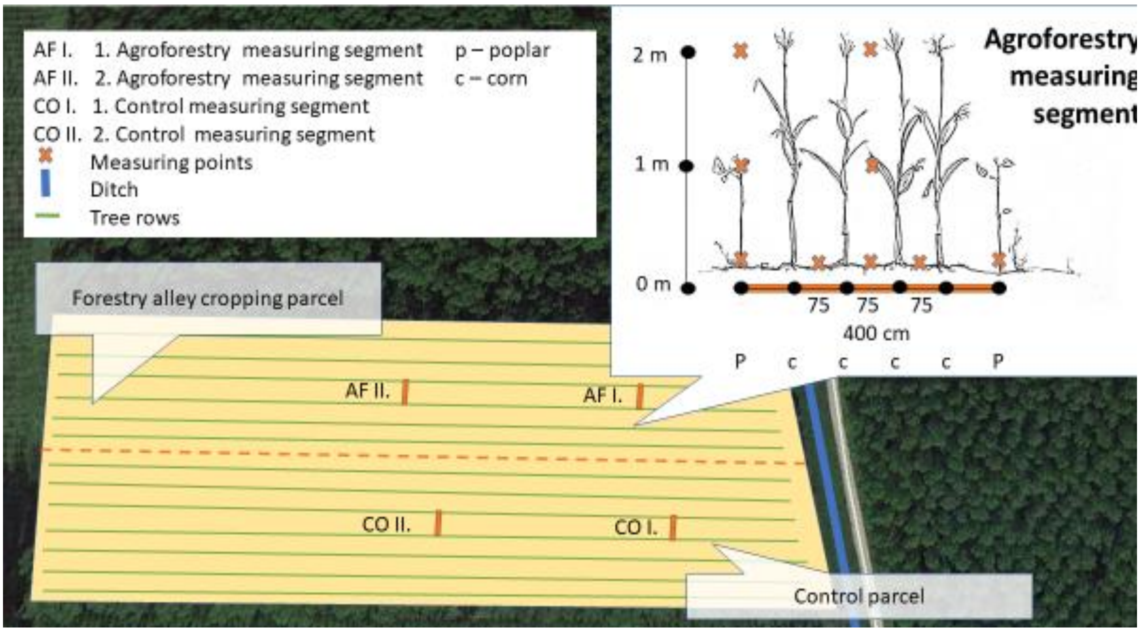

Figure 1. Experimental plot

2.2 Microclimate survey

Soil temperature, soil conductivity, air temperature (registered locally by the forest company), and air humidity (provided by the meteorological station at Andau, Austria, located within 15 km) were measured in July and August 2020. According to the results of domestic climate research, these two months are the most physiologically critical within the main growth period (May–August) (Bihari et al. 2018, Führer 2018). Table 3 lists the devices used for the measurements and the number of sampling points. We selected 2–2 measurement sections per plot (*Table 2.*) to model the cross-section (segments) of the areas. This is similar to the arrangement used in domestic and foreign experiments in shelterbelt and alley cropping systems (Danszky 1972, Singh et al. 1989). In this way, the study design included repetitions; however, the number of sections was limited as mobile instruments do not allow simultaneous measurements. To reduce the risk of measurement errors caused by rapid weather changes, the daily duration of the measurement should also be kept to a minimum. For this reason, the maximum measurement time interval was set at 2 hours. Measurements were made between 12 p.m. and 2 p.m., as the temperature is highest between 12 p.m. and 3 p.m. due to the strong radiation from the sun in this early afternoon period (Daut et al. 2012, Stefan – Iain 2016). Microclimatic parameters were measured every two days unless a major precipitation event prevented the measurements. These sorts of events affected 17% of the pre-planned measurement times.

Measurement of soil conductivity was made to compare the agroforestry (AF) and the control (CO) plots in terms of soil moisture. According to Hungarian and international research results, there is a close correlation between the electrical conductivity of the soil and the soil moisture content, provided that the site conditions are similar (*Figure 2*) (Bai et al. 2013, Milics et al. 2017).

