Volume 11 No 1 2019

Regional and Business Studies

ISSN 2061-2311

Kaposvár University
Faculty of Economic Science
Kaposvár

Regional and Business Studies

Regional and Business Studies is a scientific journal published several times a year, and contains original scientific reports, research results, critical résumés, conference reviews and letters to the editor. The topics of journal include the important fields of rural development, regional, economic- and social science.

Volume 11 No 1 2019

Regional and Business Studies

ISSN 2061-2311

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ISSN 2061-2311

Published and distributed by
Kaposvár University, Faculty of Economic Science
H-7400 Kaposvár, Guba Sándor u. 40.
Printed by Centrál Press 99 Nyomda, 50 copies produced

Responsible for publication

Dr. Orsolya SZIGETI PhD
Dean of Faculty

Kaposvár, November 2019

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Regional and Business Studies (2019) Vol 11 No 1, 1-6
Kaposvár University, Faculty of Economic Science, Kaposvár
doi: 10.33568/rbs.2393

CALL FOR ACTION FOR A HEALTHIER PLANET INTRODUCING AGROFORESTRY

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ABSTRACT

Agroforestry is a key element amongst the tools fighting today's challenges, such as environmental issues, climate change, food safety and food security. It is a common agricultural practice in many countries of the developing world, whereas it has nearly faded away in most of the world's developed countries. In the past 40 years of agroforestry research it has been clarified that the role of trees in the landscape as well as in the farm scale is essential to maintain a healthy environment and it can be an economically viable practice in the long term, given careful planning. These complex agricultural systems address several Sustainable Development Goals, offer countless ecosystem services and are expected to get more attention and role in the future of world's agriculture. In the European Union, the Common Agricultural Policy firstly had played a negative effect on trees in the land, as it had encouraged farmers to eliminate them in order to qualify for subsidies, until in the last call it was encouraging farmers by subsidizing the establishment of agroforestry systems. Today's task is to reserve agroforestry systems which have remained (e.g., wood pastures, shelterbelts); conduct research to answer ecological, economical and management questions; establish demonstartion sites and disseminate knowledge on agroforestry systems. The Monpellier Declaration calls all stakeholders for action.
Keywords: agroforestry, trees outside forests, sustainable land use, climate change, Hungary

INTRODUCTION

Agricultural deserts or thriving landscapes?

Visualize a desert – sandy, rocky landscape, where are not many creatures living– hard to picture a life, especially for someone who was born in Europe. Now imagine a landscape, let it be Europe this time, in Hungary. An undelating area, no trees, no bushes, no roads, no buildings, only bright brownish bare soil stretched out till the horizon, exposed to the forces of nature, exposed to erosion and deflation, land degradation. We can call it cultural, or agricultural desert. Just like the natural desert, it also barely sustains life, but unlike the desert, it could be managed as a thriving ecosystem. It is our decision, our responsibility. It is our duty to manage our landcapes by applying the best of knowledge, and we do know that vanishing everything other than that one sole crop, working against life supporting natural processes (regeneration, succession) is not the sustainable way. We need healthy food, but grown in healthy landscapes, we need diversity, habitats and all of that we call ecosystem services.

Agroforestry is an example of a more sustainable land use, and it is a key element amongst the tools fighting today's challenges, such as environmental issues, climate change, food safety and food security. In the past 40 years of agroforestry research it was clarified that the role of trees in the landscape as well as in the farm scale was essential to maintain a healthy environment and it can be an economically viable practice in the long term, given careful planning.

DISCUSSION

Agroforestry

Agroforestry means deliberate integration of woody perennials with crop production and/or animal husbandry for ecological and economical benefits. (*Figure 1.)*

It is a common agricultural practice in many countries of the developing world, whereas it has nearly faded away in most of the world's developed countries. One main reason globally is industrialized farming, where the goal is to acquire the highest yields with the highest profit possible, where trees are often seemed as obstacles of efficient machinery work. In the case of Hungary and Europe the Common Agricultural Policy added to this trend by encouraging farmers to eliminate the trees and shrubs on farms in order to qualify for maximum subsidies (SAPS – Single Area Payment Scheme).

Figure 1.

Alley cropping – a type of agroforestry – experimental site at NARIC in Hungary. Hybrid poplars intercropped with triticale

Some positive changes started in the last decade, and today agroforestry appears amongst the CAP where farmers can apply for subsidy for establishing agroforestry systems. This is the result of over 40 years of work of agroforestry scientists, and there is no doubt that climate change issues also highlight the importance of forests, trees, and agroforestry, amongst decision makers, politicians and even some farmers. We know that there is need to transform the farming systems, and we also know that the transition itself is costly. Therefore the outcome of the last Agroforestry Congress was a call for action (*Table 1*) for all stakeholders, phrased in the *Montpellier Declaration* (*WCAS*, 2019).

Table 1.

Some key elements of the Montpellier Declaration, which calls on different stakeholders to urge agroforestry transition

<table>
<tr><th>Who?</th><th>What to do?</th></tr>
<tr><td>Political decision-makers</td><td rowspan="2">engage in the process of deep transformation
accelerate transition, encourage the widespread adoption of agroforestry through leadership, education and finance</td></tr>
<tr><td rowspan="2">Private sector, financial and business leaders</td></tr>
<tr><td>develop financial and investment models to mobilize the capital resources necessary for the transformation of agricultural systems around the world to agroforestry</td></tr>
<tr><td>Leaders of research institutions</td><td>prioritize the ongoing refinement of high-performance agroforestry systems appropriate to all farm sizes, climatic zones and income levels</td></tr>
<tr><td rowspan="2">Researchers</td><td>publication, call for action</td></tr>
<tr><td rowspan="2">collaborate, implement research results in the field, establish pilot farms, demonstration sites</td></tr>
<tr><td rowspan="2">Farmers, agroforestry networks</td></tr>
<tr><td>advisory, mentoring – farmers most effectively learn from each other</td></tr>
</table>

Current state of Agroforestry – The 4th World Congress

It was the first time that the world congress on agroforestry systems was held in Europe. The 4th World Congress took place in Montpellier, France, in May 2019, following the congresses in the USA (2004), Kenya (2009) and India (2014). More than 1200 attendees were present from all around the world, from Indonesia to Colombia. The expenses of those 150 young researchers who arrived from developing countries was funded by the congress itself.

The aim of the congress was to contribute to advance agroforestry research, and build a bridge between science, society and politics. In the plenary sessions and more than 20 parallel sessions several popular and some under-represented topics were discussed, divided into four main categories: agroforestry and the world challenges, adoption of agroforestry, specific agroforestry systems and the biophysics of agroforestry. To mention a few of these topics: climate change, biodiversity, genetics, agroecology, land degradation and desertification in dry areas, social issues, businesses and finance, public policies, landscapes, modelling, mapping, practice, urban agroforestry, etc. There was also a section dedicated to the European Agroforestry Innovation Network (AFINET) and other themes which did not fit into the planned sections, but the topic of wood and wildlife management was not really presented. Altogether more than 300 presentations and 600 posters were presented in the congress. Looking at the participant list, it is visible that not only the number of researchers, but the number of state and business representatives was also remarkable, meaning that interest in agroforestry is growing. It is also worth mentioning that the International Union of Agroforestry (IUAF) has just been launched. The message of the congress was eventually summarized in the Montpellier Declaration.

Montpellier Declaration

The choice of the location of the world congress has its own message: Europe has joined the worldwide movement of agroforestry. Although agroforestry research started 20 years ago in Europe (40 years ago in the tropics), the awarness and acknowledgement of the scientific field between agricultural professionals, politicians and in the society had been awaited until the past few years in the old continent. While in the developing countries agroforestry systems thrive up to date due mainly to economic drawbacks, the developed countries are slowly sobering of environmental destruction and start to understand the benefits of land management combined with woody vegetations. The timing of the world congress was also a good choice considering that this was the time of forming the new CAP for the following period 2021-2027. A lot of organizations represented at the congress are lobbying and pushing agroforestry to gain more relevance – financially, professionally, and morally – and to get support for agroforestry systems. Thanks to the scientific work there is a vast amount of knowledge available in the field, yet there are still many questions to be answered, from good companion crops to financial matters, which need to be answered according to the actual configuration (site location, soil type, farmer, etc.) of the farm (*Honfy and Keserű*, 2019). The declaration calls for the research institutions to prioritize research on highly productive agroforestry systems in all climatic zones, all farm sizes and income levels. Due to the complexity of the topic exemplary cooperation is needed between different sectors to make sure that this sustainable land use system thrives again in farming practices and appear in the landscapes of developed countries, and also to make sure that it will be a living practice in developing countries just as it is today. Good examples and demonstration sites are necessities. It is one of the responsibilities of researchers that the message reaches the public, and eventually the research results are utilized on the farms. To apply agroforestry practices, mentoring, advisory and farmers' networks play a crucial role.

The participants of the congress agreed that inappropriate farming practices highly contribute to the severe loss of biodiversity reported by IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services). Agroforestry systems can contribute to treat this phenomenon, while sustaining food security.

Agroforestry systems are usually profitable practices. What is costly, is the agroforestry transition itself. This transformation takes time and requires support. Therefore the declaration calls on decision makers – the public as well as the private sector –, business and financial leaders, and leading research institutions, private leadership, education and finance for the transition, to accelerate the adoption of agroforestry systems. The participants of the congress urge these stakeholders to deeply engage in the process, and calls on to promote the benefits of agroforestry amongst the world's landowners and land managers. Furthermore, they encourage the private sector to work out financial and investment models, which ensure capital for agricultural transition towards agroforestry worldwide.

The message is clear: „Make our planet treed again!" by planting the appropriate tree to the proper place.

CONCLUSION

Crop production, orchards, animal husbandry and forestry – all exposed to extreme meteorological events – are now facing even more challenges, including climate change and the continuously growing pressure from the society. Climate change mitigation and adaptation techniques now direct more attention to forests and trees outside forests, and to the important role of trees.

There are several reasons why it is worth considering seriously the diversification of the farm or land by introducing trees, either by farmers, communities, or municipalities. Agroforestry has become a movement. The 40 years of research, and politics seeking for solutions for global challenges seem to meet eventually at a point. (*Honfy et al.,* 2019)

Today's task is to reserve agroforestry systems which have remained (e.g., wood pastures, shelterbelts); conduct research to answer ecological, economic and management questions; establish demonstration sites and disseminate knowledge on agroforestry systems. Eventually we need to work on the enabling atmosphere where farmers are encouraged to implement agroforestry systems, for a healthier living planet.

ACKNOWLEDGEMENTS

The publication of this paper is supported by the EFOP-3.6.2-16-2017-00018 "Produce together with the nature – agroforestry as a new outbreaking possibility" project.

