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*Regular research paper*

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# ALTITUDINAL VARIABILITY OF THE SOIL WATER CONTENT IN NATURAL AND MANAGED BEECH (*FAGUS SYLVATICA* L.) FORESTS

ABSTRACT: European beech (*Fagus sylvatica* L.) ranks as one of the most adaptive species among European indigenous trees. Variable interactions between the trees and soil water depend on both phenotypic plasticity of the species and natural conditions. They are controlled through stomatal regulation and the ability of beech trees to accelerate quickly their growth if available resources increase. However, the effect of forest density at various altitudes on the soil water content in beech stands has been studied rather scarcely. Therefore, we monitored soil moisture by means of Time Domain Reflectometry in series of natural and managed stands located on sites representing the lower altitude (200–550 m a.s.l.), middle altitude (550–1050 m a.s.l.) and higher altitude (1050–1300 m a.s.l.) zones of the natural beech belt in the Western Carpathians, Slovakia. Forest stand density, expressed in terms of basal area, *i.e.* the sum of cross section areas of the tree stems at 1.30 m height, was unchanged in natural stands, but it was reduced by 60% in the shelterwood stands. In the clear-cuts, all trees were removed. Total soil water content (SWC) under forest stands was calculated in mm as the product of soil moisture and soil depth, the latter acquired by electrical resistivity tomography. SWC differences between natural and shelterwood stands of the lower altitude, middle altitude and higher altitude zones averaged 18 mm, 36 mm and –3 mm, respectively. According to the Friedman test on ranks, followed by *post-hoc* multiple comparison testing, the difference was only significant within the middle altitude zone. In it, soil water consumption by the natural stand was limited only by the hormonally controlled seasonal regulation. The comparatively low water loss in the shelterwood stand resulted from a small rainfall interception by forest canopy and a decreased soil water uptake due to reduced basal area, leaf area index and simple age-size forest structure. In the lower altitude zone, the precipitation deficit and limited extractability of soil water were responsible for the absence of larger SWC differences. As opposed to that, low potential evapotranspiration prevented any noticeable SWC differences within the higher altitude zone.

KEY WORDS: European beech, stand density, forest structure, altitude, soil water content

## 1. INTODUCTION

Today, European beech seems to be a successful tree species owing to its phenotypic plasticity and evolutionary adaptability. It may counteract a further contraction of its range arising from climate change in the future (Bolte *et al.* 2007). In recognition of the outstanding universal value of these ecological patterns, a series of ten European beech (*Fagus sylvatica* L.) forest sites was inscribed in 2007 into the World Heritage List.

The interactions of trees and soil water are generally determined by stomatal regulation, a process controlled through species specific physiological responses to microclimate, plant hormones and soil water potential, among other factors (Kutsch *et al.* 2001, Ježík *et al.* 2007, Zweifel *et al.* 2007). In beech, a high and almost instantaneous response of transpiration rate to variation in soil water content or global irradiation was documented by Čermák *et al.* (1993), Střelcová *et al.* (2006) and others. Schipka *et al.* (2005) suggested that soil moisture could limit transpiration at annual precipitation bellow *ca* 700 mm year$^{-1}$, while precipitation higher than 1000 mm year$^{-1}$ would inhibit the transpiration by increased cloudiness or leaf wetness. On the other hand, microclimate and soil water potential also vary due to multiple factors, *e.g.* forest density and forest structure (Roberts 2000). Both forest density, expressed as the sum of cross section areas of the tree stems at 1.30 m height (DBH – diameter at breast height), known as stand's basal area (Assmann 1961), and forest structure, resulting from age, vertical and diameter differentiation of trees, are often reduced. The reduction results either from forestry interventions, such as shelterwood cuttings, or from small-scale to intermediate natural disturbances. For instance, intermediate wind disturbances play a more important role in the beech forest dynamics than it was previously thought (Nagel and Diaci 2006). Kenderes *et al.* (2008) found an overall increase of gap area from 2.5 to 7.7% of the forest area in a temperate natural beech forest during the last thirty years. Also simple, monolayer forest structure limits the stands' capacity to utilize available resources (Bublinec 1994). In spite of the fact that water fluxes were studied in various species (*e.g.* Aussenac 2000), including beech forests (Granier *et al.* 2003), simultaneous effects of stand density and the climatic factors associated with altitude on the soil water content (SWC) were not taken into account in the recent studies. For instance, it remains uncertain, whether there is a higher SWC in low-density beech stands irrespective of altitude. Therefore, our study aimed to explore the plasticity of beech and the competitive role of suppressed beech trees. These overtopped trees are entirely below the main forest canopy and consequently they receive little or no direct insolation from above or from the sides. Their responsiveness to the amount of extractable soil water was assessed in terms of soil water loss resulting from rainfall interception and soil water uptake under forest stands with natural and reduced density. The assessment leaned on comparing the variation in SWC under natural and managed forests at altitudes representing the lower altitude (200–550 m a.s.l.), middle altitude (550–1050 m a.s.l.) and higher altitude (1050–1300 m a.s.l.) zones of the beech belt in the Western Carpathians, Slovakia. This division is similar to those used by Plesník (1978), Korpel (1995), Maycock *et al.* (2000), Dittmar *et al.* (2003) and others. A hypothesis was formulated that SWC differences between stands of different densities would vary with altitude in a predictive manner.

