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Effects of Simulated Forest Cover Change on Projected Climate Change – a Case Study of Hungary

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Abstract – Climatic effects of forest cover change have been investigated for Hungary applying the regional climate model REMO. For the end of the 21st century (2071–2100) case studies have been analyzed assuming maximal afforestation (forests covering all vegetated area) and complete deforestation (forests replaced by grasslands) of the country. For 2021–2025, the climatic influence of the potential afforestation based on a detailed national survey has been assessed. The simulation results indicate that maximal afforestation may reduce the projected climate change through cooler and moister conditions for the entire summer period. The magnitude of the simulated climate change mitigating effect of the forest cover increase differs among regions. The smallest climatic benefit was calculated in the southwestern region, in the area with the potentially strongest climate change. The strongest effects of maximal afforestation are expected in the northeastern part of the country. Here, half of the projected precipitation decrease could be relieved and the probability of summer droughts could be reduced. The potential afforestation has a very slight feedback on the regional climate compared to the maximal afforestation scenario.

climate change / forest cover change / drought probability

Kivonat – A klímaváltozás hatáskorlátozásának esélyei erdőtelepítéssel Magyarországon. A magyarországi erdők klímaváltozás-hatáskorlátozó szerepét három felszínborítás-változási forgatókönyvre számszerűsítettük a REMO regionális klímamodell segítségével. A 2071–2100-as időszakra vizsgáltuk, hogy a feltételezett maximális erdőtelepítéssel (minden növényzettel borított felszín erdő), valamint a hazai erdőterületek gyeppel történő helyettesítésével milyen irányban és mértékben befolyásolhatók az előrevetített hőmérséklet- és csapadéktendenciák. A 2021–2025-ös periódusra a rossz adottságú és gyenge minőségű szántók helyére tervezett erdők éghajlati hatását elemeztük. A modellszimulációk eredményei alapján az erdőterület változás, amennyiben nagy kiterjedésű, összefüggő területeket érint, hatással van a regionális klímára. A feltételezett maximális erdőtelepítéssel a nyári hónapban a csapadékmennyiség növekszik, a felszínhőmérséklet csökken, melynek nagysága régiónként eltérő. A legnagyobb hatás az ország északkeleti részén várható, ahol a klímaváltozással járó csapadékmennyiség-csökkenés fele kiegyenlíthető lenne és az aszályos nyarak száma is csökkenhet. A potenciálisan megvalósítható, országos átlagban 7%-os erdőterület növekedésnek nincs jelentős hatása a regionális éghajlati viszonyokra, bár a lokális klimatikus hatások kedvezőek lehetnek. Az erdő-klíma kölcsönhatások számszerűsítése nem csak az erdők klímavédelmi szerepéről ad információt, hanem az éghajlatváltozás következményeinek megelőzését, enyhítését célzó stratégiák alapja is lehet.

klímaváltozás / erdőtelepítés / aszálygyakoriság

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1 INTRODUCTION

For Hungary, the projected warming and drying trend of summers is significant in the 21st century (Christensen 2005; Bartholy et al. 2007; Bartholy – Pongrácz 2007; Szépszó – Horányi 2008; Krüzselyi et al. 2011; Pieczka et al. 2011). Not only the climatic means but also the extremes are affected by climate change. The latter are more important from ecological point of view. Probability and severity of summer droughts are expected to be significantly higher, droughts might occur in every second summer for the period 2071–2100 (Gálos et al. 2007) that may have severe impact on agriculture and forestry. Forests are not able to adapt to rapid changes of climatic conditions. Especially zonal tree species are affected at their lower (xeric) limit of distribution (Mátyás et al. 2009). Regional impact studies show that recurrent droughts cause growth decline and mortality, e.g. in beech forests in Southwest Hungary (Berki et al. 2009; Lakatos – Molnár 2009). Ecological models of forest distribution expect the reduction of macroclimatically suitable areas for beech for the future and the possible disappearance of this species from Hungary (Mátyás et al. 2010; Czúcz et al. 2011).

In turn forests interact with climate through biogeophysical and biogeochemical processes. Focusing on the physical effects, they can alter the climate conditions, precipitation and temperature variability through their influence on surface energy fluxes and water cycle on various scales (e.g. Pielke et al. 1998; Pitman 2003; Betts 2007; Seneviratne et al. 2010; Móricz 2010). Changes of the land cover due to climatic conditions and human influence feed back to the atmosphere, can lead to the enhancement or reduction of the projected climate change signals (Feddema et al. 2005; Bonan 2008; Wramneby et al. 2010).

