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Fall-Winter 2024

Environmental management, land use, biodiversity

IMPLICATIONS FOR GREENHOUSE GAS BALANCE IN CONVERTING TEN HECTARES OF ROTATION FOREST TO CONTINUOUS COVER MANAGEMENT

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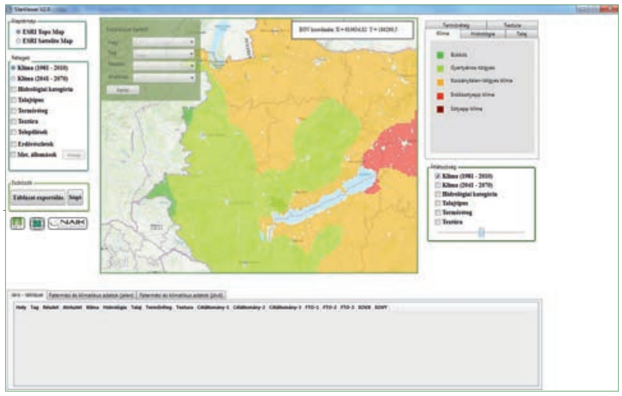

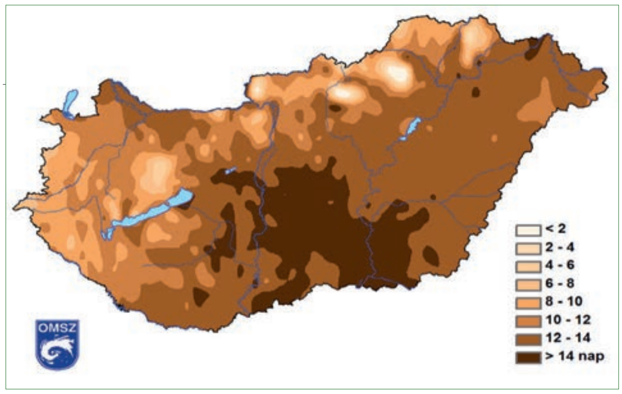

IMPLICATIONS FOR GREENHOUSE GAS BALANCE IN CONVERTING TEN HECTARES OF ROTATION FOREST TO CONTINUOUS COVER MANAGEMENT

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ABSTRACT

With the Paris Agreement and the EU Climate Law setting ambitious climate goals, land-based climate change mitigation solutions are gaining increased importance. The EU's recent Carbon Removal and Carbon Farming (CRCF) regulation underscores the dual priorities of enhancing biodiversity and increasing land-based carbon sequestration. Effective modelling tools are essential for planning and implementing climate change mitigation measures that target future carbon balances of these land-based approaches. One such tool, the Forest Industry Carbon Model (FICM), was developed at the University of Sopron's Forest Research Institute as a country-specific carbon balance calculation system. This model assesses future carbon balances in forests and harvested wood products while also accounting for material and energy substitution effects. Our current research focused on developing the Continuous Cover Forestry Module within the FICM, which was tested in a pilot forest stand. Findings suggest that transitioning from traditional rotation forestry to continuous cover forestry management can be an effective climate mitigation strategy. This approach allows for sustained carbon sequestration while promoting forest resilience and biodiversity. The results highlight the potential of continuous cover forestry as a valuable tool in achieving the EU's 2050 climate and biodiversity targets through improved land management practices.

keywords: climate change mitigation, carbon sequestration, forest management system, nature conservation, carbon balance modelling, continuous cover forestry

INTRODUCTION

The Paris Agreement and the European Green Deal set ambitious targets for reducing emissions and addressing climate change (Verkerk et al. 2022, Király et al. 2022). Achieving these goals requires rapid and substantial reductions in anthropogenic greenhouse gas (GHG) emissions and effective offsetting of inevitable emissions. Forests, along with other sectors of land use, are crucial in removing carbon dioxide (CO_2) from the atmosphere and storing it in biomass and soils (Verkerk et al. 2022). According to Hungary's Greenhouse Gas Inventory (GHGI), the land use and forestry sector (LULUCF) offsets approximately 10% of the country's total GHG emissions (NIR 2023, Borovics and Király 2023). Hungary's Agriculture sector emissions are of a similar magnitude to the removals achieved by the LULUCF sector (NIR 2023, Borovics and Király 2023). To enhance offsetting for other sectors, such as Energy, Industrial Processes and Product Use, and Waste, additional increases in LULUCF carbon sequestration are essential.

Forestry is subject to various demands under multiple policy frameworks, with Verkerk et al. (2022) identifying three main objectives for the forest-based sector: protection, restoration, and management with wood use. Different forest types and objectives can thus contribute to climate goals through distinct mitigation pathways (Verkerk et al. 2022, Kottek et al. 2023), including carbon storage in biomass and soils, storage in wood products (HWPs), and avoided emissions through product and energy substitution (IPCC 2022, Verkerk et al. 2022, Borovics 2022, Király et al. 2023). Optimal climate mitigation outcomes depend on tailored combinations of measures and management goals specific to each region and forest type (Verkerk et al. 2022, Borovics et al. 2023). The IPCC's Sixth Assessment Report (2022) highlights that effective mitigation assessments should account for the full forest and wood use system. Forest management strategies aimed at increasing biomass stock may have unintended effects, including reduced structural complexity, biodiversity risks, and lower resilience to natural disasters. Some studies suggest that carbon losses from forest harvest may outweigh the carbon offset benefits of HWPs and material substitution for decades (Soimakallio et al. 2016, Seppälä et al. 2019, Somogyi 2019). Conversely, examples from certain countries show that investments in forest management have led to increased growing stocks alongside increased wood production (Cowie et al. 2021, Diao et al. 2022, Dong et al. 2023, Lin and Ge 2020, Schulze et al. 2020, Ouden et al. 2020). Long-term forest growth should be prioritized over maximizing short-term carbon accumulation (Wernick and Kauppi 2022), with evidence indicating that actively managed forests that maintain high biomass yields and large carbon stocks can provide substantial long-term climate benefits (Nabuurs and Masera 2007, Lundmark et al. 2014, Lundmark et al. 2016).

The IPCC's Sixth Assessment Report (2022) also lists continuous cover forestry (CCF) as a promising mitigation approach, known for producing multiple ecosystem services and offering an alternative to clear-cut forestry (Csépányi 2017, Lundmark et al. 2016, Tahvonen 2009, Kuuluvainen et al. 2012, Pukkala et al. 2012). While CCF's impact on carbon balance remains under-explored relative to rotation forestry (RF) (Lundmark et al., 2016), studies have suggested positive effects on carbon dynamics (Lindroth et al. 2012, Pukkala 2014). For instance, Lundmark et al. (2016) found that, assuming comparable growth, extraction, and product use, RF and CCF management strategies offered similar long-term climate benefits, with biomass growth and yield emerging as more critical factors than the choice of management system itself. Additionally, Roth et al. (2023) observed that different management practices affect the quality and durability of soil organic carbon, which influences the mitigation potential of each system.

In Hungary, Csépányi (2017) evaluated the economic efficiency of CCF compared to RF, concluding that continuous cover methods could match the economic returns of traditional systems in beech *(Fagus sylvatica)* and Turkey oak *(Quercus cerris)* stands (Csépányi 2017, Csépányi and Csór 2017). The Pilis Gap Experiment aims to further investigate the benefits of continuous cover management on forest structure, vitality, and ecosystem services in Hungary (Horváth et al. 2023, Aszalós et al. 2023).

Sustainable forest management, which balances social, ecological, and economic outputs, is central to contemporary forestry (MCPFE 2003, Duncker et al. 2012), with many certification programs viewing forest contributions to the global carbon cycle as key indicators of sustainable practice (Forest Stewardship Council 2004). Policies increasingly demand accurate projections of future carbon stock changes to meet international reporting standards (Kurz et al., 2009), as reflected in the Paris Agreement and Regulation (EU) 2018/841, which mandates accounting for emissions and removals from managed forest land within EU climate goals (Grassi and Pilli 2017). With the 2025 implementation of the EU's Carbon Removal and Carbon Farming (CRCF) certification framework regulation, parcel-level carbon balance modelling is becoming increasingly important.