## 2. STUDY AREA, MATERIAL AND METHODS

The study was conducted in three forest areas located within the West Carpathian volcanic range in the central part of Slovakia. The natural, monodominant European beech forests from natural regeneration occur on soils developed from andesite and tuff slope deposits.

The 14.5 ha, 100 yr old lower altitude zone beech forest in the Kremnické Vrchy Mts (48°38′09″N, 19°04′06″E) grows on a NNW slope with 19° inclination. Its elevation ranges from 470 to 510 m a.s.l. The site has the mean annual temperature of 6.8°C and 750 mm annual precipitation. The local soil is Eutric Cambisol with a clayey loam texture and 33% soil skeleton fraction. The forest belongs to the *Carici pilosae-Fagetum* forest association. Gömöryová (2004) gave the mean height and diameter at breast height (DBH) of the beech forest at 28 m and 31 cm, respectively.

The 25 ha middle altitude zone beech forest site is located in Javorie Mts (48°26′27″N, 19°16′18″E). It extends on the northern, 17° megaslope of Mt. Javorie massif, at an elevation of 920–960 m a.s.l. Its local annual temperature is 4.0°C and the yearly precipitation

Table 1. Dendrometric characteristics of forest stands on the respective sites. Basal area represents the sum of cross section areas of the tree stems at 1.30 m height per hectare.

| Site | Forest stand type | Years since last cutting | Basal area ($m^2$ $ha^{-1}$) | Number of trees per hectare |
|---|---|---|---|---|
| Lower altitude zone, 200–550 m a. s. l. (Kremnické Vrchy Mts) | Natural | 90 | 41.2 | 633 |
| | Shelterwood | 10 | 18.5 | 160 |
| | Clear-cut | 10 | 0.0 | 0 |
| Middle altitude zone, 550–1050 m a. s. l. (Javorie Mts) | Natural | 95 | 38.1 | 570 |
| | Shelterwood | 5 | 21.5 | 143 |
| | Clear-cut | 5 | 0.0 | 0 |
| Higher altitude zone, 1050–1300 m a. s. l. (Vtáčnik Mts) | Natural | 120 | 43.7 | 476 |
| | Shelterwood | 5 | 22.3 | 121 |
| | Clear-cut | 1 | 0.0 | 0 |

averages 850 mm. The forest's substrate is Andic Cambisol with a 30% stony fraction content. The forest is 95 yr old and it belongs to the *Asperulo-Fagetum* forest association. The stand's mean height is 32 m and its DBH reaches 47 cm.

The higher altitude zone, 140 yr old forest in the Vtáčnik Mts occurs on the eastern slope of Mt. Vtáčnik (48°37′32″N, 18°38′49″E) at 1050–1130 m a.s.l. It has 30 ha in size. The slope has a 20° inclination. Its average annual temperature is 3.0°C and the yearly precipitation range is 950–1000 mm. Local soil is a Mollic Andosol with 30% of the stony fraction. The forest falls into to the *Asperulo-Fagetum typicum* forest association. The mean height of beech trees is 32 m with DBH approximating 41 cm.

Triplets of experimental plots were established in all three sites, each plot representing a different forest density: (i) natural stand, (ii) shelterwood stand and (iii) clear-cut with a combined natural and artificial regeneration. Dendrometric characteristics of experimental plots by treatment are given in Table 1. Every plot contained three pits excavated among neighboring dominant trees, or scattered randomly in the middle section of clear-cuts, in which soil moisture probes were installed and buried. Soil moisture was monitored at fortnight intervals by an array of Time Domain Reflectometry (TDR) probes inserted into 10 cm layers and connected to a Field Operated TDR Meter (Easy Test, Lublin, Poland). Ten soil moisture measurements were taken at each locality during one vegetation period from May till the end of October. Respective SWC values were calculated as a product of soil moisture and the soil depth in mm. The average soil depths were measured by electrical resistivity and integrated polarization imaging system (ARES, GF Systems Brno, Czech Republic), after its calibration for local substrates (Máliš 2007). So as to evaluate the SWC data from the different zones, Friedman test, also called two-way analysis on ranks, along with the corresponding *post-hoc* multiple comparison test were applied (Sokal and Rohlf 1995).