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Regional and Business Studies (2019) Vol 11 No 1, 7-11
Kaposvár University, Faculty of Economic Science, Kaposvár
doi: 10.33568/rbs.2401

SYSTEMATIC AND SIMPLE COST-BENEFIT INVESTIGATION OF SOME ADVANTAGES OF THE REGENERATIVE AGRICULTURE

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ABSTRACT

Regenerative agriculture aims to stop soil degradation with some systematic steps of advantageous treatments i.e. no-till, using crop covers, etc. It is considered as one of the best candidates to capture anthropogenic CO2 from the atmosphere via natural carbon cycle of plants. However, its measure is not certain yet and it is a bone of contention now. But this method has some other useful consequences as well. We try to calculate their fiscal advantages.
Keywords: soil degradation, climate changes, cost-benefit, regenerative agriculture

INTRODUCTION

Hungary is situated in the temperate climatic zone, its climate and weather are significantly affected by the climate change. One of the most important economical fields, agriculture is largely subjected to the changes in the climate. Not only climate change itself influences adversely the agricultural production but the harmful effects caused by the industrial agriculture in the soil, therefore soil as a natural resource is in danger due to the climate change and intensive tillage as well. Agriculture has to adapt to these new challenges.

There are only few good practices existing, however one of them, so-called regenerative agriculture is a promising medicine for the above mentioned problems. There has been a robust debate recently on this method's ability to sequester carbon-dioxide from the atmosphere, but the other positive effects, which are indisputable, have not been investigated from the point of view of a simple cost-benefit analysis. In this paper some aspects of this question are investigated.

DETAILED RISKS IN CROP PRODUCTION

Changes in weather due to the climate change

In Hungary, thanks to the stability of the climate, there has been a crop production system which considered the order of seasons, the uniform distribution of precipitation as standard. Due to the past stability of these circumstances the present challenges and the relatively fast emergence of present weather anomalies, the crop production has not been able to adapt to the new circumstances. It was pointed out (*Hetesi and Kiss*, 2017) that the average temperature in Hungary had increased significantly (and exceeded the linear increase) and the number of extreme weather events had increased as well. E.g. there is significant increase in the daily precipitation in a concrete geographic coordinate or the number of days when average temperature exceeds 30 C ° has increased significantly as well.

These phenomena mean that agriculture has to prepare for higher average temperatures in the future and to more extremity as well.

Soil degradation

The formation of soil is a slow process unlike the harmful effects of cultivation, the speed of the latter processes can be larger with one or two orders of magnitude in many cases. The FAO Report (2015) on the soils declares the soil degradation as one of the most urgent challenges we have been facing with. The crop cultivation machinery's contribution to soil degradation is significant. There is a historical example of this effect, the so called Dust Bowl in the 1930's on the Great Prairie, USA. Dust Bowl is the collective noun of those dust storms which was caused by the extremely drought and the incorrect cultivation practice used on the Prairie's fields (*Young et al.*, 2015).

Recently the most common way of cultivation is ploughing, which contributes to the decrease of the humus content of soil. It was also observed if regenerative agriculture had been used and then terminated and the filed was ploughed again, the organic matter growth due to the regenerative cultivation diminished by setting back ploughing (*Yang et al.*, 2008).

There is a further problem emerging due to ploughing, the so called plough pan phenomenon, which is formed by the weight of the plough itself and makes up a tight compact layer below the ploughed layer. This layer is not permeable either for most of the roots or water.

It means that the upper 25 to 35 cm layer of the soil has to receive and store the precipitation. Recently the precipitation can be extreme and the upper soil is not capable of storing the whole quantity of it (the cultivation also reduces the number of pores in the soil).

A GOOD PRACTICE: REGENERATIVE AGRICULTURE

There is a good practice, recently emerging, which may handle these problems adequately (degradation of soil, harmful effect of extreme weather events). The major elements of this practice are the lack of tillage or minimal tillage, a good crop rotation, and cover crops after the crop year of the main plant, e.g. corn, wheat or soybean.
In natural systems the best soil can be found in the forest or on the prairie. On a bare soil the first step of the successive ecological level is the occurrence of pioneer plants (referred to as „weeds" in everyday speech). After them scrubs and later trees occur, meanwhile there is a strong interaction between roots and soil bacteria and later fungi to produce more humus and increase the organic matter content of the soil.

The remnant of the organic matter creates a mulch layer on the topsoil and at the bottom of this layer the early signs of soil formation occur. This layer is called moder in forests and mull on steppes. Recent studies pointed out that soil formation is very active when living roots and active bacteria and fungi presence can be observed in the soil. Crop covering ensures the presence of living roots in the major part of the year (*Kallenbach et al*, 2016; *Sokol et al*, 2018).

It seems to be obvious from these that a healthy usage of soil has to mimic the natural system's run. The aforementioned four elements of this practice need some more explanation.

1. Lack of tillage: it can be achieved by direct seed planters which are able to sow into a mulch layer. On smaller farms it is also a viable way to cultivate the topsoil without ploughing in the absence of direct planters.
2. After the main commercial crop (e.g. soybean or wheat) one has to sow a special combination of crop cover plants. Special means that there are different soil types with different properties and therefore a unique mix of cover crops does not exist that uniformly acts in every situation. There are many different advantageous effects of cover crops which can be used in different cases, e.g. oat with its large root mass is suitable for sandy soils to block erosion, or nitrogen fixation with using bean family plants, using daikon radish to break through the plough pan etc.
3. Living roots in the soil: during the crop year it is realized but after harvesting the commercial crop bare soil remains. Crop covering ensures living roots in the soil in late autumn as well.
4. Soil coverage: crop cover plants freeze during winter and create an organic layer on the topsoil (this method is similar to the natural system's work). The sowing at spring happens into this layer.

With these elements several advantages of this practice can be observed, which are beneficial to handle extreme weather effects or adapt to the climate change and are also cost effective as well.

1. Porosity of the topsoil increases during the use of crop cover plants, the elimination of the plough pan is also beneficial, these two effects increase the water storage capacity of the topsoil. Therefore, the exposure to extreme precipitation decreases.
2. Crop cover plants are good devices in weed control. Due to their large mass, dense stands and shadow, they are effective to control the growth of weeds.
3. Artificial nutrition with fertilizer is needed especially in the transitional period. The increase in the soil life needs more nutrition. After the dispersion of the soil bacteria and fungi the nutrition opens up.

Systematic and cost advantages of regenerative agriculture

If we compare the conventional and regenerative agriculture, we can find some sound differences (*Table 1*).

If we want to determine the financial benefits of this technology and calculate costs wherever it is possible, we can construct another table (*Table 2*). The results are partly based on personal experiences in a small farmland, with a tractor of 80 HP used, cost data are from the NAIK (National Agricultural Reseach and Innovation centre Hungary)[1]

[1] https://agrarium7.hu/data/kepek/1000/eredeti/1435.jpg

Table 1

Systematic differences between agricultural systems

	Conventional	**Regenerative**
Water storage capacity	Porosity till 30 to 40 cm depth	Porosity till 40+ cm depth
Nr of tillages per year	5 or more	None (no till); 1-2 (minimal till)
Demand for chemicals	1 (= conventional as base)	0.2-0.5
Yield	1 (=conventional as base)	0.8-1.1

Table 2

Costs of steps in different agricultural systems

	Conventional		**No till**		**Minimum till**[2]	
Costs of cultivation	Ploughing	15 127 Ft	Direct sowing[3]	6 960 Ft[4]	Combinator	10 167
	Seedbed construction	6 059 Ft			Seedbed construction	6 059 Ft
	Stubble elimination	10 167 Ft				
Crop cover seed		0 Ft		25000 - 45 000 Ft		25000 - 45 000 Ft
Fertilizer usage	NPK	1	NPK	0.25	NPK	0.25
	N27	1	N27	0.50	N27	0.50
Pesticide usage	Weed control	1	Weed control	0.25	Weed control	0.25
	Other herbicides	1	Other herbicides	1	Other herbicides	1
Yield	1		0.9		0.9	

CONCLUSION

Regenerative agriculture can improve the soil's water storage capacity, using crop covers and no till together can help to prevent the formation of plough pan effect. Because of this, the soil is a better source of water even if there are extreme precipitation events.

Leaving behind ploughing, one can save fuel and let soil conserve its structure which is the base of further soil formation. True or not that this type of practice is able to increase the organic matter content of soil, it indisputably contains other attractive and cost-beneficial advantages.

[2] These are partly personal observations of the author using this method.
[3] Direct sowing is considered here as cultivation process.
[4] Estimated by corn planting. Corn seed planters are similar to direct seed planters.

ACKNOWLEDGEMENTS

The publication of this paper is supported by the EFOP-3.6.2-16-2017-00018 "Produce together with the nature – agroforestry as a new outbreaking possibility" project.

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Regional and Business Studies (2019) Vol 11 No 1, 13-19
Kaposvár University, Faculty of Economic Science, Kaposvár
doi: 10.33568/rbs.2402

RESULTS OF SOIL MICROCLIMATE RESEARCH IN FORESTRY INTERCROPPING SYSTEMS IN HUNGARY

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ABSTRACT

A special form of alley cropping system is the intercropping of forest, which is traditional and still used nowadays worldwide in afforestation. In Hungary this practice is used mostly on the non-protected areas of the Great Hungarian Plain. The aim of this study was to examine the extent to which intercropping modifies the development of seedlings compared to the current practice of reforestation. Measurements and observations have been proceeded in two trial sites: Hajdúhadház and Kapuvár, and in both cases, control areas were also designated, close to the trial site, with similar parameters. The experimental areas have different ecological features, but in both cases intermediate cultivation has been applied. The Hajdúhadház experimental area was established in 2015 and measurements were carried out until 2017, while in Kapuvár, the experiment started in 2019. At both sites, soil temperature, conductivity and growth parameter measurements were performed. The two examined areas are different regarding to tree species and plantation structure, but the main purposes of both forestry companies were to maximize the utilization of available space, protect seedlings and ensure the success of afforestation. The research results so far show that soil microclimate is more favourable in the intercropping system, which contributes to the better development of seedlings. By using maize as an intercrop in the alleys, fodder production for animal stock and game management was also feasible. Further investigations on yield and microclimate are planned in the area of Kapuvár Forest Office in the next three years.
Keywords*:* agroforestry, alley cropping, afforestation, maize, microclimate

INTRODUCTION

A special form of intercropping is still applied in artificial reforestations on non-protected forest areas in the Great Hungarian Plain and all over the world. (*Chamshama et al.*, 1992; *Kang et al.*, 1995; *Watson*, 2014; *Fan et al.*, 2006; *Haggar et al.*, 2003; *Muwamba et al.*, 2015; *Gichuru and Kang*, 1989; *Helton et al.*, 2010) As documented in Debrecen's municipality records dating back to the 1820's, forestry intercropping systems have a long history in sandy soil areas in eastern Hungary. (*Miklós*, 1974) These systems had a main purpose that afforestation was implemented at very low prices by poverty-stricken peasantry. They planted agricultural and horticultural plants between rows with the aim to ensure the cost of living. (*Balogh*, 1936) As these systems had lost their initial aim by now, thus the lifestyle ended even though the practice is pursued to apply in initial years of afforestation. According to observation, the forestry alley cropping systems would have a prosperous future. The experience shows the intercropping can improves the efficiency of artificial afforestation and allows maximum use of limited space. We carried out measurements in areas of two forestry companies to verify observations and provide scientific evidence of the success of young forest intercropping systems. This study addresses measurements and observations performed in two trial sites: Hajdúhadház in eastern Hungary and Kapuvár in north-western Hungary. Control areas with similar parameters were designated near the trial sites in both locations.