Forest carbon cycle models typically simulate growth either through photosynthesis-driven methods (e.g., 3-PG, Landsberg and Waring 1997; BIOME-BGC, Running and Gower 1991; CENTURY, Metherall et al. 1993; TEM, Tian et al. 1999) or empirical yield curves (e.g., EFISCEN, Nabuurs et al. 2000; CO2FIX, Masera et al. 2003; FORMICA, Böttcher et al. 2008a). Yield-driven models, reliant on empirical data on merchantable wood volume and inventory statistics, are well-suited for simulating human impacts and disturbances on forest carbon stocks in the short term (Pilli et al. 2017; Böttcher et al. 2008b), making them valuable for assessing forest management impacts from local to national scales (Pilli et al. 2016). The Forest Industry Carbon Model (Borovics et al. 2024) is a country specific carbon balance model developed for Hungary in the framework of the ForestLab project (Borovics 2022, Borovics 2024).

Our study aimed to analyse the climate benefits associated with converting 10 hectares of RF to CCF management. Using the FICM modelling framework, we compared the climate balance of these two contrasting management strategies.

MATERIAL AND METHODS

We modelled carbon sequestration, storage, and emissions in forest carbon pools (biomass, dead organic matter, and soil) using the RF and CCF modules of the Forest Industry Carbon Model (FICM). The FICM, a newly enhanced version of the spatially explicit DAS forest model (Kottek 2023), includes additional submodules for soil, dead organic matter (DOM), harvested wood products (HWP), and substitution effects. This stand-based model is designed to project standing volume, increment, harvest, and carbon balance at stand, regional, or national levels. The model was validated against historical NFD data from 2006–2015, showing a deviation of just 1.1% from national volume stock data (Kottek 2023).

In this study, we evaluated the carbon balance impacts of converting RF to CCF in even-aged sessile oak *(Quercus petraea)* forests at two different ages: 60 and 110 years, across a 10-hectare area. We calculated the total carbon stock and annual carbon sequestration of RF and CCF over a 350-year projection period. Additionally, we assessed the total climate change mitigation potential for relevant climate target periods to evaluate the potential impact of this conversion on achieving climate goals.

RESULTS

Our results indicate that in both RF and CCF management systems, the majority of carbon sequestration occurs in the biomass pool, followed by the soil pool (Figures 1, 2). RF management leads to high emissions during the single year of clear-cutting, whereas CCF management produces a more balanced carbon sequestration and emission profile (Figure 3). When converting RF to CCF at age 60, biomass carbon stock continues to accumulate until approximately age 130 (i.e., year 2154), after which a stable biomass carbon stock is observed (Figure 2).

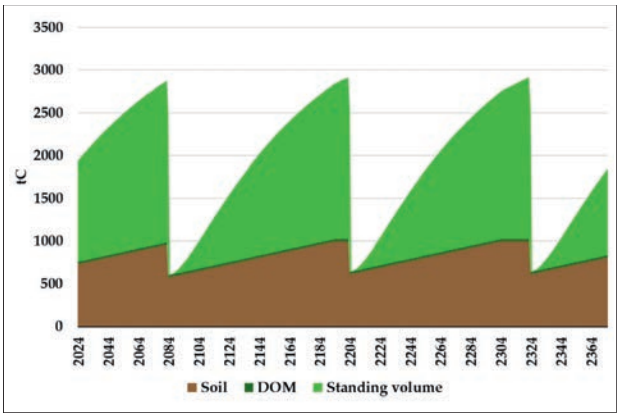

Figure 1: Carbon stock of the soil, DOM and biomass pools of 10 ha forest under RF management.

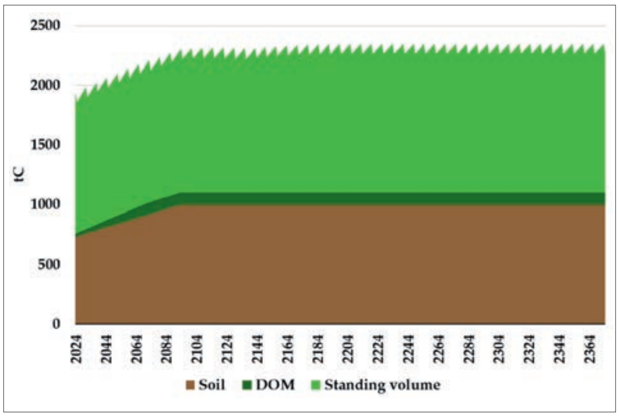

Figure 2: Carbon stock of the soil, DOM and biomass pools of 10 ha forest converted from RF to CCF management at age 60.

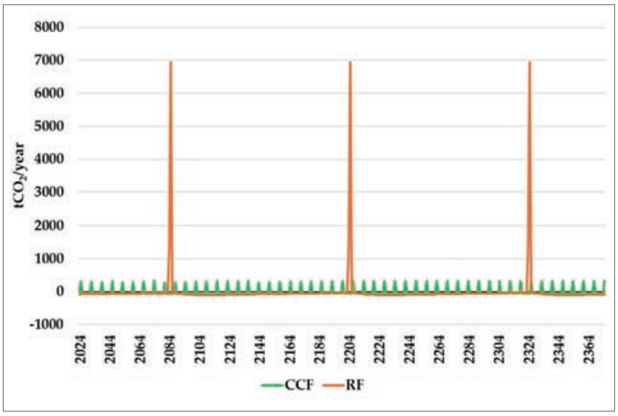

Figure 3: Total carbon balance of the examined RF and CCF forest. (Negative numbers indicate carbon sequestration, while positive numbers indicate emissions.)

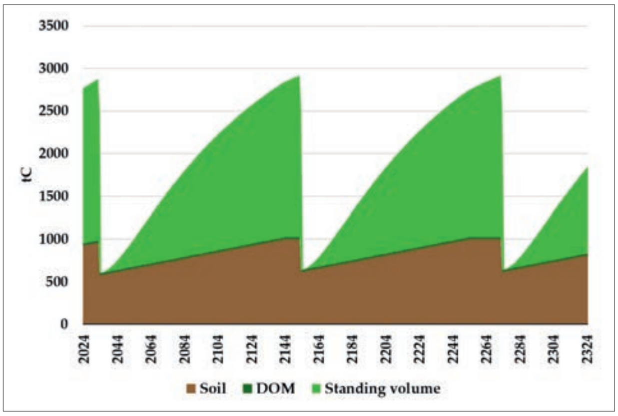

Figure 4: Carbon stock of the soil, DOM and biomass pools of 10 ha forest under RF management.

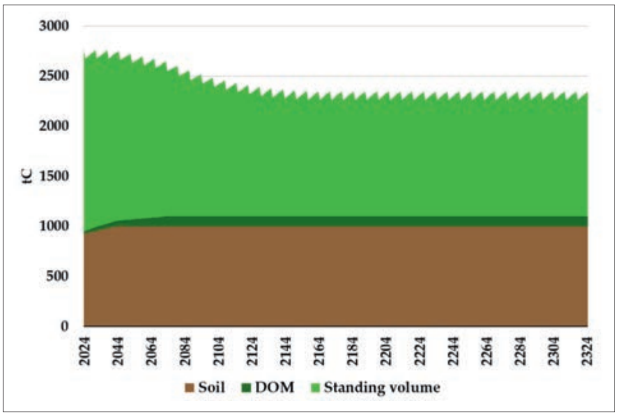

Figure 5: Carbon stock of the soil, DOM and biomass pools of 10 ha forest converted from RF to CCF management at age 110.

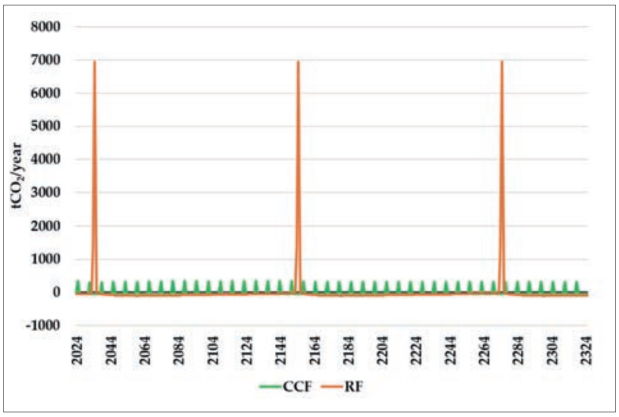

Figure 6: Total carbon balance of the examined RF and CCF forest. (Negative numbers indicate carbon sequestration, while positive numbers indicate emissions.)