## 3. RESULTS AND DISCUSSION

Fig. 1 shows SWC mean values in the respective forest sites and stands, their 95% confidence intervals and the standard deviations. The average SWC differences between natural and shelterwood stands reached 17.5 mm, 36.6 mm or – 3.0 mm in the lower altitude zone, middle altitude zone and higher altitude zone forests, respectively. The Friedman test showed the forest density effect on the average SWC to be significant in the lower and middle altitude zones (Table 2). However, according to the *post-hoc* multiple comparison test the particular average SWC difference between the natural and shelterwood stands was only significant in the middle altitude zone (Table 3). Reaching *ca* 37 mm, it is approximately fifteen times higher than the daily transpiration of 2.4 mm per day in European beech stands (Střelcová *et al*. 2006), thus corresponding to a 35–40 mm soil retention capacity observed in temperate zone forests under usual conditions (Badoux *et al*. 2006).

Our results can be directly compared only with a rather sparse and incomplete set of results representing various species,

Table 2. Friedman test of the forest density influence on the soil water content (SWC) in various altitude zones of the Western Carpathian beech belt. The average SWC rank for the respective row gives the mean relative position of each SWC value within triplets representing ten measurement series (N = 10). $\chi^2$ represents the chi-square statistic at two degrees of freedom (df) and *P* is the level of significance.

| Site | Forest stand type | Average SWC rank | Mean SWC (mm) | $\chi^2$ (N = 10, df = 2) | *P* |
|---|---|---|---|---|---|
| Lower altitude zone, 200–550 m a.s.l. (Kremnické Vrchy Mts) | Natural<br>Shelterwood<br>Clear-cut | 1.30<br>2.25<br>2.45 | 157.00<br>174.50<br>183.30 | 7.74 | *P* <0.028 |
| Middle altitude zone, 550–1050 m a.s.l. (Javorie Mts) | Natural<br>Shelterwood<br>Clear-cut | 1.00<br>2.30<br>2.70 | 208.40<br>245.00<br>251.15 | 15.80 | *P* <0.000 |
| Higher altitude zone, 1050–1300 m a.s.l. (Vtáčnik Mts) | Natural<br>Shelterwood<br>Clear-cut | 1.89<br>2.00<br>2.11 | 288.92<br>285.89<br>296.50 | 2.70 | *P* <0.890 |

Table 3. *Post-hoc* multiple comparison test of the soil water content (SWC) differences between forest stand types within altitude zones, in which the forest density influence on SWC was identified as significant by the Friedman test on ranks. Values in cells are absolute differences between average SWC ranks (see Table 2).

| Site | Forest stand type | Natural | Shelterwood | Clear-cut |
|---|---|---|---|---|
| Lower altitude zone, 200–550 m a.s.l. (Kremnické Vrchy Mts) | Natural | – | 0.95 | 1.15* |
| | Shelterwood | 0.95 | – | 0.20 |
| | Clear-cut | 1.15* | 0.20 | – |
| Middle altitude zone, 550–1050 m a.s.l. (Javorie Mts) | Natural | – | 1.30* | 1.70** |
| | Shelterwood | 1.30* | – | 0.40 |
| | Clear-cut | 1.70** | 0.40 | – |

Significance labels: * 0.01 <*P* <0.05; ** *P* <0.01

biogeographical zones and altitudes. Aussenac and Granier (1988) reported a maximum 42 mm of SWC difference between a natural and a low density Douglas fir stand. Gregor (1999) identified significant soil moisture differences up to 5–10% between a shelterwood stand and a natural stand in a lower altitude beech forest. Koshi (1959) and Breda *et al.* (1995) established that SWC values in low density oak stands averaged 25 mm or 40 mm higher than in natural stands under semi-aride or temperate conditions, respectively. Thus, our results fell within the range of other studies and they compare particularly well with the lower SWC difference in the semi-aride zone, or the somewhat higher difference in the temperate zone, which approximate the lower altitude and middle altitude conditions in our case. In the lower altitude zone, the SWC difference was likely dampened by an approximate 200 mm deficit of precipitation with regard to potential evapotranspiration, typical of submontane Carpathian sites (Škvarenina *et al.* 2004). Such conditions usually lead to extractable soil water deficits indicated by soil matrix potential of approximately –700 hPa, at which the transpiration rate of beech trees may decrease sharply (Papritz *et al.* 1991). It is because uneven distribution of