MATERIALS AND METHODS

Initial data for the systems under investigation

The microclimate experiment was extended to two surveying plots. The first plot is located in the area of Hajdúhadház Forestry Office of Nyírerdő Forestry Co. (eastern part of Hungary) (*Vityi et al.*, 2016), the other plot is in the area of Kapuvári Forestry Office of Kisalföld Forestry Co. (north-western part of Hungary). The effects of intercropping was surveyed in a variety of stands where the tree species and plantation structures were different (*Table 1* and *Table 2*), but the objectives of forestry companies operating in both locations are essentially the same: utilizing available space, protecting seedlings and ensuring successful afforestation. In both areas, using maize as intercrop in alleys made fodder production for animal stock and game management feasible. Control and agroforestry sites close to each other and of similar site conditions were involved in the experiment in both cases

Table 1

Basic data of the experimental areas in Hajdúhadház

	Alley cropping system	Control
Area	0,66 ha	4,0 ha
Plant	Oak (*Quercus robur*) and corn (*Zea mays*)	Oak (*Quercus robur*)
Row spacing (cm)	90-70-90	250
Orientation of row	North-south	North-south
Irrigation	No	No
Physical characteristics of soil	Sandy soil with humus	Sandy soil with humus
Period	3 years	-

Table 2

Basic data of the experimental areas in Kapuvár

	Alley cropping system	Control
Area	5,13 ha	4,24 ha
Plant	Poplar (I-214)(*Populus euramericana* cv.) and maize (*Zea mays*)	poplar (I-214)(*Populus euramericana* cv.)
Row spacing (cm)	~90 -75-75-75- ~90	400
Orientation of row	Northwestern-southeastern	Northwestern-southeastern
Irrigation	-	-
Period	1 year	

Measurements in Plot 1: Hajdúhadház

Based on the monitoring results of the first year (2015), an initial research plan was developed for the following year, focusing on the measurement of soil temperature and soil conductivity as well as the development of plant biomass. (*Table 3*) Parameters of soil microclimate were measured for one month, in the statistically driest and hottest period of summer which is a critical and stressful period of the year for the plants. Based on soil conductivity, comparison of soil moisture in the two areas is feasible, due to a strong correlation between the soil's electrical conductivity and the soil moisture content. (*Nagy*, 2014) Soil parameters of the sites at Hajdúhadház were tested in two sampling points per area in 2016.

Sampling points were designated to have the same site conditions, thus ensuring the comparability of the samples. Due to its sloping terrain, the control area has tendency to soil erosion and leaching, thus sampling points were selected lowland, in a more fertile part of the area with similar site conditions of alley cropping. Also the distance between two sampling points, and thus covering of the sampled area, was equal.

In order to increase the reliability of the results, the number of soil sampling points were raised to 17 in each plot equally distributed in 2017. The height of seedling was measured once by measuring tape. (*Table 3*)

Table 3

Measured parameters of the experimental plots in Hajdúhadház (August 2016, 2017)

Examined parameter	Soil temperature	Soil conductivity	Growth parameter
Period	01. Aug. - 02. Sept.	01. Aug. - 02. Sept.	02. Sept.
Data collection	systematic sampling design technique		systematic sampling design technique with random starting point
Sampling points	2 points/plot (2016) 17 points/plot (2017)		5×10 meters/plot
Test method and equipment	Soil temperature and conductivity meter (Hanna HI 98331)		Height measurement with measuring tape

Measurements in Plot 2: Kapuvár

Measurements were carried out every second day during August and September. We focused on soil temperature and conductivity at two different depths (on the surface and 10 cm below surface). The survey was more complex compared to the one carried out at Hajdúhadház, as it included air humidity and temperature testing in three different heights. In addition, three different features of seedlings were recorded (diameter at the base (Db), diameter at breast height (DBH) and height of trees (H)).

Table 4

Measured parameters of the experimental plots in Kapuvár (August, September 2019)

Examined parameter	Soil temperature	Soil conductivity	Growth parameter	Air humidity and temperature
Period	Aug. 01-Sept. 30.	Aug. 01-Sept. 30.	Aug. 05.-Sept 25.	Aug. 01-Sept. 30.
Sampling points	5 horizontal and vertical segments/plot 10 points/segment (2019)		10 trees/plot 2 trees/segment (2019)	5 vertical segments/plot 3 points/vertical segment (2019)
Data collection	Systematic sampling design technique		Once per month, systematic sampling design technique	Systematic sampling design, stratified sampling procedure
Test method and equipment	Soil temperature and conductivity meter (Hanna HI 98331)		Height measurement with measuring tape	Air humidity sensor

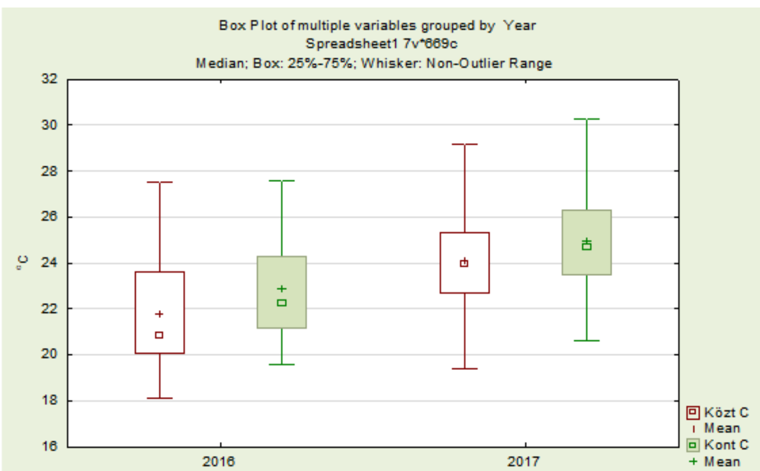
RESULTS

Plot 1: Hajdúhadház

The results show that the daily average soil temperature data in the agroforestry (AF) plot were below the soil temperature mean values of the control plot, which indicated a moderated soil microclimate in the intercropping system. (*Figure 1*)

Figure 1

The change of daily average of soil temperature in Hajdúhadház (August 2016, 2017)



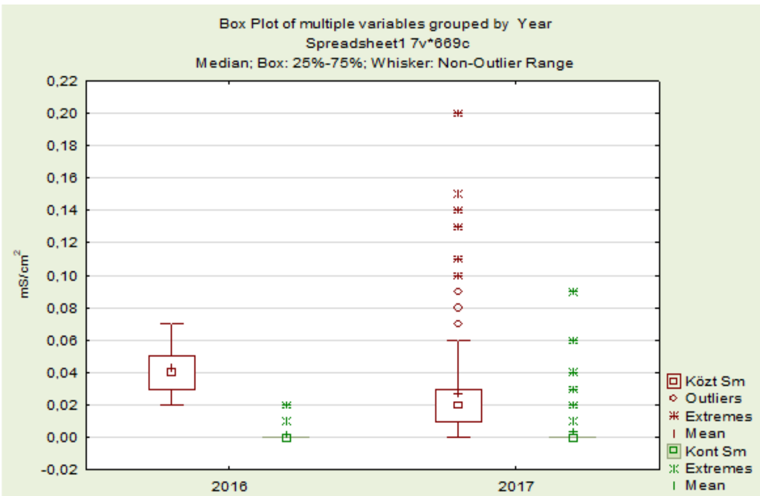
Közt C: agroforestry system; Kont C: control system)

In the average daily soil temperature there was a difference of about 0.2-2.0 ° C between the AF and the control plots, which influenced the evaporation intensity and the growth of the plants. Based on the results under the same soil conditions, we can infer that due to the presence of the intercrop, the soil moisture conditions of the two systems were different.

The conductivity values of the soil in comparison with the distribution of precipitation show massive correlation, but in the intercropping system the soil conductivity exceeded the values of the control plot in concluding that the agroforestry parcel had more favourable soil moisture values during the drought period. (*Figure 2*)

Figure 2

The change of daily average of soil conductivity (August 2016, 2017)



Közt C: agroforestry system; Kont C: control system)

The assessment involves developing parameters of sampling trees. The survival rate of seedlings shows that there is a significant difference between the agroforestry and the control systems. In 2015 the mortality rate was 50% in the control plot, requiring double plant replacement, on the contrary in the agroforestry parcel no drought damages were recorded (both systems are non-irrigated). Additionally, in the following years, the trees in the intercropping plot showed significantly better growing in height, 18 cm on average (2016) and 21 cm difference (2017) compared to the control parcel. ($t<0,05$; $p=0,0023$)

Plot 2: Kapuvár

The results are under processing, but the observations at the agroforestry site is overly positive if the two areas are compared. The values of temperature and air humidity measured during August and September were more balanced in the intercropping area (2019).

EVALUATION OF THE TEST RESULTS, CONCLUSIONS

Based on the results, the water balance of agroforestry system proved to be better than the control area in the examined drought periods. Significant difference was found between the data of the two afforested parcels in terms of soil microclimate. The daily mean temperatures of the forest intercropping area in the arid period were significantly lower than the values of the control area. The more favourable microclimate resulted in a significantly stronger growth of alley cropping area. There was no noticeable drought damage in the agroforestry experimental field and the growth parameters of the plants were more favourable, so it can be concluded that in the cultivation system associated with maize the development of the stand was more prosperous in all respects.

Based on our experience and measurements, application of intercropping can significantly increase the efficiency of (artificial) afforestation, reduce the drought damage, and improve the survival and growth parameters of seedlings. By maximising the utilisation of the available area to serve other purposes (production, ecosystem services), the afforestation may be coupled with resource efficiency and economic returns.