In the conversion of RF to CCF at age 110 (Figures 4, 5), biomass carbon stock continues to accumulate until around age 130 (i.e., year 2154), after which it stabilizes (Figure 5). RF management leads to high emissions during the year of clear-cutting, while CCF management maintains a more balanced carbon sequestration and emission profile (Figure 6).

Our results indicate that converting mature-aged RF to CCF has a positive climate benefit up to 2050, while converting middle-aged RF to CCF results in a carbon sequestration deficit (Figure 7). This trend is also evident in the calculated climate change mitigation potentials for converting RF to CCF (Figure 8).

When RF is converted to CCF at age 60, the climate change mitigation potential for the periods 2025–2030, 2031–2050, and 2025–2300 is negative, indicating that RF management would be more beneficial for carbon sequestration during these times. Conversely, for RF conversion to CCF at age 110, the mitigation potential is positive for the periods 2031–2050, 2025–2100, and 2025–2300, showing that this transition supports climate change mitigation compared to RF management in the medium to long term. However, it should be noted that for the period 2025–2030, even in this case, a negative mitigation potential is observed, meaning that in the very short term, conversion to CCF reduces carbon sink capacity compared to RF.

DISCUSSION

The findings of our study highlight significant insights regarding the climate benefits of converting RF man-

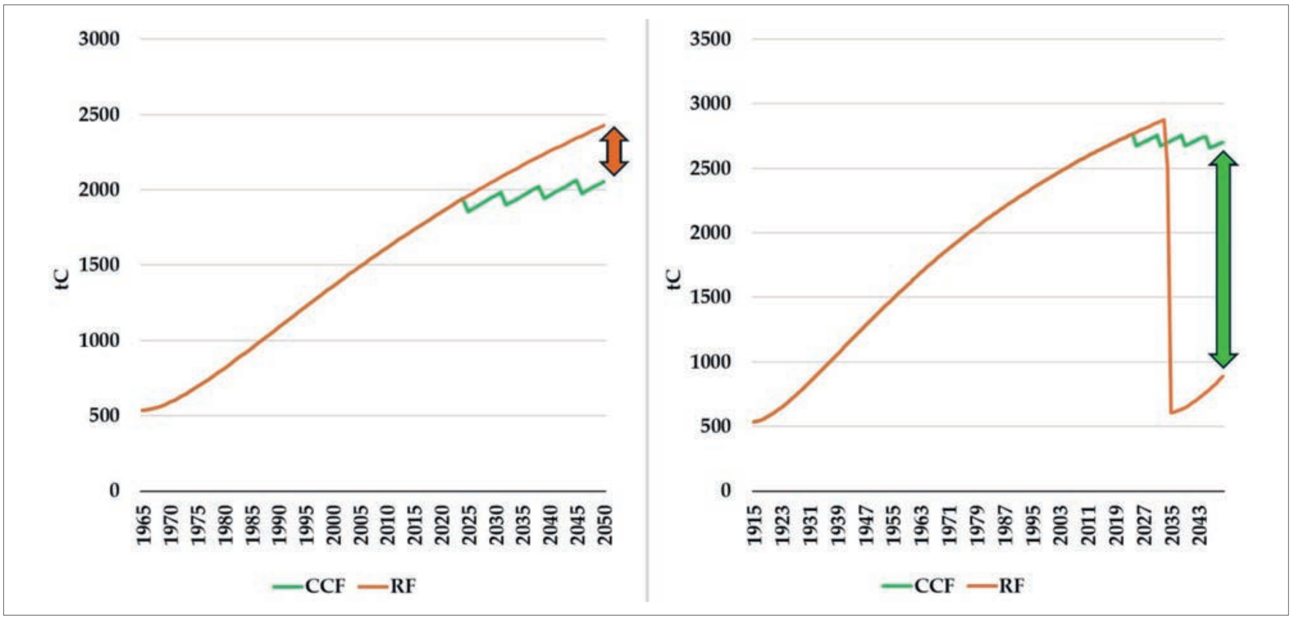

Figure 7: Comparison of the climate change mitigation implications up to 2050 of converting RF to CCF at age 60 or 110.

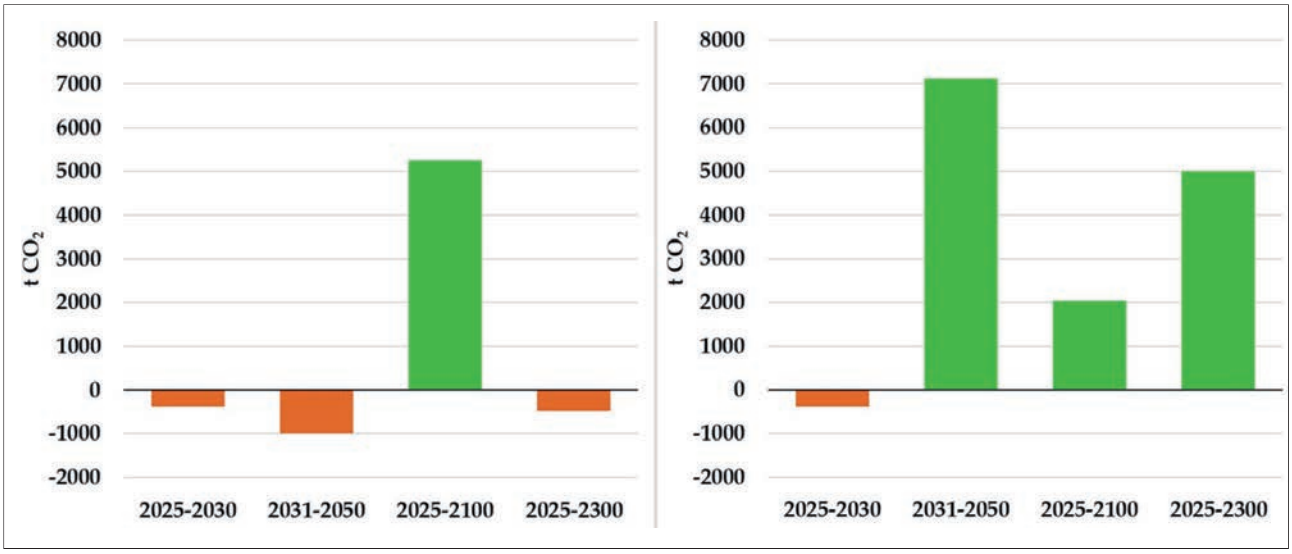

Figure 8: Total climate change mitigation potential of 10 ha CCF as compared to RF. Left: the conversion of RF to CCF occurs at age 60. Right: the conversion of RF to CCF occurs at age 110.

agement to CCF management. Our results indicate that while the transition from mature-aged RF to CCF yields positive climate benefits up to 2050, converting middle-aged RF to CCF presents challenges in terms of carbon sequestration, particularly in the short term.

The carbon sequestration dynamics reveal that the age at which conversion occurs plays a crucial role in determining the overall climate benefits. Specifically, when middle-aged RF is converted to CCF, we observe a carbon sequestration deficit, as indicated in Figure 7. This outcome emphasizes the need for careful consideration of forest age and growth stage when implementing management changes aimed at enhancing carbon stocks.

Converting mature-aged RF to CCF appears to provide a net positive climate benefit, as demonstrated by the positive climate change mitigation potential for the relevant periods. As shown in our analysis, the transition at age 110 results in a favourable climate mitigation potential for the periods 2031–2050, 2025–2100, and 2025–2300. However, it is important to note that even with the conversion of mature-aged RF to CCF, a short-term negative mitigation potential is observed during the period 2025–2030. This underscores a potential trade-off, where immediate carbon sink capacity is compromised despite longer-term benefits. Such findings highlight the importance of implementing management strategies that balance immediate carbon sequestration needs with long-term climate goals.