Climatic effects of forests are determined by various contrasting feedbacks (e.g. Hogg et al. 2000; Anav et al. 2010; Teuling et al. 2010). Results of model simulations agree quite well regarding biogeophysical effects in boreal and tropical forests (Dickinson – Kennedy 1992; Bonan 2008; Göttel et al. 2008). Whereas the magnitude of the net climate forcing and benefit of temperate forests and their role in the climate change mitigation is considered smaller or uncertain (Bala et al 2007; Jackson et al 2008), as model results are conflicting.

Hungary has been selected as study area because of

- large scale land use changes,
- high sensitivity of zonal forest belts of the lowlands (Mátyás – Czimber 2004; Jump et al. 2009),
- serious consequences (i.e. forest cover loss) of climate change at xeric limit.

In Hungary, large scale afforestations were carried out in the last 50 years, which is planned to continue also in the near future. Results of mesoscale model studies showed that land use change in the 20th century already altered weather and climate (Drüszler et al. 2010). So far however, climatic effects of forest cover change in Hungary have not been investigated for longer future time periods on regional scale. Information about the forest-climate interaction is essential both for the assessment of mitigating effects, and for the development of future adaptation strategies.

Case studies have been carried to investigate

- climatic influences of maximal afforestation, deforestation and potential afforestation and its regional differences,
- magnitude of the climate change mitigating effects of maximal afforestation with special focus on precipitation and drought probability.

2 MODEL AND METHODS

2.1 The regional climate model REMO

The climate change driven by emission change and land cover change have been studied applying the REgional climate MOdel, REMO (Jacob 2001; Jacob et al. 2001; Jacob et al. 2007). This is a regional three-dimensional numerical model of the atmosphere. The prognostic variables are calculated based on the hydrostatic approximation. Land cover is described by its physical properties in REMO: leaf area index and fractional vegetation cover for the growing and dormancy season, background albedo, surface roughness length of the vegetation, forest ratio, plant-available soil water holding capacity and volumetric wilting point. These properties are allocated in the global dataset of land surface parameters (Hagemann et al. 1999; Hagemann 2002) for each land cover type.

In the current model version biogeochemical processes and vegetation dynamics are not considered. Vegetation phenology is represented by the mean climatology of the annual cycle of leaf area index, vegetation ratio and background albedo (Rechid and Jacob 2006; Rechid et al. 2008a,b). The values of these vegetation characteristics are varying monthly throughout the year, the other land surface parameters remain constant in time.

For Hungary, REMO has been validated against observations for temperature, precipitation (Jacob et al. 2008; Szépszó – Horányi 2008) as well as for the occurrence and severity of droughts (Gálos et al 2007). It has been also applied to climate change projections (Szépszó – Horányi 2008; Szépszó 2008; Jacob et al. 2008; Gálos et al. 2007; Radvánszky – Jacob 2008; Radvánszky – Jacob 2009) and land use change studies (Gálos et al. 2011) for the Carpathian basin.

2.2 Experimental setup

The simulation domain covers Central Europe *(Figure 1)* with 0.176° horizontal grid resolution. The model has been initialized and driven by REMO 0.44° simulations, applying a double nesting procedure.