Further investigations on yields and microclimate are planned in the Kapuvár Forest Company area in the next three years.

ACKNOWLEDGEMENTS

The publication of this paper is supported by the EFOP-3.6.2-16-2017-00018 “Produce together with the nature – agroforestry as a new outbreaking possibility” project.

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Regional and Business Studies (2019) Vol 11 No 1, 21-27
Kaposvár University, Faculty of Economic Science, Kaposvár
doi: 10.33568/rbs.2399

SOIL MOISTURE AND TEMPERATURE CHARACTERISTICS IN A YOUNG SILVOARABLE AGROFORESTRY SYSTEM

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ABSTRACT

The aim of the present research is to investigate the effect of a young alley cropping system (planted for experimental purposes) on the soil microclimate, compared with a control site. The trial system, involving the agroforestry plantation and a control site, has been implemented in 2013 in an intensive monoculture agricultural environment. Measurement of soil microclimatic parameters started in 2014. Based on the results of the examination carried out in an agroforestry and a monoculture production site, there is a clear difference between soil moisture and soil temperature of the two cultivation systems. This effect can be observed even from the second year of the fast growing tree (Paulownia) plantation.
Keywords: agroforestry, alley cropping, soil moisture

INTRODUCTION

Intensive agricultural land use has a complex negative impact on soil, involving contamination, decreasing biological activity, fertility loss, etc. (*Li et al.*, 2019; *Kraut-Cohen et al.*, 2019; *Baysal and Saygin*, 2018). In addition, more and more frequent occurrences of weather extremes, such as drought and water floods, have a negative effect on natural vegetation and the qualitative and quantitative parameters of agricultural production as well as its ecological sustainability (*Johansson et al.*, 2015). Agroecological systems can prove the opportunity to maintain productivity and in a sustainable form (*Ball et al.*, 2018). One promising aspect of adapting to climate change is agroforestry, which integrates woody vegetation into agricultural cultivation, exploiting its various economic, social and ecological benefits. *Cherubin et al.* (2019) found that agroforestry improves the physical quality of the soil, taking into account the characteristics of soil aggregate and biological activity in degraded lands.

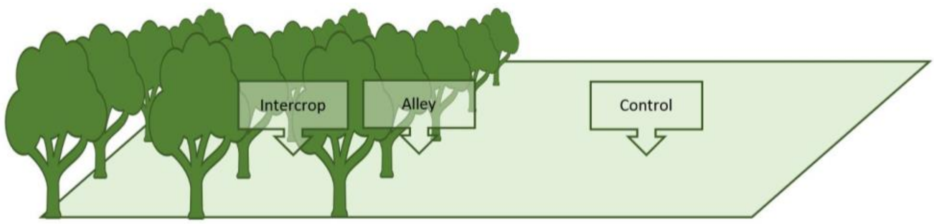
In our research we measured soil microclimate parameters in a trial agroforestry and a control site to investigate the effect of the tree grows in their first years in an intensively cultivated agricultural area.

MATERIALS AND METHODS

The trial alley cropping plantation has been implemented in 2013 in an intensively cultivated environment in South Hungary. The control site is a monocrop field next to the agroforestry system. A comparative test of soil parameters proved, that the main characteristics (alkaline clay / clayey loam type slightly solonchak soil) of the researched habitats are the same. On the alley cropping site, 126 pieces of Paulownia tomentosa var. Continental E. tree saplings have been planted on a 1 ha area. The distance between the rows and trees is 14 m and 5m, respectively. The alleys are intercropped with alfalfa. The control site, with the same size is an alfalfa monocrop plantation. This study is based on the soil moisture and temperature data collected from 2013 to 2017, at four different depths: 0-10 cm, 10-20 cm, 20-40 cm and 40-60 cm by installed tensiometers and soil thermometers. Air temperature was also measured in the trial site. The sensors have been installed so that the intercrop, the tree rows, and also control areas are monitored (*Figure 1*). Data have been collected automatically for four years, in two hours' interval. For ease of use, the analysis is based on the daily averages, calculated from the data series in the growing seasons (1. April to 30. September) of the four years. The annual changes in soil moisture and temperature values are shown in box diagrams, which also indicate the deviation of data. In the arid periods, which the agricultural cultivation is particularly sensitive to, the typical processes are well illustrated by the curves of daily averages compared to the air temperature, rain amount and wind speed. Statements based on the diagrams have been controlled and supported by statistical t-tests.

Figure 1

Installation of the sensors to monitor the intercrop, the tree rows and the control areas.



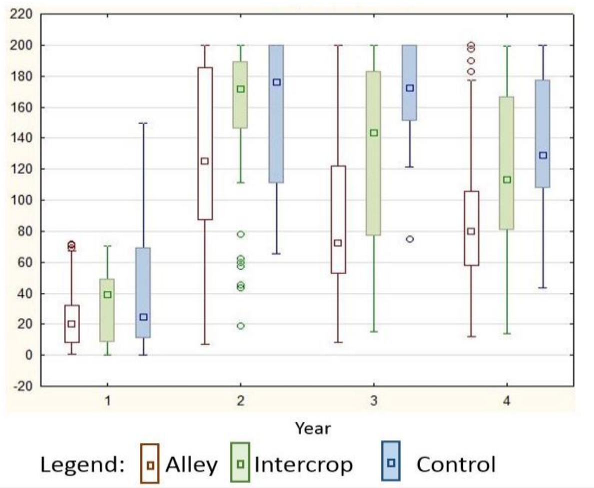
RESULTS AND DISCUSSION

According to soil moisture, in the control site, the upper layer of soil - up to 20 cm depth -, was significantly drier than in the alleys and intercrop plots. More frequent and higher soil dryness could be observed in monoculture production, while the majority of the data collected in the agroforestry system was located in a more favourable range, the total dehydration appeared only occasionally (*Figure 2*). Soil dryness refers to water potential values above 100 cm, where water scarcity is already threatening to achieve maximum yield.

In the deeper soil layers (> 20 cm) this tendency is not so clear; in the last examined growing season the soil moisture of the control area was more favourable (*Figure 3*). In this depth, soil moisture could be affected by the (partial) aquitard layer in 30 cm depth, the deep roots of trees and alfalfa, and the availability of ground water.

Figure 2

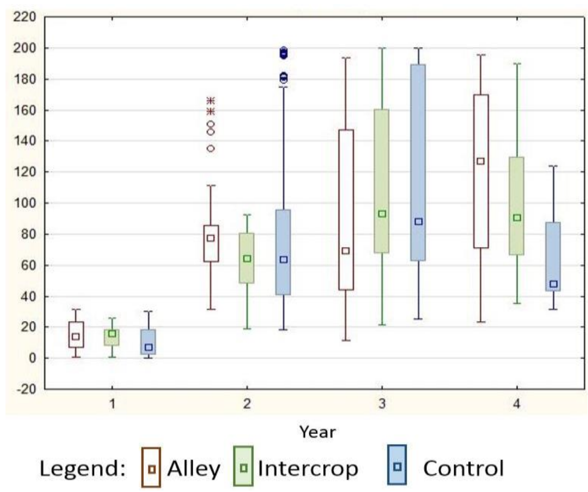
Soil moisture in 0-20 cm depth



The water potency of the soil moisture measured by tensiometer (water shortage) expressed in centibar in the upper soil layers in the four growing seasons

Figure 3

Soil moisture in 20-60 cm depth

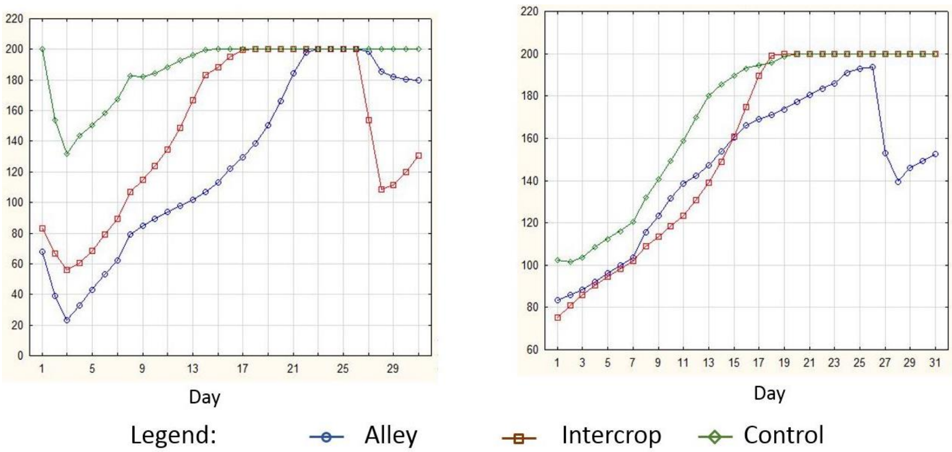


The water potency of the soil moisture measured by tensiometer (water shortage) expressed in centibar in the deeper soil layers in the four growing seasons

According to the data, the presence of trees in the arable cultivation has a favourable effect on the water content of upper soil layers already in the first years, by reducing the drying effect of wind and direct sunlight. During arid periods, dehydration occurred later in agroforestry site and took shorter periods in the upper soil layers than in the control plot. In the deeper soil layers (below 20 cm) the difference in soil moisture values of the agroforestry and control plots was smaller during the same drought period (*Figure 4*).

Figure 4

Soil moisture in a drought period



The water potency of the soil moisture measured by tensiometer (water shortage) expressed in centibar in the upper (0-20 cm, left) and deeper (>20 cm, right) soil layers during a drought period 21.08.2016 23.09.2016. The soil moisture values measured with the tensiometer indicate the absorption capacity of the soil, so higher values mean drier soil conditions.

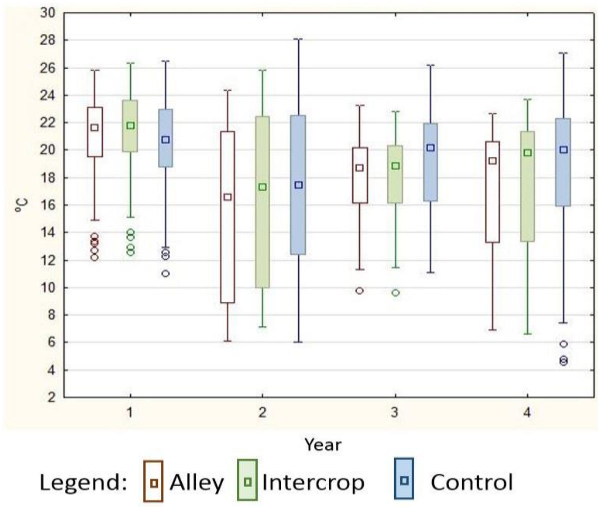
Examining the soil temperature data, we can state that the deviation in the control site was higher than in the agroforestry system in all four examined soil layers, but most at the upper measuring points. The annual average of the values and the majority of the data collected in the agroforestry site were in a more favourable range for productivity than in the monoculture (*Figure 5* and *Figure 6*).