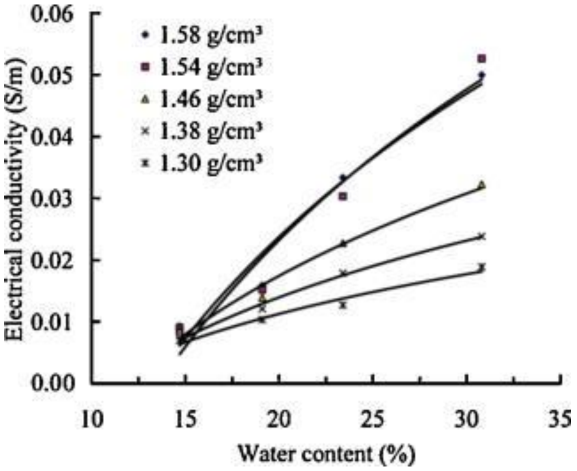

Figure 2. The relationship between electrical conductivity and water content of soil according to soil density (Bai et al. 2013)

Table 2. Features of examined parameters in 2020

Parameters	Soil temperature	Electrical conductivity	Air temperature	Air humidity
Period	Jul. 01-Aug. 30. (2020)	Jul. 01-Aug. 30. (2020)	Jul. 01-Aug. 30. (2020)	Jul. 01-Aug. 30. (2020)
Measuring	2 segments/parcel	2 segments/parcel	2 segments/parcel	2 segments/parcel
Plot	5 points/ segment	5 points/ segment	2 points/ segment	2 points/ segment

The 2-2 measurement sections were placed in the plots mirror-symmetrically to exclude the edge effect (*Figure 1*). In each measurement section, five sampling points were selected on an imaginary line perpendicular to the rows of trees connecting two poplar trees planted opposite each other, (2 points) and in the lane between the rows of trees (3 points) at equal distances from each other. Soil temperature and soil conductivity were measured at two depths (0 and 10 cm) per point. At the same sampling points, air temperature and humidity were also detected on the ground surface and, using a measuring rod, at heights of 1 m and 2 m. The wind speed was measured at 2 m and in the same orientation. The above parameters were performed with the instruments detailed in *Table 3*.

Table 3. Features of the devices used for the experiment in 2020

Name	Hanna HI 98331		KESTREL 3000		
Company	Hanna Instruments Inc.		Nielsen-Kellerman		
Country	US		US		
Parameter	Soil temperature	Soil conductivity	Air temperature	Wind speed	Relative humidity
Accuracy	0.1 °C	0.01 mS/cm	0.1 °C	0.1 m/s	0.1 % RH
Range	0.0 to 50.0 ºC	0.00 to 4.00 mS/cm	-29.0 to 70.0 °C	0.0 to 40.0 m/s	5 to 95% 25°C non-condensing

2.3 Data analysis

The microclimate data were analyzed by using main effects ANOVA after logarithmic transformation of those variables that violated the normality assumption. A one-way ANOVA was applied for the data of soil temperature, soil conductivity, and wind speed. A two-way

ANOVA was used for the data of air temperature and conductivity in each of the three studied layers (soil surface, 100 and 200 cm above soil surface). The main experimental factors are chosen Cultivation System (CS) (with AF and CO thesis) and Alley Position (AP) (with tree intra-row and tree inter-row). As a result, we get the impact of different parameters, including the interaction of the Cultivation System (CS) and Alley Position (AP). We used TIBCO Statistica ™ version 13 for statistical analysis. Statistical samples are the results of microclimate measurements of the same dependent variable on two independent groups (agroforestry and control area). The means of the obtained variable were compared. Statistical samples were taken from a normally distributed population, so the dependent (studied) variables were continuous. By statistical evaluation of the microclimate result, we can determine whether there is a significant relationship between the agroforestry plot and the control plot.