The differences in carbon sequestration profiles between RF and CCF management systems illustrate the complex interplay between management practices, forest age, and carbon dynamics. Our findings indicate that while CCF management can effectively contribute to climate change mitigation, the timing of the transition and the specific management strategies implemented are key factors affecting the results. Additionally, it is essential to emphasize that within the framework of the CRCF regulation, converting RF to CCF represents a valuable strategy that offers biodiversity co-benefits, which can offset short-term carbon sink deficiencies.

CONCLUSIONS

In conclusion, our study underscores the complex relationships among forest management strategies, forest age, and carbon dynamics. By strategically planning the conversion from RF to CCF and taking timing into account, we can optimize carbon sequestration outcomes and help achieve climate change mitigation targets.

Considering the EU's CRCF regulation, it is essential to design and implement climate change mitigation measures that align with 2050 climate goals at the forest stand level. In this regard, the CCF module of the FICM model can serve as a valuable tool.

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SITEVIEWER A DECISION SUPPORT TOOL FOR FOREST MANAGEMENT

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ABSTRACT

Climate change requires effective adaptation oriented decision making. We developed the SiteViewer software as a GIS based impact assessment tool in order to help forest managers assessing yield class changes of major tree species. Besides yield class assessment the software provides options for the most suitable tree species of any given site, too. Additionally, SiteViewer supports the practical utilization of the new digital site-maps, compiled by the researchers of NARIC FRI and HAS RISSAC. With the integration of online GIS resources, the application enables users to access site maps, and climatic datasets to use them. The targeted users of this software are the forest planning experts and forest owners. We provide information about site conditions that are essential to determine forest utilization options. The map resolution of the software is 1 ha / pixel, and it covers the whole territory of the country.

SiteViewer supports the process of forest planning by providing information on climatic and soil conditions of selected production sites, and revealing differences in yield potential of larger forest sections.

The software can be download from the website of NARIC FRI Geoportal (www.ertigis.hu) after clicking on „Térképszolgáltatások" menu item.

Keywords: decision support tools, climate change, forest management planning

INTRODUCTION

Climate change requires effective actions aiming to improve adaptation capacities. The need for adaptation is more crucial in forestry than in other fields of agriculture due to the long term production phase and, the restrictions of technological interventions. These limits make forestry one of the most extensive, site depending sector that has to adapt to site conditions through appropriate species selection (Settele et al. 2014).

In the last decade remarkable research efforts were made to assess and reveal the exposure of forestry sector to climate change. Research aimed to discover the expected impacts of projected changes on forest ecosystems by first of all evaluating the vulnerability of main forest stands (Bontemps and Bouriaud 2013; Dumroese et al. 2015; Misi and Náfrádi 2017)

One aspect of these research actions was focusing on the assessment of growth rates of species under changing climate, and to elaborate the most appropriate species choice options for changing or already changed sites. For this reason in the first stage we prepared a countywide fine scale pilot project for Zala County to establish the basis of the development of site-species, and site-growth statistical modelling within the framework of Agrárklíma TÁMOP project (Illés et al. 2014). In the second stage we prepared a countrywide but coarse resolution model for the main stand forming species within the AGRATÉR project (Illés and Fonyó 2016). Finally, based on the results of the coarse – countrywide and the fine – countywide approaches, we were able to compile the first implementation of a fine scale and also countrywide statistical model for growth and species pattern changes. This latter model was prepared according to the climate change predictions following RCP 4.5 scenario.

In this paper we present a brief description of the datasets which were used for model development together with the applied statistical methods, and the front-end application of developed software called SiteViewer.

MATERIALS AND METHODS

For the statistical model development between the site conditions and growth (yield class) of tree species we used the following data sets:

Climate data

Climate data was taken from the Climate EU database (Wang et al. 2016) that represents the whole territory of Europe and it provides climatic and bioclimatic variables as rasters. In this database climate data is downscaled to 1 km by 1 km spatial resolution.

By default, the following periods are available: 1961-

1990 (baseline); 1981-2010; 2041-2070; 2071-2100 (https://sites.ualberta.ca/~ahamann/data/climateeu.html).

Soil data and soil related data

Soil data was taken from the new digital soil map series of Hungary that was created by our research team (RISSAC – NARIC FRI). The map series compilation was based on the data of almost 60,000 soil profile locations throughout the country. Soil data maps spatial resolution is 1 ha (100 m by 100 m) (Pásztor et al. 2018)

The soil dataset contained factor variables including genetic soil type, soil depth category, and texture class.

In an additional map layer we provide information on possible occurrence and type of extra water supplies beside precipitation. This map layer categorizes sites having no additional water supplies, or sites having surface accumulated water sources, or sites having additional water supply from groundwater sources.

Forest growth data

For forest data we used the National Forestry Database selecting the seven most frequent stand forming species. These species are as follows: beech (Fagus sylvatica), black locust (Robinia pseudoacacia), Austrian pine (Pinus nigra), Scots pine (Pinus sylvestris), sessile oak (Quercus petraea), pedunculate oak (Quercus robur), and Turkey oak (Quercus cerris). Only those stands were involved where the area proportion of targeted species reached or exceeded 75%.

Prediction methods

The climate – soil – forest datasets were joined and we set up the yield class – site condition models species by species applying random forest algorithm in R Studio. The models' accuracy assessments were done by test runs on separate datasets for each species. Accuracy was found between 65-92%. For the predictions we used the RCP 4.5 emission scenario based ensemble climate projections for the period of 2041-2070 as boundary condition.

Application development

The resulted maps serve as core data for SiteViewer application. The program was developed as a .NET based Windows program for end users. Map data are stored in our GIS server and the necessary data is provided to each standalone program instances via Internet connection. This way we can continuously improve and maintain the map databases, while the users do not need to upgrade their front-end application.