In the drought periods, while the temperature of the upper - up to 20 cm depth - soil layer of the sites followed the changes of air temperature, the soil in the agroforestry system had a milder degree of warming on the one hand, and was considerably more temperate on the other hand. Although to a smaller extent, but this phenomenon could be observed even in layers up to 60 cm depth (*Figure 7*).

Contrary to our experience, several examples can be found in international literature, where tree rows have a neutral or negative effect on the intermediate crop. *Ssekabembe et al.* (1994) indicate the importance of soil type when determining soil moisture in a black locust alley cropping system. According to tree-crop competition, *Swieter et al.* (2018) found that the average, long term crop yield of oilseed rape and winter wheat did not differ significantly in a 10 year old alley cropping and monoculture system.

Figure 5

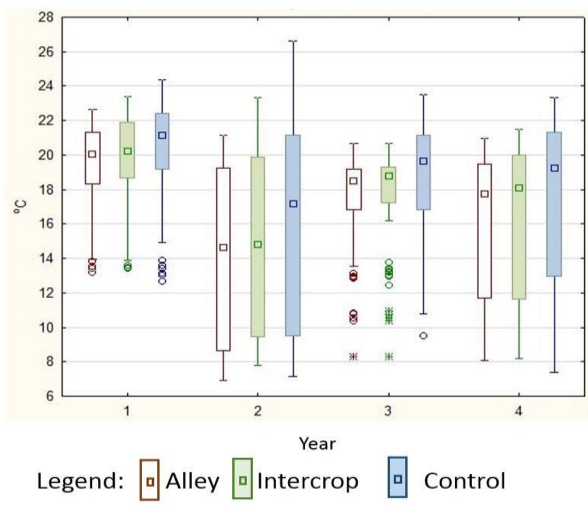
Soil temperature in 0-20 cm depth



Soil temperature values in the upper (0-20 cm) soil layers during the four examined growing periods

Figure 6

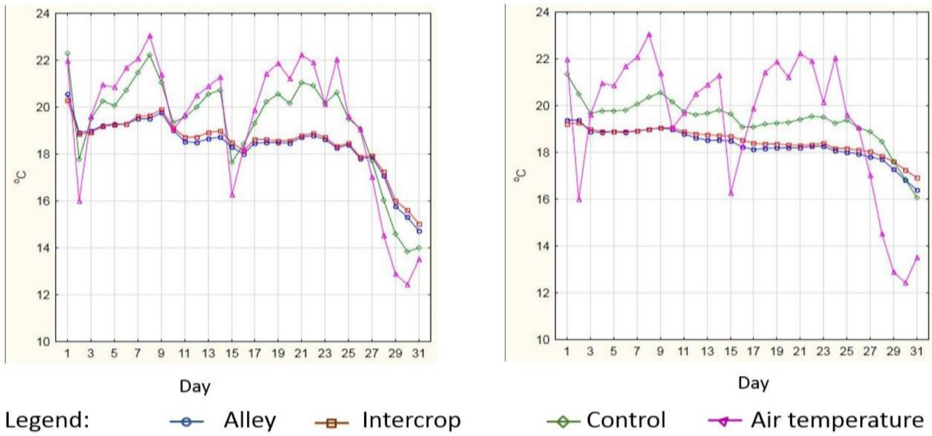
Soil temperature in 20-60 cm depth



Soil temperature values in the deeper (>20 cm) soil layers during the four examined growing periods

Figure 7

Soil temperature in a drought period



Soil temperature values in the upper (0-20 cm, left) and deeper (>20 cm, right) soil layers in a drought period 21.08.2016 23.09.2016.

Besides the soil types, the tree species also can negatively affect the production in alley cropping, as highlighted by *Malik and Sharma* (1990). On the other hand, intercrop can also support the growth of tree alleys, as it is highlighted in several publications (*Williams and Gordon*, 1995; *Vityi et al.*, 2016).

CONCLUSIONS

Based on the results of the examination carried out in an agroforestry and a monoculture production site, there is a clear difference between soil moisture and soil temperature of the two cultivation systems. This effect can be observed even from the second year of the fast growing tree (Paulownia) plantation.

Woody vegetation helped to preserve soil moisture in the upper 20-30 cm layer, but caused a decrease in layers below 30 cm (under aquitard layer). The presence of trees is beneficial for the soil temperature; the soil microclimate is more balanced in the agroforestry system than in monoculture due to the decrease of the mean values in the upper layers, the smaller deviance of data and the less frequent prevalence of extreme values of temperature.

Overall, based on the results of the experiment, the alley cropping system can be particularly favourable for shallow-rooted intercrops, by controlling the water and heat balance of the soil and by moderating harmful extremities such as drought, extreme cold or heat.

AKNOWLEDGEMENT

The publication of this paper is supported by the EFOP-3.6.2-16-2017-00018 "Produce together with the nature – agroforestry as a new outbreaking possibility" project.

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Regional and Business Studies (2019) Vol 11 No 1, 29-37
Kaposvár University, Faculty of Economic Science, Kaposvár
doi: 10.33568/rbs.2400

ONLINE SOIL MOISTURE AND MICROCLIMATE INVESTIGATIONS ON AGROFORESTRY AND AGRICULTURAL FIELD PLOTS

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ABSTRACT

Agroforestry is a traditional cultivation method, which can bridge the gap between nature conservation and agriculture systems. Hungary is one of the most vulnerable countries in the term of climate change, and according to climatological forecasts, several areas in the Carpathian basin will be exposed to extensive and prolonged droughts in the next decades. Agroforestry can moderate the negative effects of the projected changes. The regional share of this new concept should be increased, but first science has to demonstrate its clear benefits. So using online measurement technologies microclimate and soil moisture changes can be detected with high temporal and spatial distribution for longer periods in order to obtain information on the smallest deviations of microclimatic elements that could not be detected in conventional ways. In our study a 1 ha completely wind shielded agroforestry plot and a nearby situated natural wind-running field were investigated, using 1-1 automatic weather station as well as 5 + 1 of 90 cm soil probes, which were used to measure the changes of soil moisture among 10cm layers. We examined the climatological response to the forest belt compared to the open, traditional field ("control area") based on the following parameters: 10meter wind speed, 10meter wind direction, 2m temperature, relative humidity, the amount and intensity of rainfall, the amount and duration of dew formation, the volume% of soil moisture.
Keywords: agroforestry, microclimate, soil moisture, climate change

INTRODUCTION

Nowadays agriculture has to face a lot of challenges, like nourishing the growing population or the negative effects of climate change. One possible solution could be achieving higher yields or increasing the rate of agroforestry in less favourable plots. By definition, this is a form of land usage, where combinations of different branches of agriculture alongside elements of forestry materialize at the same time, the members of this system interact, which creates ecological and economic benefits (*Gyuricza and Borovics*, 2018). Local climate factors can be improved by applying systems of agroforestry in the area (*Vityi et al.*, 2014). Due to the reduced wind speed, the lower radiation, and the higher relative humidity, the atmospheric drought can be reduced. Also, free-range animals and different kinds of crops can benefit from the shade. Also, the falling fruits and leaves can supplement the food supplies of livestock and wildlife, who can find also refuge in the forest belt (*Keserű et al.*, 2015). Agroforestry contributes to biodiversity, maintains protection against deflation and erosion, improves water quality and carbon sequestration. Subsequently, by cutting down the trees we can expect additional revenue (*Nair and Garrity*, 2012). One of the benefits of this environmentally friendly production method is being less vulnerable to market conditions, it can create a link between agriculture personnel, hunting associations and beekeepers, while it enriches the diversity of the countryside. With varied planting of tree species with different flowering times it can be used as a bee pasture to provide nourishment for the bees throughout the whole growing season (*Keserű et al.*, 2014). This system's productivity exceeds the production of equivalent plots of solely arable crops or forestry.

MATERIALS AND METHODS

Our investigations were carried out in two areas around Földes in Hajdú-Bihar County. One is a closed agroforestry plot and the other one is an open, traditionally cultivated field ("control area") in 5 km apart. In the agroforestry experimental area there are 3 soil probes in the crop field (grain in the time of the investigation), 2 soil probes in the forest belt and 1 automatic meteorological station in the geometric center of the area. There is a meteorological station and a soil probe on the control area. Both BOREAS meteorological stations were installed in March 2018. 10meter wind speed (m/s), 10meter wind direction (degrees), 2m temperature (°C), relative humidity (%), the amount (mm) and intensity (mm/h) of rainfall, the amount (%) and duration (s) of dew formation are recorded with 10-minute resolution. SENTEK soil probes measure the volume of soil moisture (V_{TF}%) and soil temperature (°C) from 5 to 85 cm up to a depth of 10 cm with 60-minute time resolution. The measurements were started on April 20, 2018. The hourly differences of 2m temperature, relative humidity were calculated. The sample size was at least 180 in every hour of the day in each month, which made proper statistical calculations possible. Besides, the comparison of evapotranspiration, soil moisture and wind speed are presented. To visualize the changes of soil moisture along the depth of 85 cm in 2D flow charts, linear interpolation was applied to increase the spatial resolution from 10 cm to 1 cm. We assumed that the change of soil moisture was linear between two measurement points (5, 15, … 85 cm). All the figures were created with R free statistical software (*R core team*, 2017)

The goal of the research is to highlight the differences and similarities of agroforestry and open field crop production from the perspective of soil water management and microclimate properties. By analyzing and comparing the received results we can determine the effects of agroforestry on the crop production.

RESULTS AND DISCUSSION

Comparison of temperature, humidity and evapotranspiration

As a first step, the daily means of temperature, relative humidity and evaporation were calculated, but it was too robust to highlight the fine differences in the microclimate. After the visualization of the temperature in 10-minute resolution, systematic deviation can be assumed in similar times of the day (*Figure 1*), so the hourly differences of temperature and relative humidity were calculated (*Figure 2* and *Figure 3*). Zero line shows when the temperature and relative humidity is equal in both areas. The values are positive, when the temperature/relative humidity is higher in the control area, and inversely, the negative values refer to the condition when the temperature/relative humidity is higher on the agroforestry plot.