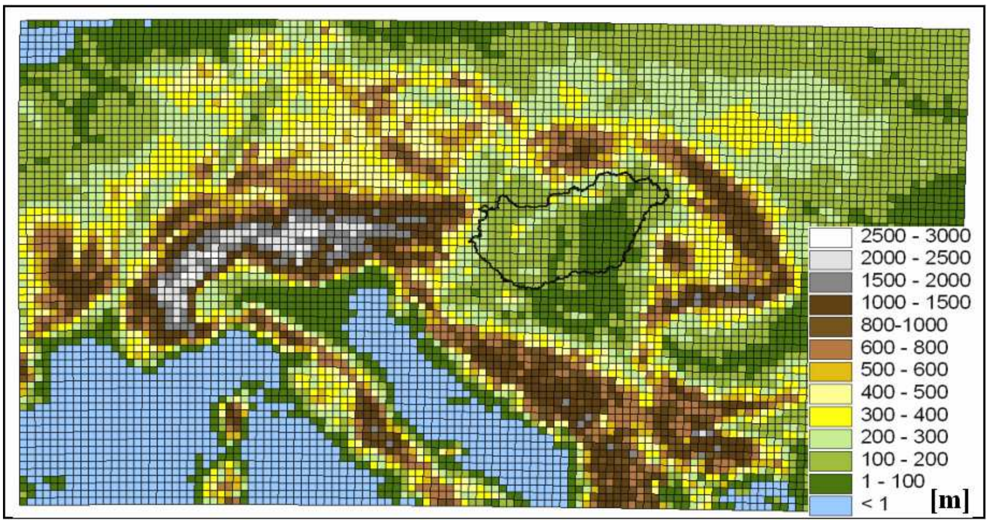

Figure 1. Simulation domain

The following model simulations have been performed and analyzed *(Table 1):*

- *Reference simulation* for the past (1961–1990) with present forest cover based on the CORINE Land Cover vector database[1] for Hungary.

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[1] http://dataservice.eea.eu.int/

- *Climate change simulations* for the future (2021–2025, 2071–2100) with present land cover applying the A1B IPCC-SRES[2] emission scenario (IPCC 2007) serving as reference simulations for the land cover change experiments.
- *Forest cover change simulations* for the future, under enhanced greenhouse gas conditions (A1B IPCC-SRES emission scenario):
    - *a) Maximal afforestation simulations* for 2021–2025 and 2071–2100 with the assumption that the whole vegetated area of Hungary will be forest *(Figure 2)* and the new afforestations will be carried out with deciduous species;
    - *b) Deforestation simulation* for 2071–2100 replacing the whole forested area in Hungary with grassland *(Figure 2)*;
    - *c) Potential forest cover simulation* for 2021–2025 based on a survey of ecological potential for afforestation in Hungary (Führer 2005). For the 50 forest regions, this afforestation plan suggests to increase forest cover on marginal agricultural land *(Figure 3).* This means a 7% increase (6.5% deciduous and 0.5% coniferous) of the present 20% share of forests until the 2030s. The exact location of the additional forest area within the region is not determined. Considering the spatial distribution of the agricultural land, the potential increase of deciduous and coniferous forests has been allocated to all model gridboxes *(Figure 3).*

Table 1. Experiment characteristics and time periods

Experiment	*Reference*	*Deforestation*	*Maximal afforestation*	*Potential forest cover*
Characteristics	Present forest cover unchanged	Grassland over all forested area	Forests covering all vegetated area	Some agricultural areas replaced by forest
Time period	1961–1990 2021–2025 2071–2100	2071–2100	2021–2025 2071–2100	2021–2025

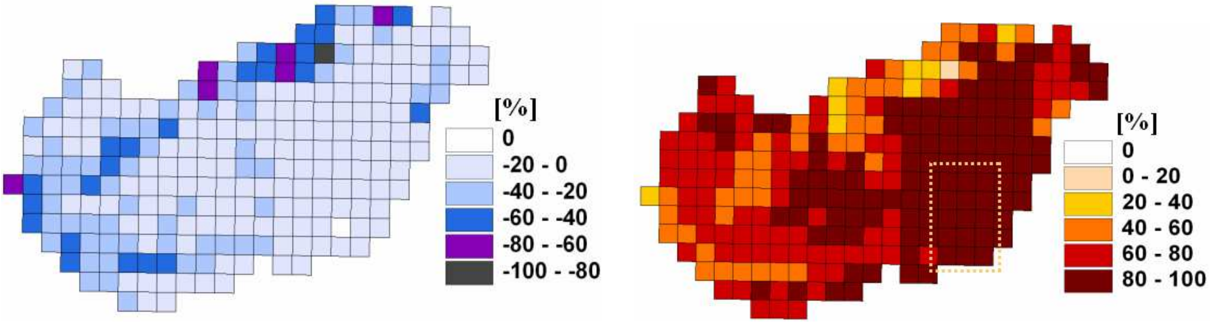

Figure 2. Change of the forest cover for deforestation (left) and maximal afforestation (right) compared to the reference. The region in Southeast Hungary with the largest increase of forest cover is marked

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[2] A1: very rapid economic growth, global population peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system; A1B means a balance across all sources.