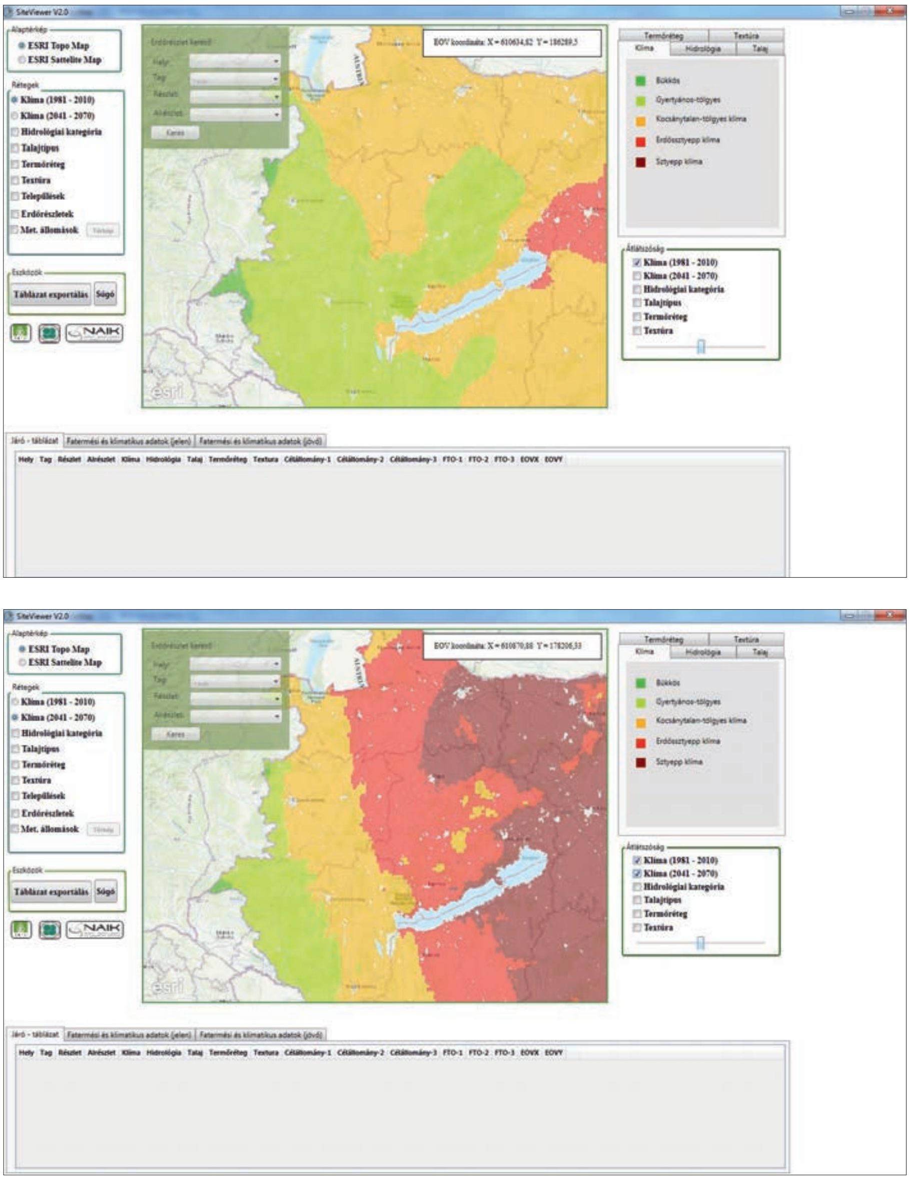


Figure 1: Example of recent (up) and future (down) forestry climate zone maps in the software

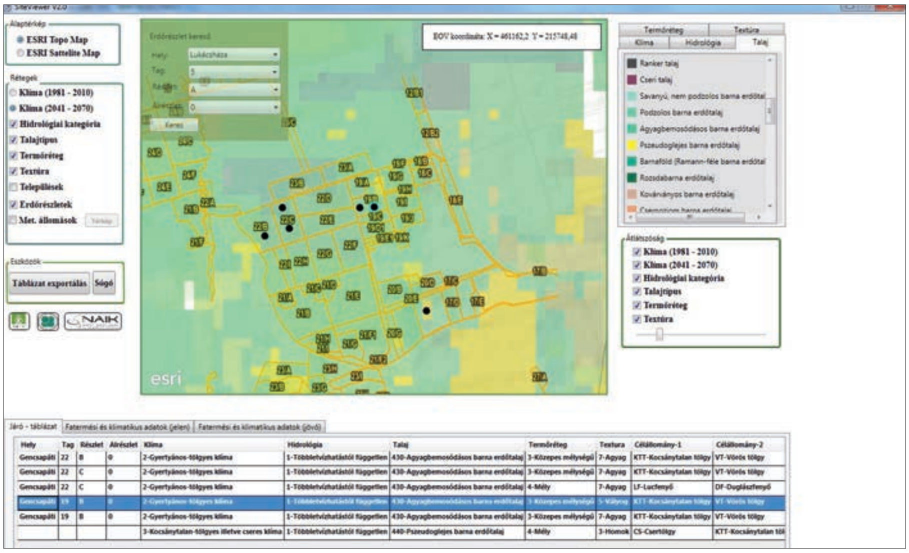
Additional services are also included into this desktop application, such as forest stand map thanks to erdoterkep.nebih.gov.hu, administrative boundary map of municipalities, and forest compartment finder to help navigation. The program also provides access point to the data of our network of forestry meteorological stations.

RESULTS

We present here some utilization options of SiteViwer. Not all the options are covered in this chapter due to size limitations. For further details check the help documentation of the software.

An obvious way of utilization is using map overlays (Fig. 1). All the included map layers can be overlaid and by setting transparency of layers the application offers the option of visual data interpretation for larger areas.

Getting more in the details SiteViewer provides an easy way for evaluating the site condition of selected forest compartments – found even by the compartment search module or by map navigation (Fig. 2).



Hely	Tag	Részlet	Alrészlet	Klíma	Hidrológia	Talaj	Termőréteg	Textura	Célállomány-1	Célállomány-2
Gencsapáti	22	B	0	2-Gyertyános-tölgyes klíma	1-Többletvízhatástól független	430-Agyagbemosódásos barna erdőtalaj	3-Közepes mélységű	7-Agyag	KTT-Kocsánytalan tölgy	VT-Vörös tölgy
Gencsapáti	22	C	0	2-Gyertyános-tölgyes klíma	1-Többletvízhatástól független	430-Agyagbemosódásos barna erdőtalaj	3-Közepes mélységű	7-Agyag	KTT-Kocsánytalan tölgy	VT-Vörös tölgy
Gencsapáti	22	C	0	2-Gyertyános-tölgyes klíma	1-Többletvízhatástól független	430-Agyagbemosódásos barna erdőtalaj	4-Mély	7-Agyag	LF-Lucfenyő	DF-Duglászfenyő
Gencsapáti	19	B	0	2-Gyertyános-tölgyes klíma	1-Többletvízhatástól független	430-Agyagbemosódásos barna erdőtalaj	3-Közepes mélységű	5-Vályog	KTT-Kocsánytalan tölgy	VT-Vörös tölgy
Gencsapáti	19	B	0	2-Gyertyános-tölgyes klíma	1-Többletvízhatástól független	430-Agyagbemosódásos barna erdőtalaj	3-Közepes mélységű	7-Agyag	KTT-Kocsánytalan tölgy	VT-Vörös tölgy
				3-Kocsánytalan-tölgyes illetve cseres klíma	1-Többletvízhatástól független	440-Pszeudoglejes barna erdőtalaj	4-Mély	3-Homok	CS-Csertölgy	KTT-Kocsánytalan töl

Figure 2: Forest stand selection and site evaluation with SiteViewer

The selected compartments' site data and the most appropriate target species together with their expected growth rates under recent climate are reported to the user. Additional tables provide information on future growth rates predicted under future climate conditions. The bioclimatic indicators and climate data are also provided. Result tables can be exported to MS Excel files where not only the compartments' descriptors and their site data are listed but also the X, Y coordinates of the compartments are involved.

Another useful option in SiteViewer is the compilation of preliminary site and species composition maps as a preparatory step for afforestation. Using the software one can easily create virtual sampling for preliminary site-evaluation. Based on the results a decision can be made whether it is worth at all to think about afforestation project on the given site. This virtualized site exploration however, is better to use for creating sampling design for soil sampling before the afforestation takes place. Based on the underlying satellite image and the virtualised sampling's result the major site types can be assessed and the number of sampling points can be optimized by using the site patch map via e.g.: tessellation (Fig. 3).

Hely	Tag	Részlet	Alrészlet	Klíma	Hidrológia	Talaj	Termőréteg	Textu		
				3-Kocsánytalan-tölgyes illetve cseres klíma	1-Többletvízhatástól független	460-Rozsdabarna erdőtalaj	3-Közepes mélységű	3-Hor		
				3-Kocsánytalan-tölgyes illetve cseres klíma	1-Többletvízhatástól független	710-Típusos réti talaj	3-Közepes mélységű	3-Hor		
				3-Kocsánytalan-tölgyes illetve cseres klíma	1-Többletvízhatástól független	710-Típusos réti talaj	3-Közepes mélységű	5-Vályog	KST-Kocsányos tölgy	CS-Csertölg
				3-Kocsánytalan-tölgyes illetve cseres klíma	1-Többletvízhatástól független	430-Agyagbemosódásos barna erdőtalaj	3-Közepes mélységű	5-Vályog	Nincs javaslat	Nincs javasl.
				3-Kocsánytalan-tölgyes illetve cseres klíma	1-Többletvízhatástól független	710-Típusos réti talaj	3-Közepes mélységű	5-Vályog	KST-Kocsányos tölgy	CS-Csertölg
				3-Kocsánytalan-tölgyes illetve cseres klíma	1-Többletvízhatástól független	710-Típusos réti talaj	3-Közepes mélységű	5-Vályog	KST-Kocsányos tölgy	CS-Csertölg
				3-Kocsánytalan-tölgyes illetve cseres klíma	1-Többletvízhatástól független	460-Rozsdabarna erdőtalaj	3-Közepes mélységű	3-Homok	EF-Erdeifenyő	CS-Csertölg

Figure 3: Afforestation site preliminary site evaluation and identified site patches (inner image) for sampling using SiteViewer

DISCUSSION

There is a huge variety among forestry decision support systems (Mátyás et al. 2018)annual temperatures have increased by 1.2 °C–1.8 °C in the last 30 years and the frequency of extreme droughts has grown. With the aim to gain stand-level prospects of sustainability, we have used local forest site variables to identify and project effects of recent and expected changes of climate. We have used a climatic descriptor (FAI index. This has been originating from the long history of their developments sincs the 1980s. Nowadays, there are almost 70 different systems listed on forstsdss.org. These DSS tools in the beginnings were developed to support bussiness related management decisions. Later, tasks became more diverse, with more mainstream systems focusing on, for example, integrated landscape assessment, or the vulnerability of forests to abiotic damages, or the suitability of species to local site conditions, or even assessing the effects of afforestation. Some of these systems have spatial representation and some have not. The major systems offer the option of spatial analysis as well. Regarding the basic level of analysis most of them report the results on stand level, others have spatial units such as square km or hectare (forstsdss.org).