Figure 1

Daily range of temperature on the agroforestry plot and the control plot between 1-5 July 2018

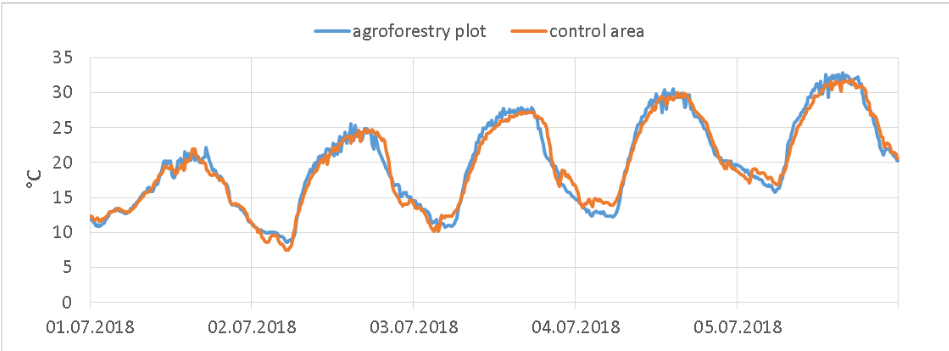
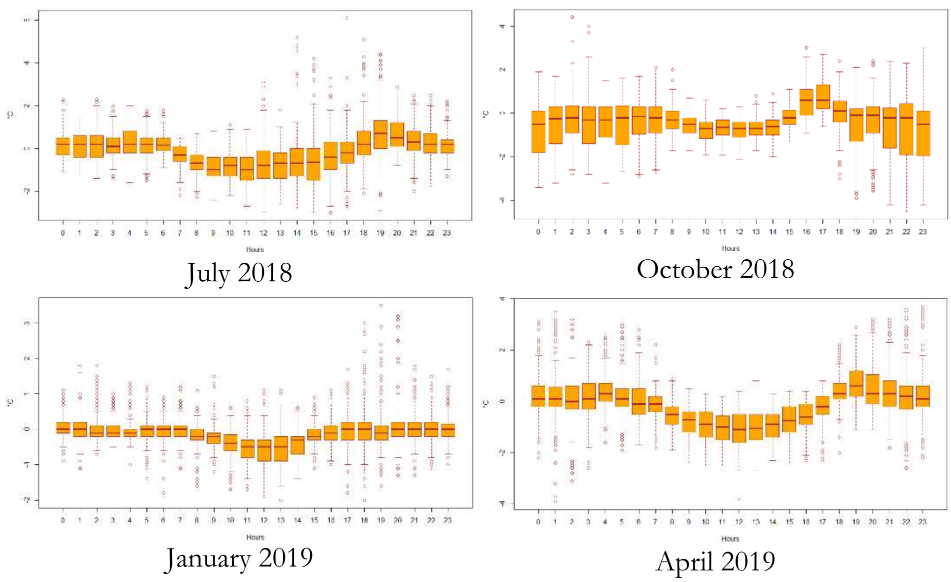


Figure 2

Hourly temperature differences between the control plot and the agroforestry plot

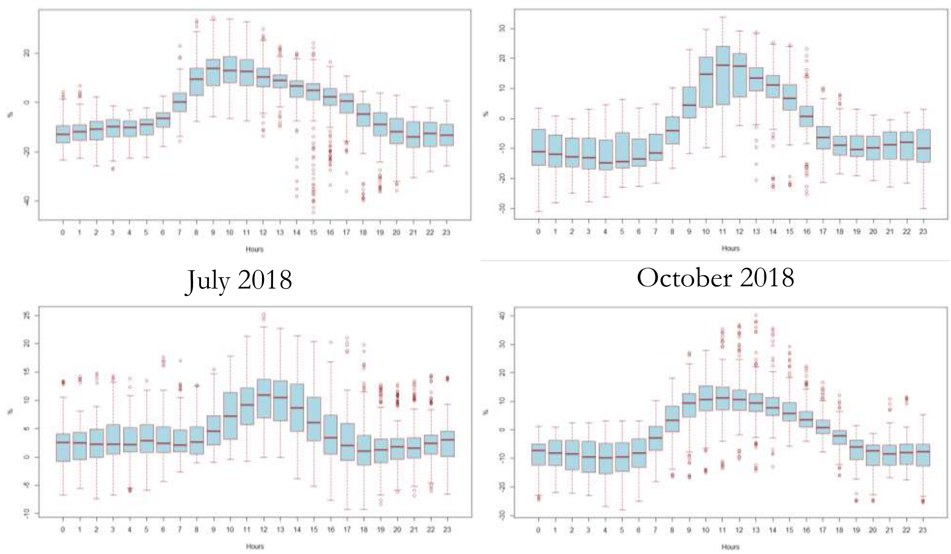


In July 2018 the average temperature of the control area was a few tenths of a degree hotter at night and dawn compared to the agroforestry plot. However, from dawn to late afternoon, the agroforestry area had higher temperatures compared to the control area. This can be explained by the fact that the wind speed in the agroforestry plot was significantly lower and as a consequence, the atmospheric mixing could not exert its effect, therefore the atmospheric energetics (radiation and irradiation) governed the degree of temperature rise and cooling in the agroforestry plot. As a result, the temperature rose after dawn and dropped after twilight at a higher rate (*Figure 2* upper left). In October, in late afternoon, the shade effect of the forest could be detected due to the lower angle of incidence, so the temperature decreased faster on the agroforestry plot (*Figure 2* upper right). In winter (*Figure2* bottom left), in the absence of deciduous leaves, the temperature values in the two areas were almost completely equalized.

The atmosphere is a dynamic system, so temperature and humidity are closely related. The warmer the air is, the more water vapour can be absorbed proportionally per unit volume. As a result, the area with higher daily temperature fluctuations showed higher daily fluctuations of relative humidity as well (*Figure 3*).

Figure 3

Hourly differences of relative humidity between the control plot and agroforestry plot

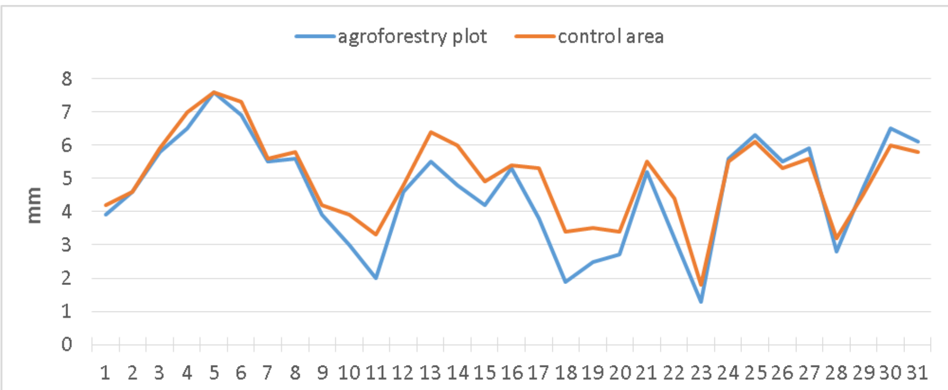


At night and dawn, when the temperature on the control area was higher, the relative humidity of the air was lower. During the day, a reversed trend could be observed. In this case, the forest surrounded area had a higher temperature, and at the same time had lower relative humidity. However, this did not mean lower absolute water content in the air, because relative humidity strongly depends on the air temperature. Using statistical t-probe it can be stated that there were significant differences in relative humidity in July and October 2018, and in April 2019. In winter there was no significant effect of the forest belt around the agroforestry plot.

Evaporation rate strongly depends on temperature, relative humidity and wind speed. Higher temperatures and higher wind speeds increase the evaporation, while high humidity prevents more intensive evaporation. The average wind speed in the agroforestry plot was lower due to the effect of the wind shade and the temperature was higher than the control area's value, especially at noon in summer. Potential daily evapotranspiration in July 2018 was lower in the agroforestry plot than in the control area (*Figure 4*). Evaporation of green vegetation ensured higher water vapor content, and due to the area being closed, it was easily retained. These differences were more determined in the area of high pressure systems (anticyclone), when there was no mixing effect in the lower atmosphere owing to the low wind speeds. On the contrary, on 25th July 2018 a cold front passed over the area causing higher wind speeds, and the rate of evaporation equalized on the experimental areas. In October, evaporation was more balanced, which can be explained by the leaf fall and the cooler weather. However, in January there was a significant difference in the values of potential evapotranspiration, as evaporation in the agroforestry plot was significantly higher than in the control area. This can be explained by the higher moisture content of the soil.

Figure 4

Daily value of potential evapotranspiration (mm) on agroforestry and the control plot in July 2018



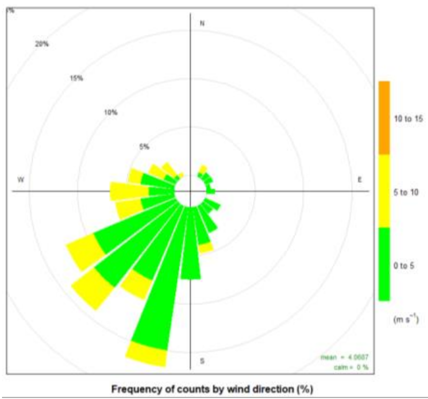
The vegetation period begins when the plants begin to breathe, which ensured a higher water vapor content again in April 2019. At the same time, the evaporation in the control area was higher than in winter, because the daily exposure to radiation increased, while the shade effect was still greater in the agroforestry plot. On the other hand, the air movement was also intensifying, because spring is the windiest period in Hungary.

Effects of the forest belt on wind speed

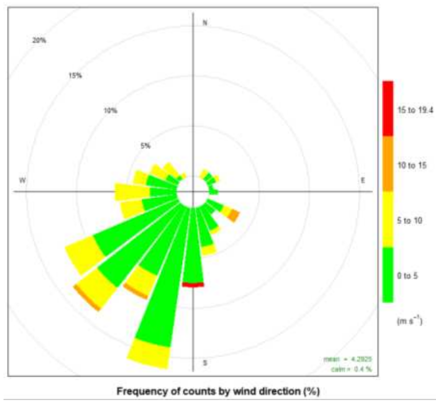
Wind conditions were compared in the control area and agroforestry plot using wind roses, plotted from 10-minute wind speed values between April 2018 and March 2019 (*Figure5*). The typical wind direction on both areas was southwest (180° to 270°). The relative frequency of wind speed from 260° to 90° (from western, northern and eastern directions) was 10-15% with typical wind speed under 10 m/s in both areas. The differences could be detected between 180° and 210° (southern, southwestern directions). On the control area the wind speed was significantly higher, which occasionally exceeded 15 m/s (stormy wind).