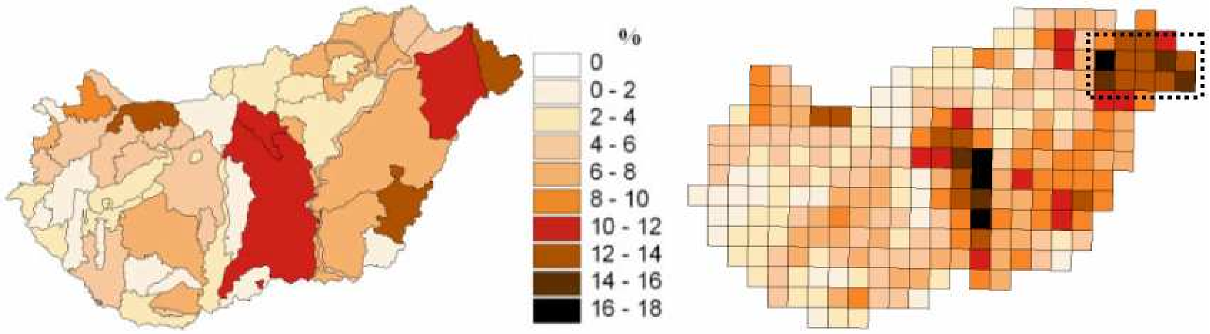

Figure 3. Potential increase of forest cover for the 50 forest regions (left; Führer 2005) and its appearance on the model grid (right). The region in with the largest increase of deciduous forests is marked

Within the simulation domain, land cover has been changed only in Hungary. For each forest cover change scenario a new land surface parameter set has been calculated. Afforestation leads to the increase of the leaf area index and roughness length and to the decrease of the surface albedo, whereas deforestation has opposite effects (not shown in detail). The changes of these parameters correlates linearly to the magnitude of the forest cover change in the grid boxes.

2.3 The main steps of the analyses

Because of the special focus of the study on summer droughts, simulation results for May, June, July and August have been selected for analyses and considered '*summer*'. In these months water availability is especially important in Hungary for forest growth (e.g. Czúcz et al. 2011). The leaf area index reaches its maximum, which has a strong influence on the land-atmosphere interactions.

First, *climate change driven by maximal afforestation and deforestation* have been assessed comparing simulated evapotranspiration, surface temperature and precipitation with and without forest cover change for the time period 2071–2100. The theoretical options of maximal afforestation and deforestation provide information about the maximal climatic effects of forest cover change in the model. Secondly, feedback of the potential afforestation on transpiration and precipitation has been investigated for the near future (2021–2025).

Third, the magnitude of the effect of maximal afforestation on precipitation as well as on the probability and severity of droughts has been analyzed relative to the magnitude of the climate change signal for the end of the 21st century. Simulations without any land cover changes for 2071–2100 vs. 1961–1990 served as reference. *Climate change driven by emission change and maximal afforestation* has been determined comparing the results of the maximal afforestation experiment (2071–2100) to the reference study of the past (1961–1990). For the detailed analysis of the regional differences, sub-areas (the region with the largest increase of forest cover, the region most affected by warming and drying, the area in which the precipitation increasing effect of maximal afforestation is simulated to be the largest) have been selected.

Meteorological droughts have been defined and classified based on Gálos *et al* (2007): for each investigated year the relative precipitation anomaly has been calculated taking mean summer precipitation sum in the period 1961–1990 as reference. Weather conditions were considered as drought if the relative precipitation decrease was larger than 15% of the reference. For more severe precipitation anomalies, further severity classes have been determined. A Mann-Whitney U-Test (Mann – Whitney 1947) has been applied to investigate the significance of the climatic effects of forest cover change. This ranking test does not assume a normal distribution.

3 RESULTS

3.1 Climate change driven by maximal afforestation and deforestation

The spatial correlation between the magnitude of forest cover change and its climatic effects has been investigated including all Hungarian grid boxes. In the case of the *maximal afforestation simulation*, the higher leaf area index and roughness lengths of forests support the enhanced ability of evapotranspiration. For the time period 2071–2100 the 30-year mean of the summer evapotranspiration rate may be up to 20% higher than with the unchanged forest cover *(Figure 4)*. The changes are statistically significant at 95% confidence level. Due to the cooling effect of the enhanced evapotranspiration, surface temperature might be reduced by up to 0.7 °C. The 30-year mean of the summer precipitation sum may increase by 15% relative to the reference *(Figure 4)*. Based on the results of the Man-Whitney-U-test, the change is significant at 85% confidence level in all grid boxes where precipitation increase due to maximal afforestation exceeds 10%. This confidence level indicates high interannual variability of precipitation within the investigated time period.