In this context, our system's main goal is to evaluate climate change impact on the growth of tree species. It implements a random forest based site-climate-yield class model. For the site evaluation our system incorporates the Hungarian expert system for forest site evaluation and extends it with yield class assessments for future climate according to newly appearing climate-site combinations.

CONCLUSIONS

Decision support systems has an increasing role in forest management. Not only for the reason of improving timber production processes but for the reason of sustainability of forest ecosystems exposed to changing climate. We made only the first step towards a sectoral DSS, which would help to identify the best solutions including management, protection and other aspects too. Our results are promising and this encourage us for further efforts. In next steps we have to integrate other modules e.g. for selection of appropriate propagation materials and to perform abiotic damage risk assessment.

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BREEDING RESPONSES TO CLIMATE CHANGE IN VEGETABLE BREEDING

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ABSTRACT

In the last years, the climate change has been a big impact of the success of a vegetable production farm. As a vegetable breeding company, we have a big responsability to create new vegetable varieties, which varieties have good answer for the climate change anomalies. It is not an easy job, but we do a hard work to achieve our goals. In the following, we show you the breeding answers in our four bred species.

Keywords: breeding, climate change, traits, sweet-pepper, cucmber, green peas

EFFECTS OF CLIMATE CHANGE ON PLANTS

The annual yield of a crop production is determined by the soil, the weather and the agronomic techniques used, including the quality of the seeds sown and the nutrient replenishment. While the latter factor reflects the decision and competence of farmers, the first two factors are characteristic of the place of production.

Agricultural science is trying to quantify the impact of weather on agricultural crops in many ways. The success of the methods usually depends on how well their developers know about the living nature (the actual species) and how rich mathematical apparatus they can handle and provide real data with which they can simulate the complexity, of the non-linear nature relationship between climate and yield.

Table 1. summarizes the adverse effects on crop production by season following Terbe (2009).

In spring, the first problem is caused by late frosts. The vegetative period of the plants is expected to start earlier due to climate change, their developmental phases will occur earlier, which will increase their exposure to early frosts. Premature warming interrupts the dormant phase of the plants, and the usual cooling in late April and early May can be very dangerous for all planted vegetables.

In the summer, drought is the main cause of crop failure, but floods are also common over a large area, with hail in some places. However, as the intensity of precipitation increases, not only does runoff increase, but so does soil erosion. Due to improper tillage and soil protection in many places, we must be afraid not only of erosion caused by water but also by wind. Increased solar radiation can degrade crop quality, cause color defects, sunburn, and interfere with nutrient uptake and nutrient transpiration.

Autumn can also cause damage from prolonged growing seasons and early frosts.

The harsh colds of winter will ease, the snow cover will become more precarious, the period of extreme cold will be less. The temperature at the lower boundary of the snow cover is significantly higher than at its surface, and the temperature fluctuation is also greater in the upper layer. Due to the low thermal conductivity of the snow cover, it reduces the cooling of the soil, which allows the plants to overwinter. Snow-covered soils are thus less likely to develop low temperatures that would damage plant organs and soil-dwelling pests in the soil.

The future development of vegetation is in any case influenced by the fact that the carbon dioxide concentration increases, which enhances the photosynthesis of the plants. As a result, biomass increases and yields also but in lesser extent. The ratio of individual plant parts may change. Higher CO_2 concentrations reduce the specific evaporation capacity of plants, thus improving the utilization of available water.

Table 1: Adverse climate impacts threatening vegetation based on Terbe (2009)

Spring	Summer	Autumn	Winter
premature warming early wake up, frost, flooding	drought, deflation, flood soil erosion, hail, new pests from the south, southeast, sunburn,	prolonged vegetation period, early frosts, flooding	without snow cover a damage to overwintering plants, low water reserves, flooding

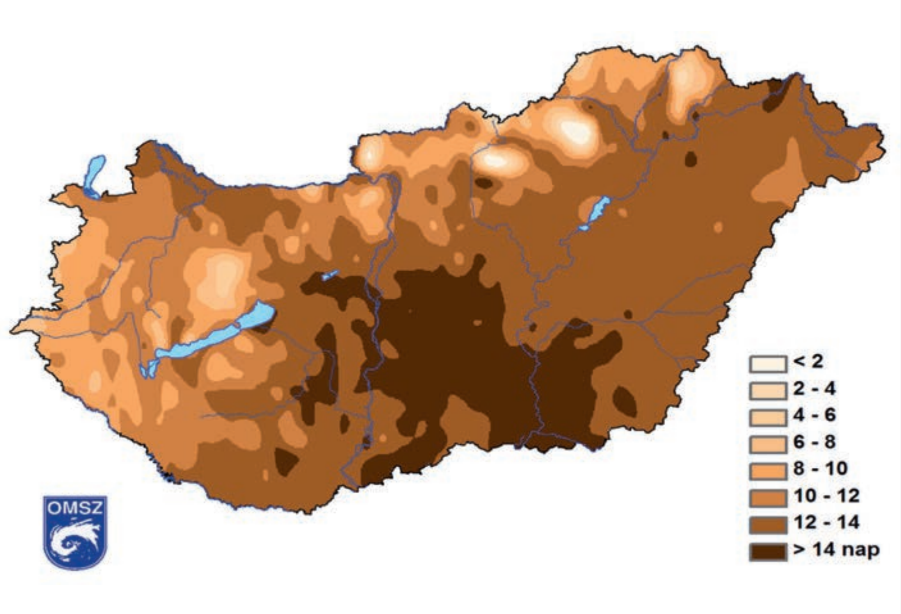

Figure 1: Number of heat days 1981-2016

Temperature extremes

Not only the temperature values themselves, but also the tendencies in the intensity and frequency of the extreme values are signs of a changing climate. Both a decrease in the number of frosty days (daily minimum temperature < 0 °C) and an increase in the number of heat days (maximum daily temperature ≥ 30 °C) indicate a warming trend (Figure 1). The cooler and warmer periods are also reflected in the values of the extreme indices, but extreme warm weather situations have become more frequent since the 1980s.

Abiotic and biotic stress factors

Stress effects on plants (e.g. strong light intensity, extreme temperatures, drought, salt or heavy metal contamination, damage, insect bites or sucking, viral, bacterial or fungal infections) result in significant metabolic changes. Some of them represent a series of alternative biochemical processes following the modification of existing metabolic pathways, by canging of connections and regulations, while others represent the activation of new genes. For almost all types of stress (both biotic and abiotic), one of the most characteristic responses is the formation of reactive oxygen species (ROFs) and the formation of an oxidative microenvironment within the cell. In general, conditions affecting all organisms with a similar mechanism, such as light, temperature, air, atmosphere, water, wind, and environmental conditions affecting specific species and ecosystems, such as soil, salinity, topography and natural disasters. Together with biotic factors (evolution, symbiosis, competition, etc.) they form the natural environment.

The abiotic environment affects the stability (or instability) of an ecosystem from two directions: on the one hand, it provides the conditions necessary for life to survive (e.g. temperature, water), and on the other hand, the population must adapt to the conditions it provides (e.g., extreme temperatures, water scarcity). Even the slightest permanent (eg soil erosion) or intermittent (e.g. flood) changes in abiotic factors can make the individual of the given ecosystem unstable and cause adaptation and acclimatization problem.