Figure 5

Representation of wind speed distribution in the agroforestry plot and on the control area with 10-minute spatial resolution



agroforestry plot



control area

Optimal stoma operation requires some air movement up to 1.7 m/s. Stronger winds enhance the transpiration, and as a consequence they decrease the turgor pressure and so stomas may close in a hydroactive way. The relative frequency of wind speed below 1.7 m/s was calculated. It was found that wind speed under this threshold occurred four times more often than in the control area (*Table 1*). This means that the agroforestry plot proved to be more favourable for transpiration due to the wind shading effect of the forest belt.

Table 1

Relative frequency of wind speeds below 1.7 m/s

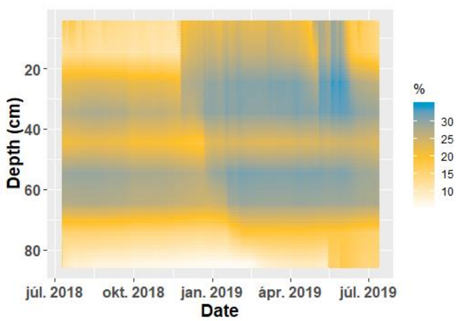
	Agroforestry plot	Control area
July 2018	77%	15,2%
October 2018	76,5%	33,5%
April 2019	41,6%	8,8%
July 2019	73,7%	17,2%

Analysis of soil moisture

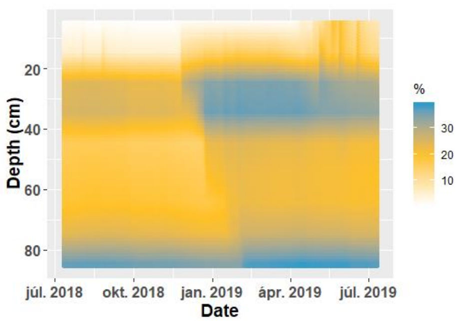
The top layer of soil is in direct connection with the atmosphere, so the external influences on the area have the greatest impact on this layer. As a result, the greatest fluctuation in soil moisture can be measured in this layer. Even the smallest amount of rainfall temporarily rose the soil moisture value, which started to decrease rapidly due to absorption or evaporation. In the agroforestry plot, the upper 5 cm soil layer was drier than in the control area. This can be explained by the extraction effect of the tree roots, which was already present in the soil slowing down the vertical infiltration. On the contrary, the changes of soil moisture content on the control area was more variable and rapid owing to the higher wind speeds, and consequently, to the more active evaporation. At a depth of 35 cm, large fluctuations in soil moisture content disappeared in the agroforestry plot (*Figure 6*). During the drought between June and August in 2018, the soil moisture in the agroforestry plot was higher due to reduced air movement and hence less evaporation. Rainfall in August temporarily increased the amount of soil moisture on the control area, but the effect was short-lived.

Figure 5

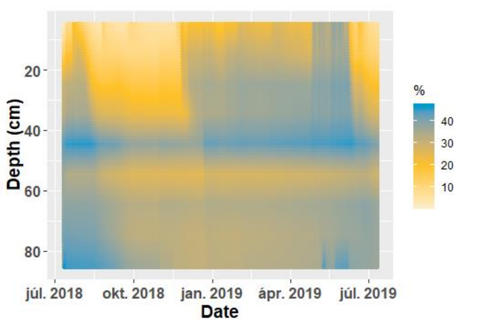
Soil moisture between 5 cm and 85 cm by 1 cm steps calculated with linear interpolation in the forest belt with north-south exposure, in the forest belt with east-west exposure and in the control area



east-west exposure



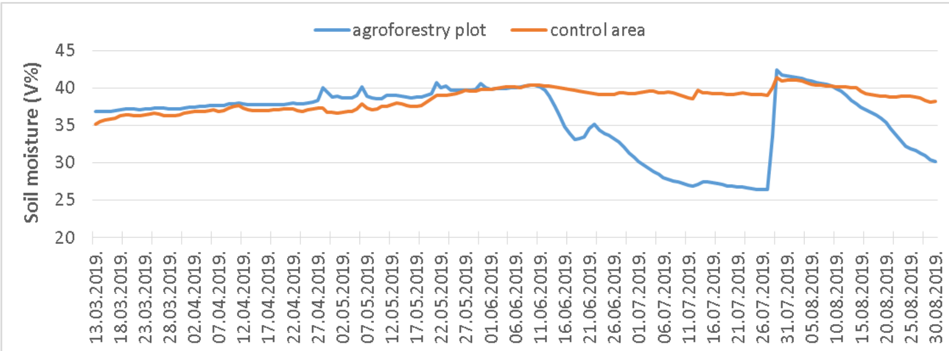
north-south exposure



control area

Figure6

Soil moisture at 35 cm depth in the agroforestry plot and on the control area between March and August 2019



CONCLUSIONS

The daily heat fluctuation in the agroforestry plot was higher compared to the control area, which can be explained by the lower wind speed in the enclosed area. The temperature rose more sharply in the morning and the cooling rate was faster in the afternoon as well compared to the control area. The daily humidity in the agroforestry plot was also higher than in the control area, which was related to the significant decrease of the wind speed and the greater daily fluctuation of temperature.

The daily potential evapotranspiration was typically lower in the agroforestry plot. The conditions in the agroforestry system are more favourable to the functioning of the stomas, which can enhance the photosynthesis of the crop. This can be explained by the fact that due to the wind shade effect of the forest belt, there were fewer and less wind gusts. Based on soil moisture measurements, it can be concluded that in summer, the control area values indicated a greater degree of soil drought than the agroforestry plot. In the winter season, the parameters measured in the two areas were in balance, and in spring, significant differences began to appear again after the beginning of the vegetation period.

As a conclusion, we were able to prove some positive effects of the microclimatic and soil moisture factors influenced by the agroforestry systems.

ACKNOWLEDGEMENTS

The work is supported by GINOP 2.3.4-15-2016-00005 and EFOP 3.6.2-16-2017-00018, "Produce together with the nature – agroforestry as a new outbreaking possibility projects.

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Regional and Business Studies (2019) Vol 11 No 1, 39-45
Kaposvár University, Faculty of Economic Science, Kaposvár
doi: 10.33568/rbs.2403

NDVI-BASED DOWNSCALING OF THE CREMAP ACTUAL EVAPOTRANSPIRATION MAPS

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ABSTRACT

The increasingly used remote sensing-based evapotranspiration estimation techniques provide information about the spatial and temporal variability of evapotranspiration on the field and regional scales. For Hungary, the most reliable evapotranspiration mapping model is the CREMAP (Calibration-Free Evapotranspiration Mapping), which uses MODIS surface temperature data. The CREMAP evapotranspiration with its 1000×1000 m (1 km²) resolution can be used for examinations with larger scales, for example the comparison of the water balance of forests with different land cover types (agricultural areas, artificial surfaces, etc.). However, the 1 km² spatial resolution is too coarse to be used for smaller scales like precision forest management or agroforestry systems. Therefore, a vegetation index-based (MODIS NDVI) downscaling process of the CREMAP evapotranspiration was developed, to a resolution of 250×250 m (6.25 hectares). The downscaling experiment was done for Hungary, for a drier (2003 May-October) and for a wetter (2005 May-October) period. The products were analyzed, according to forest stand types. The vegetation index-based evapotranspiration downscaling process can be used for getting hydrological data for forest resource management, climate change impact studies on smaller scales or agroforestry system research.
Keywords: evapotranspiration, water balance, MODIS

INTRODUCTION

Through evapotranspiration (ET; which includes evaporation, transpiration and sublimation) more precipitation is disposed than through runoff. To increase the knowledge of the energy balance and the hydrological cycle of forestry and agriculture, it is essential to determine more accurately the amount of ET.

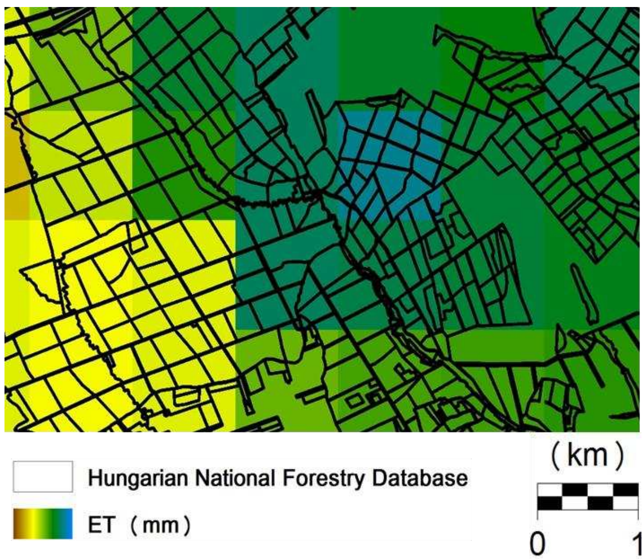
The conventional ET estimating techniques (eddy covariance, Bowen-ratio, lysimeter methods, catchment water balance equation, etc.) do not provide information about the spatial variability within a region of interest. The only possibility of estimating ET over areas with mixed landscape units is remote sensing, which allows to obtain information about spatial and temporal variability. Nowadays several remote sensing-based evapotranspiration estimation methods are available (*Nouri et al.,* 2013, *Zhang et al.,* 2016).

For Hungary, the most reliable evapotranspiration mapping model is the Complementary-Relationship-based Evapotranspiration MAPping (CREMAP, *Szilágyi and Kovács*, 2011). It is based on the complementary relationship (*Bouchet,* 1963) and the WREVAP model of *Morton* (1985) and it uses MODIS surface temperature data (linear transformation). It has a 1 km² (1000×1000 m) spatial resolution, which can be used for examinations with larger scales, for example the comparison of the water balance of forests with different land cover types (agricultural areas, artificial surfaces, etc.). In Hungary, the units of forest management are the forest compartments (fairly homogeneous forest stands) which commonly have a relatively small area (approx. 5 ha). The CREMAP ET map (raster layer) and the Hungarian National Forestry Database (vector layer) for an example area are depicted in *Figure 1*. The 1 km² spatial resolution is too coarse to be used for smaller scales, like precision forest management or agroforestry systems.

With higher resolution the ET maps could be more usable on scales of the forest stands. The aim of this study is the development of a vegetation-index based ET statistical downscaling method for Hungary. Employing the method, we compared the ET of different forest stand types during two vegetation periods.

Figure 1

The CREMAP ET (raster layer) and the Hungarian National Forestry Database (vector layer) for an example area



MATERIALS AND METHODS

Based on the literature review (*Allen et al.,* 2011; *Hong et al.*, 2011, *Mahour et al.*, 2017), the MODIS normalized difference vegetation index (NDVI) data was selected as a co-variable for the CREMAP ET statistical downscaling. To download the NDVI data (1000×1000 m and 250×250 m resolution), we used the Google Earth Engine platform (*Gorelick et al.,* 2017). Two vegetation periods (*Table 1*) were selected for the examination: a drier and warmer one (May-Oct. 2003), and a wetter and colder one (May-Oct. 2005).