3 RESULTS

3.1 Soil test results

Despite being adjacent, flat areas are managed similarly. Contrary to the information included in the forest subcompartment description sheets, the soil test results show that the mixed stand and afforestation without crop have different site conditions showing a more favorable control area in terms of humus, phosphorus and potassium content but similar in terms of soil texture, pH and $CaCO_3$ content (*Table 4*), which may explain the changes in soil conductivity values.

Table 4. Soil characteristics of the experimental parcels

Item	Depth of layer (cm)	pH H_2O	pH KCl	$CaCO_3$ (%)	Hygroscopy (hy%)	(KA %) ^{A}	humus (%) ^{B}	P_2O_5 ^{C} (mg/100g)	K_2O ^{D} (mg/100)
AF	30-60	8.0	7.8	32.1	1.1	48.5	0.7	0.8	14.9
CO	30-60	7.9	7.7	31.8	1.2	51.0	0.9	1.0	7.8
AF	0-30	7.5	7.2	16.4	3.6	63.8	7.2	4.0	20.5
CO	0-30	7.3	6.9	15.1	5.1	70.8	13.3	12.4	41.1

A: Upper limit of plasticity according to Arany, B: Fine organic matter content, C: Easily soluble P, D: Easily soluble K

3.2 Result of the microclimate test

3.2.1 Soil temperature

The soil temperature results confirmed the hypothesis based on previous observations and measurements; lower soil temperatures are expected in mixed crops due to cover (Mohammad et al. 2018) (*Figure 3*).

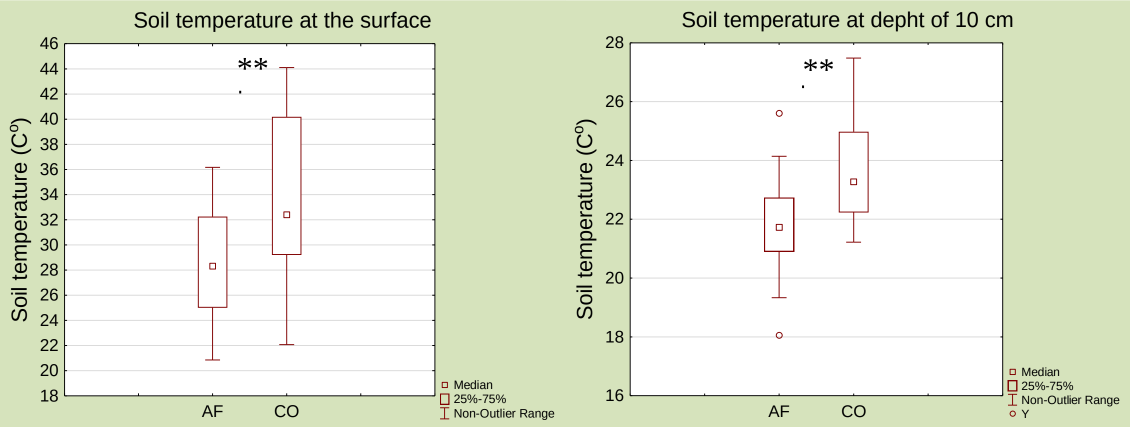

Figure 3. Soil temperature at the surface and depth of 10 cm in 2020 (AF - Average values from agroforestry measuring segment, CO - Average values from control measuring segment, n=200 observation, *significance level:**p≤0.01)*

The soil temperature values of the agroforestry system are significantly lower compared to the control area, both at the soil surface and at a depth of 10 cm. The data also show that the soil temperature at a depth of 10 cm reflects sudden changes in air temperature with smaller fluctuations (F = 24.88, p ≤0.01; *Figure 3*). Soil surface temperature data for the agroforestry area provided more favorable values (F = 14.94, p ≤ 0.01; Fig. 3) even when compared to values measured at a depth of 10 cm in the control area. The difference between the two examined soil depths was on average 8 °C in the case of the mixed system and 10 °C in the control area. If the comparison is made for the same soil depths and by comparing the two different systems, a difference of 1–14 °C in the soil surface temperature and 5 °C in the 10 cm depth can be found.