EFFECTS OF CLIMATCHANGE TO THE ZKI BRED SPECIES

Sweet peppers

The key biological need of field peppers in Hungary is the unmet heat demand for most of its growing time. Therefore, other biological needs, in particular water replenishment by cooling the environment, must be met by taking this primary need into account.

Water demand: Sweetpepper is a water-intensive plant at the level of optimal satisfaction of its other biological needs. This is evidenced by the following indicators. The transpiration coefficient of the peppers (water evaporated to produce a unit of dry matter) is around 300. An indicator that can also be used from a cultivation point of view is the water consumption coefficient (water evaporated by the plant and the soil together to produce a unit of raw fruit weight), which is around 100 for peppers. We can only talk about the water demand of peppers depending on their heat demand. The correlation between the heat demand and water consumption from several years of observation is that an average of 6 °C of heat induces 1 mm of evapotranspiration water consumption in the field pepper field.

Light demand: Sweet peppers are a light-requiring plant, but it can also be concluded from several experimental observations that the lighting required for fruit kitting, which is stronger than the variety-specific threshold, is unnecessary for the plant. Beyond a certain limit, it is harmful to cultivation. Instead of experimental data on harmful luminosity and light spectrum, which are still incomplete today, we note the simplest ways to eliminate the harmful effects of excessive luminosity:

- field transplanting must be completed by 25 May;
- late or summer sown seedlings grown outdoors (e.g. for autumn shoots) should be shaded.

Heat request.: The heat demand of peppers is 25 ± 5 °C, depending on their different stages of development. The average requirement of 25 °C increases by 5–7 °C during germination. Peppers do not kit fruits above 35 °C.

The effect of drought on pepper cultivation

Atmospheric drought:

- Poor fertilization
- Low yield
- Distorted fruits

Lack of soil precipitation:

- Low yield
- Distorted fruits

Strong UV radiation:

- Sunburn of the fruits

Breeding responses

- Atmospheric drought:

Solution primarily for cultivation technology (sprinkler irrigation)
Selection of lines in the target environment

- Lack of soil precipitation:

Selection of lines in the target environment
Selection of hybrids in the target environment, performance test, root selection.

One of the most effective selection is the root selection:
Root architecture is the most promising characteristic for drought avoidance to be used in breeding. Such characteristics can greatly improve drought-resistance of crops. (Figure 2) Based on the consistent results from a series of analyses and experimental validation, we can conclude that the ATP synthesis should be a key factor to influence the root architecture.

Effective breeding for development and identification of drought tolerant pepper, good selection criteria are needed to distinguish the drought tolerant genotypes. Numerous selection indices based on mathematical relationship between stress and non-stress conditions has been established.
These indices are based on vulnerability and tolerance of genotype to drought. Drought tolerance is defined as the ability of plants to grow and reproduce optimally and then provide satisfactory yields when water availability is limited. Drought vulnerability genotype is often measured as a function of yield reduction under drought pressure, suggested the stress susceptibility index (SSI) for measurement of yield stability that understands the changes in both potential and actual yields in variable environments. We can defined stress tolerance as the differences in yield between stress and normal conditions and mean productivity as the average yield of genotypes under stress and non-stress conditions.

Figure 2: In some cases, the root can be examined at an early stage.

Strong UV radiation:
The trong UV radiation can cause big yield loss, and damage on the fruits (Figure 3) Appearance of secondary pathogens on the affected part can also be a very dandgerous effect. Only one solution for this problem is the selection for good foliage coverage, and also selectoin of high decease resistant varieties.

Figure 3: Strong UV radiation on pepper

ZKI have already one solution for this problem, it is the CMV and Xv Resistant Tomato Peppers called: TEMES F1. ZKI Zrt is the market leader in the tomato-shaped pepper market in terms of commercial turnover, thanks to a hybrid called Bihar F1. Based on this and the needs of the market, the pepper breeding group has set itself the goal of developing a new tomato-shaped pepper, which can be considered a novelty on the world markets. With regard to the modern, high-demand, resistant tomato pepper hybrid, it is important to know that in terms of its use, tomato peppers are one of the most important raw materials in the processing industry, despite the fact that fresh market demand for them is also significant. The processing industry is placing ever higher demands on the raw material supplied: the product must be pesticide-free and of high quality.

The majority of tomato-shaped pepper cultivation takes place outdoors. The shed is perfect to protect from high UV raadiation. Among the pathogens, both cucumber mosaic virus (CMV) and Xanthomonas cause significant crop loss. It is very difficult to protect against CMV because viral vectors are aphids that can cause large infections even in relatively small numbers.


Figure 4: Temes F1

Cucumber: Important traits in cucumber productions

Soil salinization

It has long been known in vegetable production that each vegetable species reacts differently to soil salinization. Some show an acceptable level of development even on slightly saline soils, while others stop their development quickly on such soils or due to poor quality - salinating - irrigation water. In the last ten years, with the advancement of nutrient solution (simultaneous application of water and nutrients), the role of this plant property has come to the fore, it has become an important part of cultivation technology.

Among the plants, salt tolerance (halophytes), moderately salt-tolerant, and salt-sensitive (glycophytic) plants can be distinguished on the basis of salt stress, i.e. sensitivity to soil salinization. The latter group includes most of the vegetables grown and known in Hungary. In the case of vegetables, the category "salt tolerant" can only be considered relative, which means that the plants belonging to this group are less sensitive to soil salinisation or high concentrations of nutrient solution, only the so-called they are "salt tolerant" compared to a sensitive group, but they are sensitive compared to saline plants.

Drought Resistance

Drought during the production of cucurbit crops can lead to shorter vines, cause delayed flowering, and shift the plant towards maleness (with more staminate, fewer pistillate flowers), and reduce fruit yield and quality.

Flooding Resistance

In most cases, cucurbit crops are extremely sensitive to flooding, which is why they are often grown on well-drained soils, or in arid regions. Raised beds are useful in areas with rain during the production season, unless the soils are sandy.

Heat Resistance

Heat tolerance is an important trait for cucumber production, considering that many countries in the tropics struggle with food security issues.

Breeding response:

At ZKI we have established several selection criterias for the above mentioned stress factors, to decrease the adverse effect the plants.


Figure 5: The effect of high UV in cucumber cultivation

Drought:
Selecton for strong root system
Foliage with low transpiration coefficient
High temperature:
Intensely functioning root system despite high heat
Row Selection

Increased radiation (Figure 5):
Strong foliage covering the crop
Fruit-shelled genotypes less sensitive to sunburn

Wind damages:
Thick-textured leaf plate
Strong flexible petiole
Strong stem

Peas

Green peas *(Pisum sativum L.)*, a typical temperate vegetable plant with some frost tolerance, is one of the earliest to be eaten fresh. According to producer experience, it is a plant of "warm spring, cool summer". Among vegetables, the second largest crop in Hungary (after sweet corn) accounts for 20% of the domestic vegetable production area. More than 90% of the surface is machine-cleaned, and the canned canned or frozen goods are made. Its production area in Hungary - according to CSO data - has been 14-17 thousand hectares in recent years.

Reqirements:

It requires intense lighting and long day conditions. At low brightness, the growing season is extended and the flowers become less fertile. There are two critical periods in terms of water demand, the time of germination and the time of flowering. When peas germinate, they absorb 105-110% of the seed weight. Its water demand is usually provided from the stored autumn-winter precipitation. To produce one ton of crop, you need 18.9 kg of nitrogen, 5.6 kg of phosphorus, and 15.2 kg of potassium pure active ingredient.

The last two years have not been favorable for green pea cultivation in terms of weather. The year 2018 brought the worst yields of the last 15 to 20 years, with an average yield of 3.9 to 4 tons instead of the planned and expected 5.5 to 6 tons. This has had and still has an effect on the spirit of cultivation. By 2019, there was a significant reduction in production area, in 2019 the sown area was only 19 200 hectares, which means a decrease of approximately 10 percent. As the year 2019 did not do well either, the decline will continue in 2020 as well.