Table 1

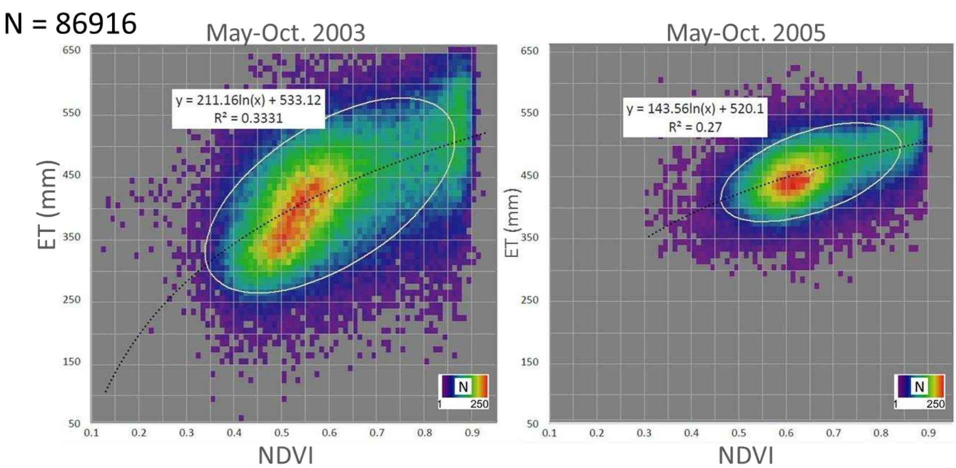
The mean temperature (T) and the precipitation amounts (P) for the total years and for the vegetation periods of 2003 and 2005

Year	Period	T (°C)	P (mm)
2003	January - December	10.8	467
	May - October	18.7	300
2005	January – December	10.2	734
	May-October	17.4	445

The water bodies and wetland areas were excluded, because they have a very low NDVI value in spite of their high ET. The correlation between the ET and the NDVI (1000×1000 m) can be seen in *Figure 2*. The logarithmic regression fitted the best, thus, we calculated the ET values using the logarithmic equations and the NDVI (250×250 m) data. In order to ensure that the mean of the downscaled 16 smaller ET pixels (250×250 m) does not change within the original 1 km² pixel, we used a quantization process.

Figure 2

The NDVI and the evapotranspiration (ET): density plots and the regression equations



The ellipse contains 86.6% of data.

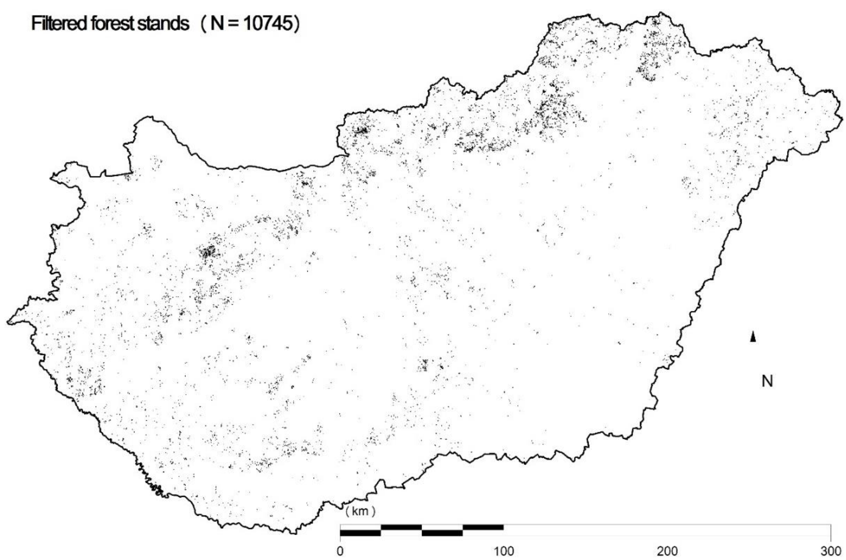
The Hungarian National Forestry Database was used to compare the ET of the following 15 forest stand types: "Beech", "Hornbeam-oak", "Sessile oak and pedunculate oak", "Turkey oak", "Pubescent oak", "Black locust", "Other native hard broadleaves (hornbeam, maple, ash)", "Non-native hard broadleaves (red oak, black walnut, etc.)", "Hybrid poplar and willow", "Native poplar", "Other hygrophil species (willow, alder)", "Other native soft broadleaves (lime tree, birch, etc.)", "Scots pine", "Black pine", "Other pines (spruce, larch, etc.)". Only those ET pixels were included in the analysis which total area (250×250 m = 6.25 ha) belonged to only one forest stand type ("homogeneous pixels").

RESULTS

The location of the filtered forest stands (N = 10745) can be seen in *Figure 3*, while the ET of the different forest stand types is depicted in *Figure 4*.

Figure 3

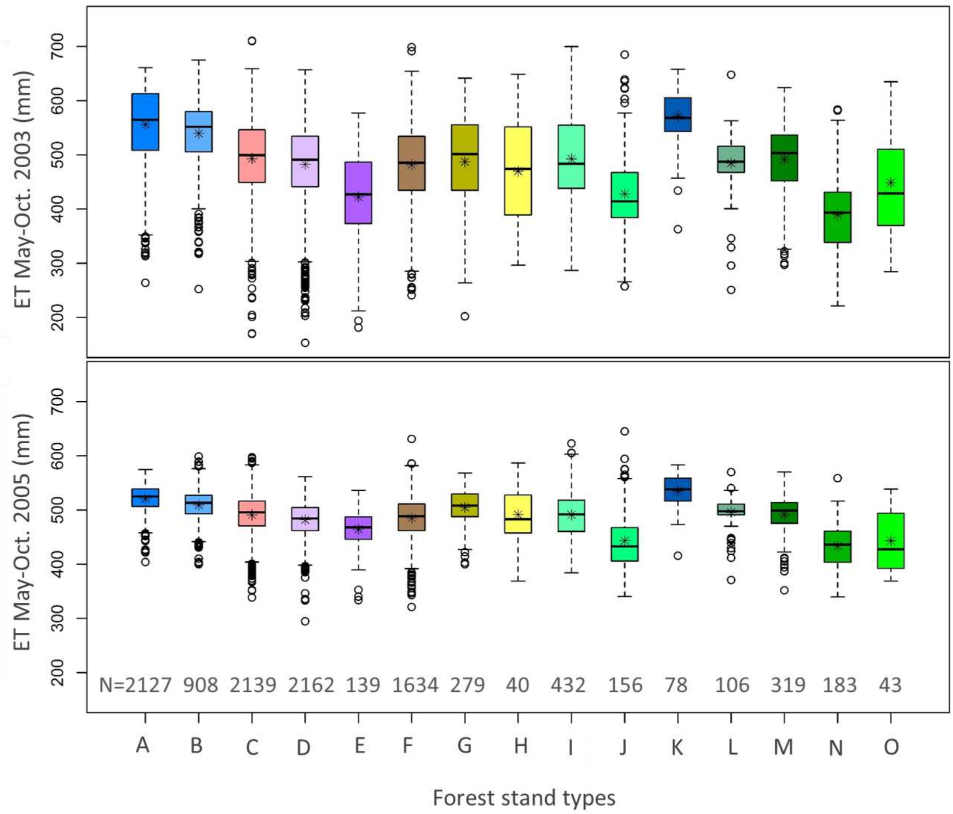
The location of the filtered forest stands in Hungary



The differences between the ET of the different stand types were higher in the drier and warmer period (May-Oct. 2003). The spread of the values within each category was also higher in that period. In both periods the "Other hygrophil species (willow, alder)" category had the highest mean ET (571 and 535 mm, respectively). It was followed by the "Beech" and the "Hornbeam-oak" categories. The lowest mean values belonged to "Black pine" in both periods (390 and 434 mm, respectively). The "Pubescent oak", "Native poplar" and "Other pines (spruce, larch, etc.)" categories also had low mean ET values. The mean ET of the "Beech", "Hornbeam-oak" and "Other hygrophil species (willow, alder)" categories were higher in the drier and warmer year (2003) than in the wetter and colder years (2005). The "Pubescent oak", "Other native hard broadleaves (hornbeam, maple, ash)", "Non-native hard broadleaves (red oak, black walnut, etc.)", "Native poplar", "Other native soft broadleaves (lime tree, birch, etc.)"and "Black pine" categories had higher mean ET values in the second period (2005). The mean values of the other categories ("Sessile oak and pedunculate oak", "Turkey oak", "Black locust", "Hybrid poplar and willow", "Scots pine", "Other pines (spruce, larch, etc.)") were similar in both periods.

Figure 4

Comparison of the evapotranspiration (ET) of different forest stand types.



A: "Beech", B: "Hornbeam-oak", C: "Sessile oak and pedunculate oak", D: "Turkey oak", E: "Pubescent oak", F: "Black locust", G: "Other native hard broadleaves (hornbeam, maple, ash)", H: "Non-native hard broadleaves (red oak, black walnut, etc.)", I: "Hybrid poplar and willow", J: "Native poplar", K: "Other hygrophil species (willow, alder)", L: "Other native soft broadleaves (lime tree, birch, etc.)", M: "Scots pine", N: "Black pine", O: "Other pines (spruce, larch, etc.)".

CONCLUSIONS

The downscaled data obviously have more uncertainty than the original values (*Hong et al.*, 2011). The main uncertainties of the downscaled products stem from the following sources: the uncertainties of the remote sensing based data − the MODIS surface temperature used for the original CREMAP ET values and the MODIS NDVI − (*Miura et al.,* 2000; *Sun et al.*, 2004), the uncertainties from the use of the regression equations, and the uncertainties of the Hungarian National Forestry Database (*Bárdos*, 2016). For water bodies and wetland areas the method cannot be used (very low NDVI in spite of high ET). The MODIS leaf area index (LAI) probably would have stronger correlation with ET, although it is currently available only with a resolution of 500×500 m.

Considering the uncertainties, the presented method can be used as a basis for statistical downscaling of remote-sensing based ET data for Hungary. With the downscaled products the ET of different forest stand types are comparable. In the future, more reliable remote sensing based data with higher spatial resolution may be available, which could help with the further improvement of statistical downscaling.

ACKNOWLEDGEMENTS

The publication of this paper is supported by the EFOP-3.6.2-16-2017-00018 "Produce together with the nature – agroforestry as a new outbreaking possibility" project.

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