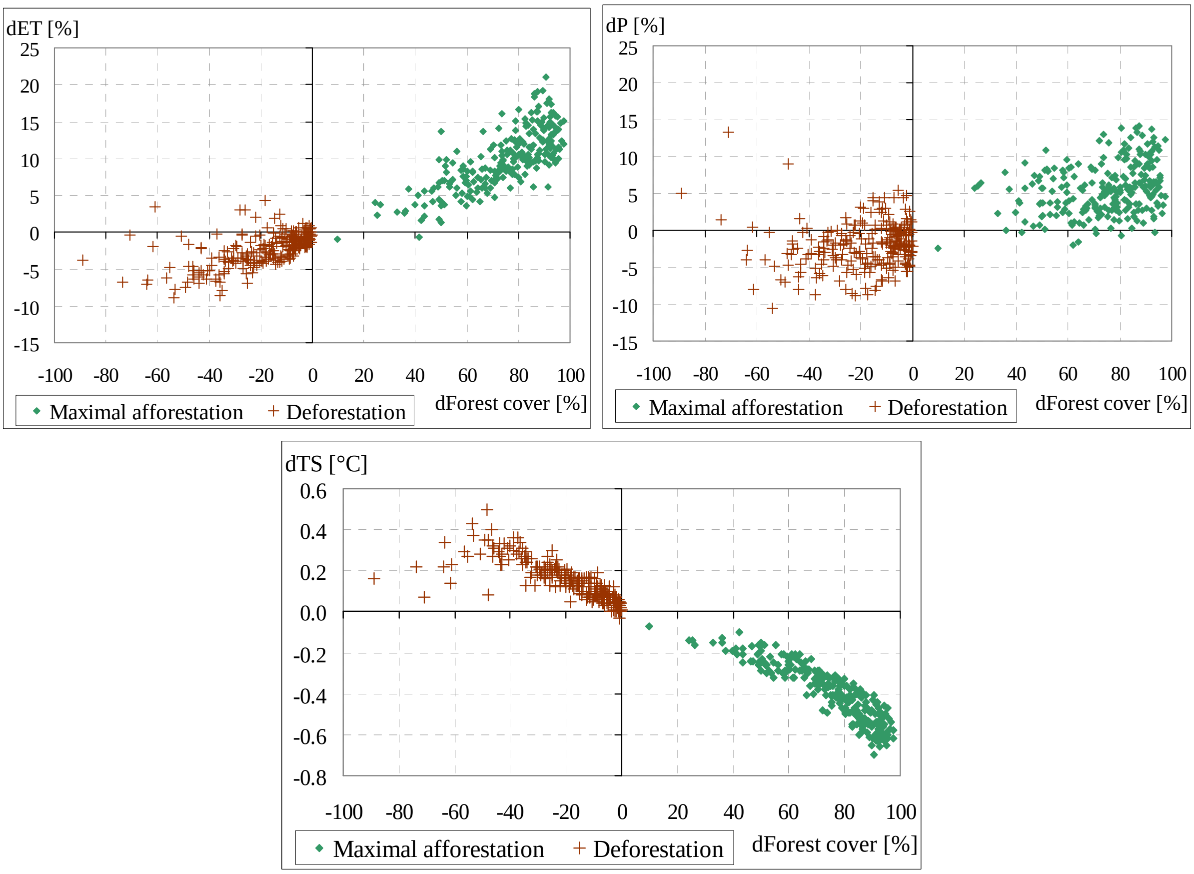

Figure 4. Correlation between the change of forest cover and the change of evapotranspiration (dET; top left), surface temperature (dTS; bottom), and precipitation (dP; top right) for all grid boxes in Hungary in the period 2071–2100

The opposite climate feedbacks can be observed in the deforestation sensitivity study, although the effects are less spectacular than for maximal afforestation. This is explained by the spatial distribution of the forested area in Hungary, which is mostly in small fragments rather than in larger contiguous forest blocks. The fraction of forests in the gridboxes, which could be replaced by grasslands was consequently small. Evapotranspiration rate may decrease by up to 10% and surface temperature may increase by up to 0.5 °C in the grid boxes where larger forest cover decrease has taken place *(Figure 4*). Whereas maximal afforestation resulted in wetter conditions for almost all Hungarian gridboxes, for deforestation the opposite signal is not so clear *(Figure 4)*. Climate change signal of deforestation shows weaker statistical significance than the one of maximal afforestation.

The larger the increase/decrease of the forested area in the gridbox, the stronger the feedbacks on evapotranspiration and thereby on surface temperature (*Figure 4*). Changes of these two variables are determined primary by local processes. Precipitation formation is influenced also by large-scale circulation therefore it cannot be directly correlated with the local forest cover change.