3.2.2 Electrical conductivity (EC)

Figure 4 shows that the control system produced higher values by 0.1 mS/cm on average. During data evaluation, a significant difference was observed between AF and CO systems (F = 11.61, p ≤0.01; *Figure 4*). In the case of the same site conditions, this would suggest that the control area has more favorable soil moisture conditions. However, the different soil properties of the two plots make the interpretation of the obtained values practically impossible due to the many interrelated factors.

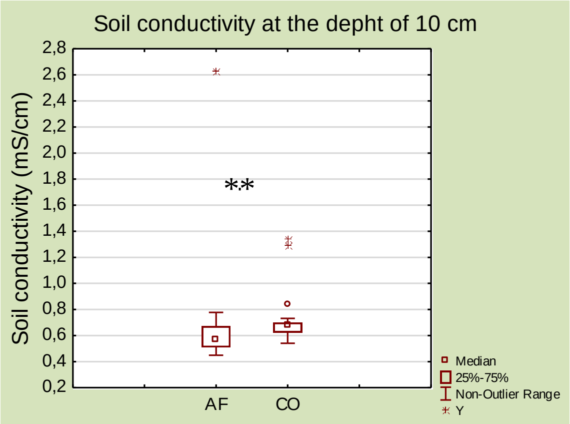

*Figure 4. Electrical conductivity at a depth of 10 cm in 2020 (AF - Average values from agroforestry are measuring segment, CO - Average values from control measuring segment, n=200, significance level:**p<0.01)*

3.2.3 Air temperature and humidity

We observed that the mean atmospheric temperature differences decreased for the two plots as we moved away from the soil surface, but a non-significant difference between the values of the two areas was observed. Regarding humidity, higher values were detected in the AF system, but these were non-significant, even in the case of pairwise comparison of the tree rows and of raw spacings of the different treatments (AF vs. CO). The results of the wind speed measurement showed that the crop vegetation reduced the turbulent exchange of air even at the height of 2 m (*Figure 5*). As air movement decreases, higher humidity develops under the canopy, so the vegetation evaporates less intensively, which improves the water management of the system.

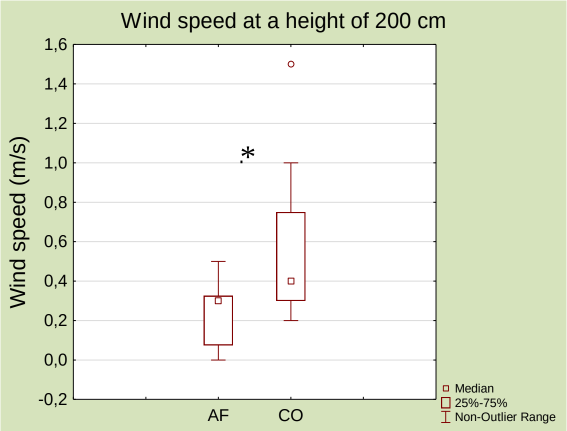

*Figure 5. Wind speed in 2020 (AF – Agroforestry system values, CO – Control system values, n=80, significance level: *p<0.05)*

The distribution of visually observed crop cover is also in line with the above results, which influences the degree of moisture retention, i.e. the higher degree of cover (AF I.) resulted in higher humidity than in the plot with lower plant density (AF II.). Higher vegetation density and the associated higher humidity reduce the local impact of atmospheric drought where, due to the high temperature and low humidity, the potential evaporation increases to such an extent that the vegetation is unable to increase evaporation adequately even if sufficient water is available in the soil. Two-way ANOVA analysis (*Table 5*), cultivation system (CS), alley position (AP), and their interactions (CS x AP) as fixed effects showed that the impact of different treatments on air temperatures was not significant, and the effects on air humidity were similar than on the values of the air temperature (*Figure 6*).