The cultivation of peas in the domestic processing industry is still 30-40% under non-irrigated conditions. Growing green peas seems simple, but it is becoming increasingly risky due to the effects of climate change. Despite its short growing season (3 to 3.5 months), it can no longer be produced reliably without irrigation and modern nutrient replenishment. In the last decade, research into cultivation technologies (use of varieties and types, tillage methods, nutrient replenishment experiments, etc.) has lagged behind, without which development is difficult.

A solution is needed to breed drought-tolerant varieties

Breeding response:

The breeding of drought-tolerant varieties in Hungary began in the second half of the 19th century. It achieved its first successes in the first half of the 20th century. At that time, yield averages were still relatively low, and breeders often started from landscape varieties, primitive forms, and ecotypes adapted to the domestic drought in the production of varieties. However, due to the transition to intensive agricultural production, these varieties, due to their productivity and many other disadvantages, soon disappeared from public cultivation. In producing increasingly abundant varieties, breeders have sought to obtain and use other genetic resources — the best genotypes in the world. Classical selection was performed in two directions:
a / for higher root mass for a higher water uptake, and
b / for smaller leaf area and better waxiness for lower water release. However, traditional breeding has not been able to show substantial progress. The main reasons for this are, on the one hand, the changing appearance and complex effect of drought.

Genetic and methodological reasons for the lack of drought tolerant varieties:

- Drought-adapted varieties produce less, even in drought conditions, than intensive, high-yielding varieties and hybrids,
- drought tolerance and yield is negatively correlated,
- knowledge of the inheritance of drought tolerance traits is lacking or incomplete,
- drought tolerance is a complex property, therefore selection for a single stamp (gene) does not lead to results,
- the interactions of genes associated with drought tolerance are unknown, there are currently no morphological, phenological, physiological or biochemical, etc. a test that is in itself suitable for determining the drought tolerance of a genotype and could therefore be used for reliable selection of drought tolerant genotypes, selection on traditional stamps (eg root mass, leaf waxiness, hairiness, stoma count, cuticle thickness, senescence, etc.) did not lead to breakthrough, substantial progress,

Figure 6: Strong roots, and effect of that

Figure 7: Double wrinkled peas

we cannot expect rapid successes from newer selection approaches - (eg infrared temperature measurement and photography, artificial drought stress, various physiological parameters, etc.), which are currently being tested or introduced.
However we have estblished some easy and well followed selection criteria such as:

- very strong roots (the stronger the roots, the more drought resistant) (Figure 6)
- good soil cover (the better the plant cover, the less soil evaporation)
- semi-afila types (due to varietal nature)
- double wrinkled types (due to varietal character)
- choosing varieties where the flower is covered with leaves (the less the pollen burns, the more it will not cause abortion)
- concentrated flowering
- 3 pods / floor

Watermelon: The effect of drought and high UV in Watermelon cultivation

Losses due to sunburn and heat shock during periods of intense summer sun exposure are a growing problem in outdoor cultivation. Sunburn alone can result in up to 10-15% loss of yield, depending on the degree of damage, which in the case of intensive growing conditions corresponds to a worthless yield of 8 000-12 000 kg / ha in watermelon. This loss may be further exacerbated by outages due to physiological processes that become unfavorable due to overheating. In addition to the symptoms of sunburn necrosis on the crop, strong irradiation and high temperatures already inhibit photosynthesis beyond a certain point, leading to a loss of quality and quantity.

High UV:
Requires 12 hours of sunlight per day, responds sensitively to light intensity. Excessive UV radiation from the fruit symptoms of sunburn. This completely destroys the integrity and marketability of the crop. Therefore, as a result of climate change, it is primarily the high, increasingly extreme levels of UV that are taken into account during breeding.
It is therefore appropriate to limit the extent of intensive exposure to crops as much as possible. With the cultivation technology and the choice of variety, the aim should be to develop sufficient foliage to protect the crops in the shade, but this alone is often not enough to prevent problems.

Figure 8: The effect of high UV in the Watermelon fruit

Drought:
Water is increasingly becoming a limiting factor for agricultural production, especially in arid, semi-arid climates such as the Mediterranean region. The competition for water resources between agriculture, industry and the population requires the continuous irrigation technology development of vegetable production. As a long-established method for woody plants, one way to increase water use efficiency and avoid yield losses in vegetable crops is to graft greenery plants to drought stress-reducing

rootstocks under water-scarce conditions.
- In order to grow the crop, it requires a very large amount of water in Hungary only by irrigation
- Evaporates very intensively due to summer heat, can lose up to 2 liters of water per day Intensive technologies Drip irrigation and nutrient replenishment

Breeding response:

Drought:

- strong deep penetrating roots, leading to more efficient water uptake

Water stress is an important cause of reduced yield in watermelon. It may be that some genotypes are more efficient in water use than others, but it probably will be difficult to develop highly efficient varieties since watermelon fruit have very high water content. In Israel, deep-rooted varieties are used in unirrigated desert areas.

Pollination problems are responsible for improper fruit development. It is necessary for all three lobes of the stigma to be fully pollinated if the fruit is to develop fully, and without curvature. Proper fruit development requires adequate numbers of honeybees or bumblebees during flowering, along with weather that is conducive to pollination. Bumblebees can be more effective pollinators than honeybees. Cold, rainy weather leads to poor pollen shed, and hot weather often leads to reduced bee activity. In the case of triploid hybrids, it is necessary to have up to one third of the field planted to a diploid pollenizer to assure adequate fruit development in the triploids which are male sterile.

The melons, once planted, grow so rapidly, if temperatures are favorable, that relatively few cultivations can be given after the plants show aboveground. The strong development of the laterals in the several species of cultivated cucurbits becomes apparent early in the life of the plant.

Figure 10: Healthy baby watermelon

- strong stems and foliage which provides better soil cover.

High UV:

- large area of foliage covering mainly the crop
- strong vigor,
- by selecting the peel less prone to sunburn.
- breeding resistance to leaf and stem diseases (a new challenge)

Deceases:

Fusarium Wilt. Fusarium wilt is caused by *Fusarium oxysporum f. sp. niveum*. The disease was first reported in 1889 in Mississippi, and was widespread throughout the southern parts of the United States by 1900. Three types of pathogen spores are commonly observed: small, colorless, oval, non septate microconidia; large, sickle shaped, septate macroconidia; and thick walled circular chlamydospores. There are three races known: 0, 1, and 2. Most current varieties are resistant to race 0, and some also are resistant to race 1. Race 2 was discovered more recently, and occurs mainly in the south central production areas such as Texas and Oklahoma, but it also has been found in Florida.

Anthracnose. Anthracnose caused by *Colletotrichum lagenarium* is an important disease of watermelon in the United States. Symptoms caused by this pathogen may occur on leaves, stems, and fruit. Lesions on leaves are irregular shaped, limited by the leaf vein, and brown to black in color. Lesions on the stem are oval shaped and tan colored with a brown margin. Lesions similar to those found on stems and leaves also appear on the fruit. Older fruit show small water-soaked lesions with greasy, yellowish centers that are somewhat elevated. Seven races of the anthracnose pathogen have been reported. Races 4, 5, and 6 are virulent in watermelon, but races 1 and 3 are most important. Many varieties are resistant to races 1 and 3, and resistance to race 2 will be needed in the near future.

CONCLUSIONS

The abiotic environment affects provides the conditions necessary for life to survive (e.g., temperature, water), and on the other hand, the population must adapt to the conditions it provides (e.g., extreme temperatures, water scarcity). All in all, we have good technics in breeding, to select varieties which are able to survive extreme climate conditions and also good understanding what to do, which directions to go in senlecting new promising, and valuable varieties for the effects caused by the climate change.

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GRASSLAND-HU LIFE Integrated Project aims to improve the conservation status of grasslands and related species on long-term

- Compilation of National Grassland Strategy Plan
- Fighting invasive alien species
- Forming model farms
- Network of Grassland Conservation Advisors
- Preparation or revision of national and international species action plans of grassland flagship species
- Raising public awareness and delivering information
- Baseline survey and monitoring

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