3.2 Climatic effects of potential afforestation

For the time period 2021–2025 the climatic influence of the proposed afforestation program has been analyzed for Hungary, comparing the results of the emission scenario simulations with and without forest cover change.

Regarding to the proposed afforestation program the relatively small increase of forest cover (7%) led to significantly smaller changes for all land surface parameters than the maximal afforestation scenario (not shown). In the investigated time period, these modifications of the physical properties of the land surface have no clear effects on the average summer climate.

The largest potential forest cover increase (13%) is proposed for the northeastern region of Hungary *(Figure 3)*. This region has been selected and studied more in detail. Due to the higher leaf area index and roughness length of deciduous stands relative to agricultural crops, local increase of transpiration rate (2.5%) has been detected *(Figure 5)*. Summer precipitation does not change significantly due to the proposed afforestation, whereas its amount would increase by 5% in the analysed region assuming maximal afforestation *(Figure 5)*. In the latter case transpiration would be 12% higher than with the unchanged forest cover.

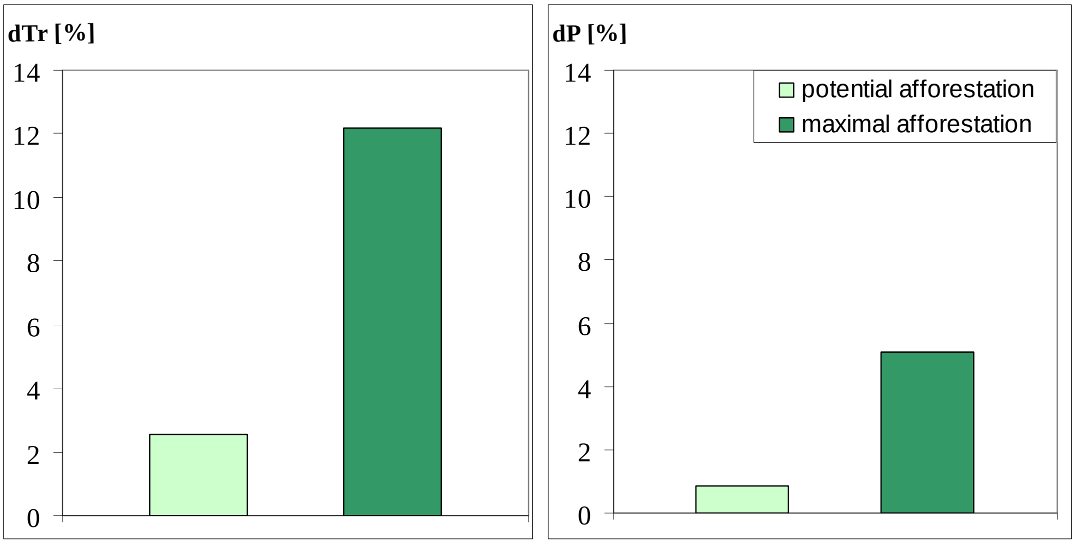

Figure 5. Effect of potential and maximal afforestation on transpiration (dTr; left) and precipitation (dP; right) for the period 2021–2025

Summing it up, the proposed afforestation, dispersed across the country would not alter the climate on a regional scale, although its effects on the local climate might be favourable.

3.3 Climate change driven by emission change and maximal afforestation

First, climate change without any land cover change has been analyzed for temperature and precipitation in the 30-year period at the end of the 21st century (2071–2100) with reference to the 30-year climate period in the 20th century (1961–1990). The simulation results indicate that the southwestern part of Hungary is affected most by warming and drying (Gálos et al. 2011). Here, the projected increase of the temperature may be larger than 3.5 °C (not shown) and the decrease of the summer precipitation sum may exceed 25% *(Figure 6).*

Second, the region has been determined, where maximal afforestation has the largest effect on precipitation in the period 2071–2100. *Figure 6* shows that the increase of the summer precipitation sum due to maximal afforestation is the largest in the northeastern part of the country, which does not correspond to the area with the largest amount of afforestation. Possible reasons for it can be the more humid air over mountains and the easier precipitation formation due to the orographic uplift as well as the characteristic large scale circulation patterns in summer.