Table 5. Results of two-way ANOVA analysis for the effects of Cultivation Systems (CS) and Alley Position (AP) on the measured parameter

Air temperature	CS		AP		CS x AP	
	F	p	F	p	F	p
surface	1.547^{ns}	0.217	0.065^{ns}	0.799	0.770^{ns}	0.383
1.00 m	1.126^{ns}	0.292	0.000^{ns}	0.989	0.216^{ns}	0.643
2.00 m	0.541^{ns}	0.464	0.002^{ns}	0.965	0.247^{ns}	0.621
Air humidity	**CS**		**AP**		**CS x AP**	
	F	p	F	p	F	p
surface	0.041^{ns}	0.839	2.835^{ns}	0.096	0.585^{ns}	0.447
1.00 m	0.006^{ns}	0.940	1.554^{ns}	0.216	0.416^{ns}	0.521
2.00 m	0.006^{ns}	0.940	1.112^{ns}	0.295	0.019^{ns}	0.892

ns: non-significant

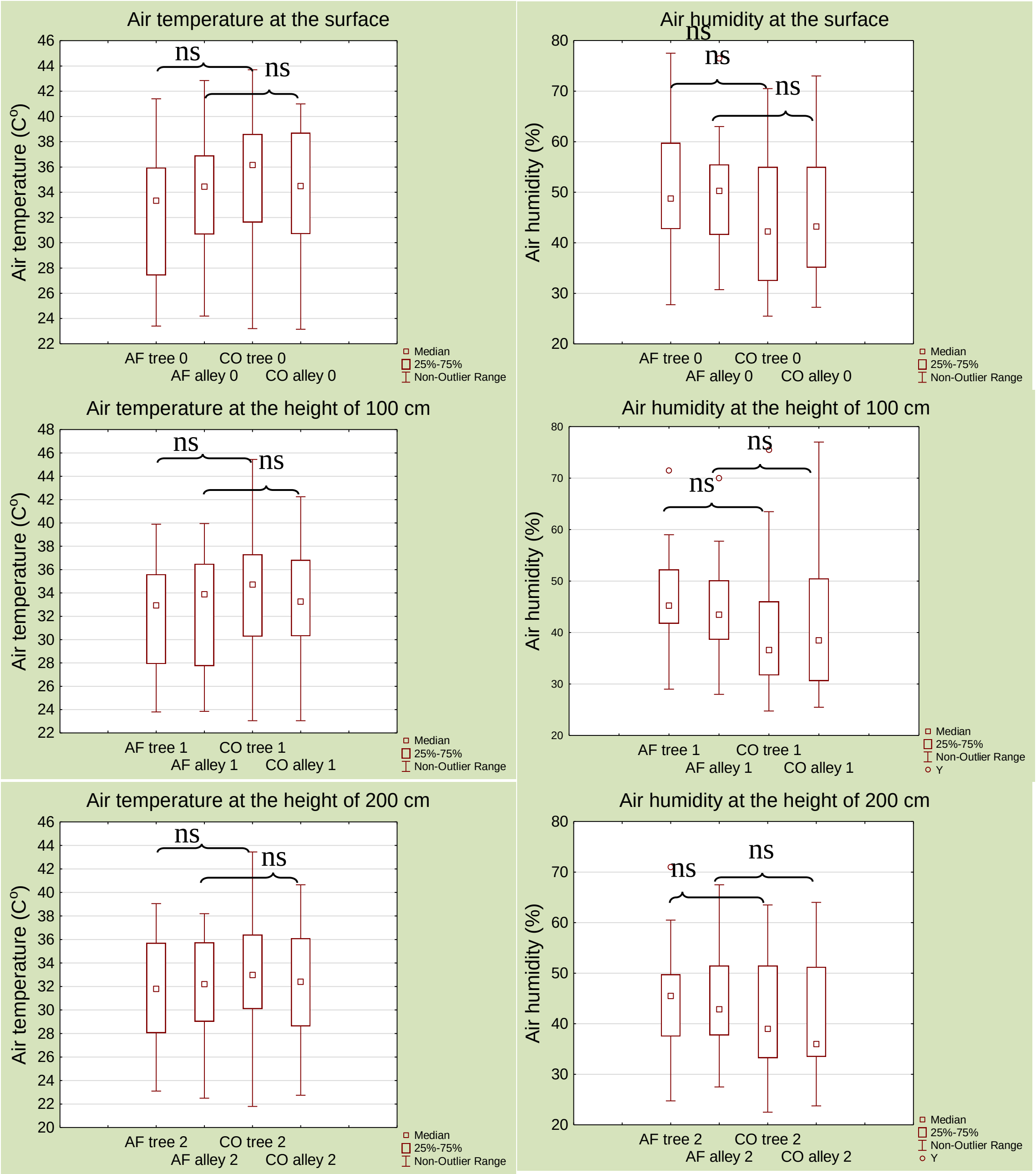

Figure 6. Air temperature and humidity values in 2020 (AF alley - Agroforestry segment values from alley, AF tree - Agroforestry segment values from tree row, CO alley - Control segment values from alley, CO tree - Control segment values from tree row, n=40, significance level: ns: non-significant)

4 DISCUSSION

Agroforestry management is more complex than the management of afforestation or homogeneous agricultural crops due to the deliberate association of several plant species. As the complexity increases, the system of processes and effects also becomes more complicated, making it more challenging to isolate the factors that influence the values measured during field studies. Therefore, this study was designed to keep the degrees of freedom to the minimum as far as possible to ensure similar soil management and water supply, use of the same tree species and tree planting structure, and chemical-free cultivation in both the intercropped and the control area.

The AF system showed statistical significance at $p \leq 0.05$ in terms of the soil temperature at the surface and 10 cm below the surface compared to the control plot. Furthermore, differences have been found in terms of air temperature and humidity between for the benefit of the intercropped area. The more favorable air temperature values of the agroforestry system have a remarkable effect on plant development because they act as a catalyst for many biological processes, influencing soil moisture content, aeration, and plant nutrient availability (Müller et al. 2016, Onwuka – Mang 2018). Even a few degrees of variation can significantly modify biomass yields (Luo et al. 2020), or the germination rate may be reduced due to high soil temperatures (Huang et al. 2008). Consequently, even a small change can have a serious impact on the development of the forest stock because extremely high temperatures can affect agricultural crops and woody vegetation (Petzold et al. 2011).

In addition, a significant difference was found in terms of soil and plant water regimes. The authors observed that even at the height of 2 m, the crop between the tree rows contributed to wind speed reduction, which makes it likely that water utilization was more efficient in this part of the area. Although rainfall interception is higher in the AF system due to the higher vegetation density, the vegetation absorbs the precipitation from heavy rain better; therefore, the rate of infiltration into the soil is also better. The importance of this function may grow in the future due to the expected increase in extreme precipitation events due to climate change (Semmler – Jacob 2004). These positive effects improve the water balance, reduce the probability of atmospheric drought, and improve system performance. The differences in the experimental area – discovered in parallel with the microclimate studies – cause uncertainties in the evaluation of the results of the conductivity measurements and, thus, in the determination of the effect of the land use practice on the soil moisture content; therefore it is not possible to draw sufficiently substantiated conclusions in this respect. Thus, the authors aim to perform further, additional studies in the future for the comparative study of soil moisture.

5 CONCLUSIONS

In summary, we conclude that soil temperature and wind speed showed significantly favorable values in the intercropped forest plantation compared to sole tree vegetation. To analyze the impact of the intercropping systems on the water management of the forest stock, we plan further studies and supplement the range of the studied parameters and test methods.

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