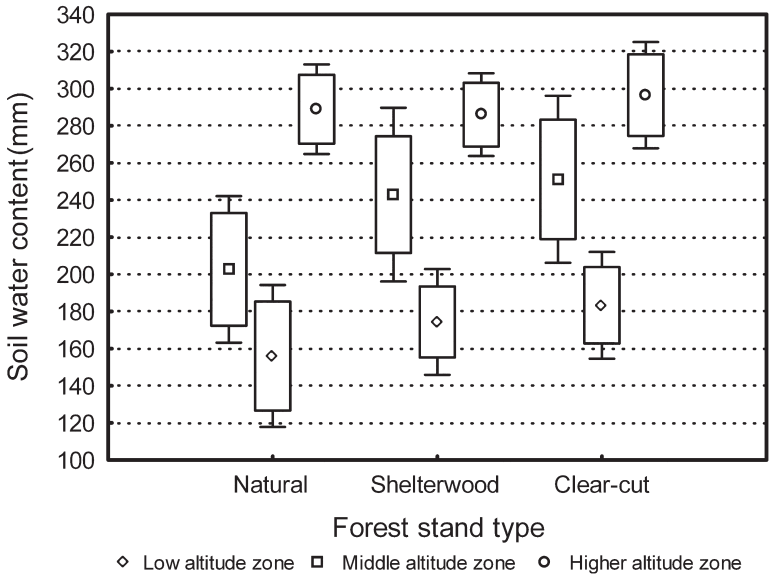


Fig. 1. Box plot showing the total soil water content (SWC) under forest stands on the respective sites, belonging to the lower altitude (200–550 m a.s.l.), middle altitude (550–1050 m a.s.l.) and higher altitude (1050–1300 m a.s.l.) zones of the beech belt in the Western Carpathians, Slovakia. The mean values are represented by markers, 95% confidence intervals for means coincide with the boxes and whiskers indicate the standard deviation.

precipitation triggers stomatal acclimation which optimises the seasonal course of water loss of beech forests (Kutsch *et al.* 2001). In the middle altitude zone, two main factors contributed to large soil water content differences: (i) the dominance of a hormonally controlled seasonal regulation of growth under optimum soil moisture conditions; (ii) the absence of suppressed, overtopped trees in the shelterwood stand. From an intraspecific competition point of view, the suppressed beech trees feature the highest responsiveness to global irradiance (Střelcová *et al.* 2002) and sudden increase in extractable water (Ježík and Voško 2002, Pichler *et al.* 2006). In other words, suppressed trees sustain transpiration under cloudy skies and use instant SWC spikes, such as following intense precipitation, even if main canopy trees do not respond. Also, the fraction of stand evapotranspiration originating at the understorey increases as the water vapour pressure deficit increases and the soil dries (Black and Kelliher 1989).

Thus, our results support the hypothesis that a more complex forest structure, including trees of different status, diameter and age, supports the convergence of forest evapotranspiration rates even in stands with contrasted leaf area index (LAI), as suggested by Roberts (1983), Vincke *et al.* (2005) and others. However, these patterns and processes are mostly offset in the upper zone again due to lower temperature, high cloudiness and fog/cloud precipitation, which adds 5% to the local water balance (Střelcová *et al.* 2006). That limits the potential evapotranspiration and consequently the development of any significant SWC differences. Generally, the limiting dry and wet conditions in the lower and higher altitude zones, respectively, also constrained the soil water content temporal variability, when compared to the middle altitude zone with a balanced precipitation – potential evapotranspiration ratio (Fig. 1).

## 4. CONCLUSIONS

Our research reported that the effect of stand density on the soil water content (SWC) was significant in the middle altitude zone of the Western Carpathian beech belt, *i.e.* from approximately 500 m up to 1000 m a.s.l. The 37 mm average SWC difference between the natural forest and the shelter-

wood stand in the respective zone resulted from a comparatively low soil water uptake and a smaller rainfall interception in the low-density shelterwood stand due to its reduced basal area and simple age-size structure. In contrast, there was a sustained soil water uptake and a higher rainfall interception in the natural stand. No significant SWC differences between natural and shelterwood stands occurred in the lower and higher altitude zones due restricting climate patterns.

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