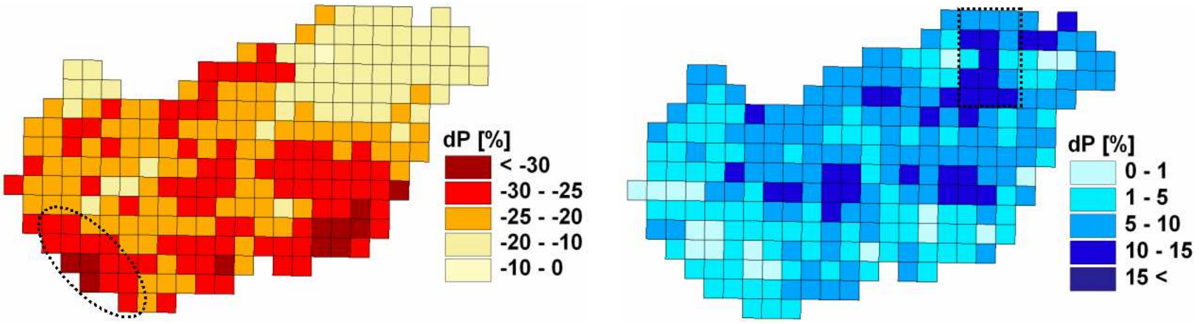

Figure 6. Change of summer precipitation (dP) due to climate change (2071–2100 vs. 1961–1990; left) and modulated by maximal afforestation (2071–2100; right). The two regions selected for detailed analyses (Southwest and Northeast Hungary) are marked

These results were the motivation to study the spatial differences of the possible climate change mitigating effects of forest cover for the country mean (Hungary) and for the following three regions:

- Southwest Hungary (SWH): the region most affected by warming and drying (*Figure 6*),
- Southeast Hungary (SEH): the region with the largest increase of forest cover (*Figure 2*),
- Northeast Hungary (NEH): the area in which the precipitation increasing effect of maximal afforestation is simulated to be the largest (*Figure 6*).

Figure 7 clearly shows that in all three regions and for whole Hungary the projected decrease of precipitation caused by emission change can be reduced by the increase of forest cover. The magnitude of the feedback of maximal afforestation on precipitation differs among regions. In the area most affected by climate change (SWH), precipitation increase due to maximal afforestation is relatively small. In Southeast Hungary, the significant decrease of summer precipitation can be weakened through the increase of the forested area. In the partly mountainous region of Northeast Hungary, the projected tendency of drying is the mildest, where the simulated increase of the summer precipitation sum due to maximal afforestation is the largest (9%). Here, more than half of the projected climate change signal for precipitation could be relieved with enhanced forest cover *(Figure 7).*

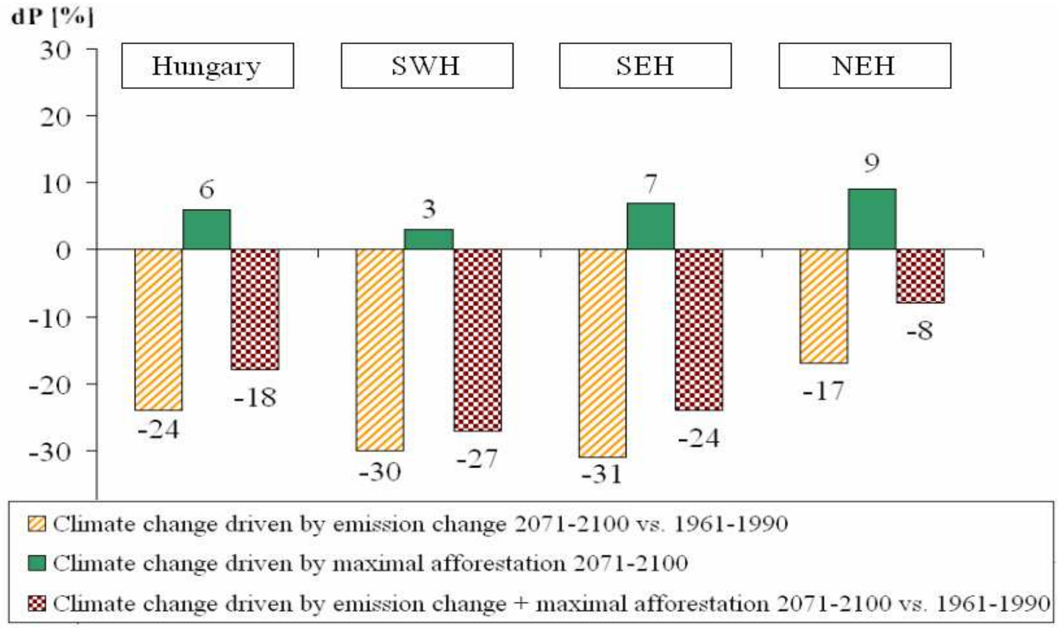

Figure 7. Change of the summer precipitation sum (dP) driven by emission change (2071–2100 vs. 1961–1990), by maximal afforestation (2071–2100) and by emission change + maximal afforestation in whole Hungary and in the three investigated regions (SWH: Southwest Hungary, SEH: Southeast Hungary, NEH: Northeast Hungary) Adapted from Gálos et al. 2011

For the end of the 21st century the significant decrease of the mean summer precipitation sums result in more frequent dry summers compared to the second half of the 20th century *(Table 2)*. The influence of maximal afforestation on the increase of the probability and severity of droughts has been studied for the selected regions. The spatial differences in the effect of the maximal afforestation are observable also for droughts (*Table 2*). For country mean and for Southwest Hungary, the enlarged forest area has almost no effect on the increase of drought probability (*Table 2*). In Southeast Hungary the total number of dry summers would be reduced by the increase of the forest cover. The largest effects of maximal afforestation would be expected in Northeast Hungary. Here, the increase of the total number of droughts would be reduced by 4 (*Table 2*) that corresponds to the number of the moderate droughts. The probability of the severe droughts above 40% precipitation decrease would not be diminished in this region. Thus, the simulations indicate that afforestation may influence moderate droughts but cannot eliminate severe droughts.

Table 2. Number of droughts in Hungary, Southwest Hungary (SWH) Southeast Hungary (SEH) and Northeast Hungary (NEH) in the period 1961–1990 and projected changes due to climate change and maximal afforestation. dP: relative precipitation decrease

Region		Number of dry summers 1961–1990	Change of the number of dry summers 2071–2100 vs. 1961–1990	
			due to emission change	due to emission change + maximal afforestation
Hungary	Total number of droughts (15% < dP)	12	+6	+5
SWH		13	+8	+7
SEH		11	+11	+8
NEH		8	**+10**	**+6**
	15% < dP ≤ 25%	3	+2	+2
	25% < dP ≤ 40%	4	**+5**	**+1**
	40% < dP	1	+3	+3

4 CONCLUSIONS

A case study has been carried out for Hungary to investigate the chances for mitigating climate change effects through afforestation. Applying the regional climate model REMO, the theoretical option of maximal afforestation resulted in an increase of evapotranspiration (10–15%) and precipitation (up to 10–15%) as well as in a decrease of surface temperature (up to 1 °C). The cooler and moister conditions could mitigate the projected climate change for the entire summer period. The mitigating effect differs among regions. It is simulated to be the largest in the Northeast (where 50% of the projected precipitation decrease could be set off), whereas it is the smallest in the southwestern region. In Northeast Hungary, projected increase of the total number of summer droughts would be significantly reduced (from 10 to 6). Climatic effects of deforestation are weaker, less significant and have the opposite sign than those of maximal afforestation.

The results have to be interpreted in the context of the initial conditions of the studied region, situated in a drought-threatened, ecologically vulnerable part of the closed forest zone at the xeric limits. Projected forest cover and forest composition shifts triggered by climate change, i.e. the expected reduction of the forested area and mass mortality in the drought threatened areas (Berki et al. 2009; Mátyás et al. 2010; Czúcz et al. 2011) and changes from coniferous to deciduous species, have not been taken into account in the simulations, so far.

The climatic benefits of the investigated potential afforestation dispersed across the country (7% increase in country mean) are surprisingly negligible. The survey shows that climatic conditions cannot be influenced meaningfully by potential afforestation on regional scale. Although even practically unrealistic increases of forest cover could not offset the projected climate change, the ecologic significance of indicated effects of land cover changes should not be underestimated. Certain services and local scale benefits of forest cover are highly valued even though their mitigating effect is presently not represented in atmospheric regional climate models.

For Hungary, results of these analyses represent the first regional scale assessment of the climatic role of forests for long future time periods and their role in adapting to climate change. Analyses of the spatial differences in the climate change mitigating effects of afforestations can help to identify the areas, where forest cover increase is the most beneficial and should be primarily supported to reduce the projected tendency of drying. Based on the deforestation scenario, certain regions can be identified, where decrease of forested area enhances the climate change signal. Here, the existing forests should be maintained to avoid the additional warming and drying of the region. Results concerning the climatic feedbacks of forest cover change and its spatial distribution for the 21st century should be an important basis of the future forest policy. Study results may also improve the public awareness of ecological services of forest cover and its role in adapting to climate change.

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