HYDRIC ECOLOGICAL FUNCTIONS OF A TEMPERATE DECIDUOUS FOREST

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In an oak-hornbeam forest at Báb, SW Slovakia (Central Europe), the ecosystem structure and processes have been studied in details (IBP 1966-1974, MaB 1975-1985, ILTER 1986-). In this paper we used the data on water balance of the forest stand, including plants and soil, to estimate hydric ecological functions of the temperate deciduous forest ecosystem. Multi-lyaered models were applied. Aerodynamic properties of the forest canopy, subcanopies as well as forest understorey determine several components of the water balance and ecological functions of the forest. The following hydric ecological functions were quantified: water storage capacity (retention capacity), forest evapotranspiration (interception, evaporation, transpiration, transpiration flow), stemflow, surface storage capacity/soil surface capacity, infiltration, soil water storage, soil water content recharge, soil moisture depletion, water retention capacity of soil humus horizon. The hydric ecological functions are closely related to water and wind erosion protection and to reduction of water erosion of soils in hilly landscape of SW Slovakia, to protection of quantity and quality of surface waters resources.

Keywords: ecological functions, deciduous forests, hydric functions, regulation ecosystem services, water storage capacity, evapotranspiration

INTRODUCTION

Ecological functions of ecosystems are considered in systems of ecological relationships. They are important for the existence/functioning of natural ecosystems. They do not depend on a human and his egotistical requirements (Eliáš 1983). They can be understand as a capacity or potential of an ecosystem to provide ecosystem goods and services. In present, a luck of quantitative data and/or knowledge of ecosystems limits quantification and valuation of ecosystem services.

Regulation functions of forest ecosystems are based on biogeochemical functions, esp. water cycle (hydrological cycle). Hydric ecological functions are considered to be very inportant ecological functions and generally known very vell (Papánek, 1978, Perry et al., 2007, Bond et al., 2008, Box, Fujiwara, 2013, Monson, 2014, Čaboun, Capuliak, 2014). But quantifications of components of the complex functions are necessary (Papánek, 1978, Eliáš, 1983, 2013, Čaboun, Capuliak, 2014,). The hydric ecological functions are closely related to water and wind erosion protection/to reduction of water erosion of soils in hilly landscape of SW Slovakia, to protection of quantity and quality of surface waters resources.

In an oak-hornbeam forest at Báb, SW Slovakia (Central Europe), the ecosystem structure and processes have been studied in details (IBP 1966-1974, MaB 1975-1985, ILTER 1986-, cf. Biskupský, ed., 1975, Jurko, Duda, eds., 1970, Eliáš, 2002, www.ilter.org). In this paper we used the data on water balance of the forest stand, including plants and soil, (cf. Eliáš, 1992) to quantitative estimation of hydric ecological functions of the temperate deciduous forest ecosystem.

MATERIALS AND METHODS

The Forest Research Site at Báb is situated ca 20 km West of Nitra, in the Danube-valey lowlands (Podunajská nížina) at 193 m above see level (160-210 m for the forest). The soil type is Chernozem on loesess, drying markedly during summer (Hraško in Jurko, Duda, 1970, Pelíšek in Biskupský, 1975). The mean annual temperature and mean annual sum of precipitation (period 1931-1960) was 9.7 °C and 580 mm, respectively, (Smolen in Jurko, Duda, 1970).

In the IBP period of the research (1966-1974), the uneven-aged and multi-species forest stand was, on average, about 80 years old and 18 m high (Biskupský, 1975). The species-rich community was dominated by oaks (*Quercus cerris* and *Q. petraea*), hornbeam (*Carpinus betulus*) and maple (*Acer campestre*) in tree layer, *Cornus mas* and *Ligustrum vulgare* in shrub-layer and many herbaceous species (*Galeobdolon luteum, Asperula odorata*, *Mercurialis perennis, Melica uniflora etc.*) in herb layer (Kubíček in Jurko, Duda, 1970). Leaf area index (LAI) of woody plants was 4 to 6. More than 80 % of the leaf area of the trees was accumulated in the layer 10 to 22 m above the forest floor (Oszlányi in Biskupský, 1975). Shrub and herbaceous plant species were frequent and abundant. LAI of the herb layer changed from 0.26 to 0.67, relative to different months, seasons and years (Kubíček in Biskupský, 1975).

Water regime of the deciduous forest has been studied, starting with the project of the I.B.P. (Reichle, ed., 1981). Different methods and approaches (water balance, micrometeorology, eco-physiology, combined methods) were used to analyse the individual components and water balance of the deciduous forest ecosystem (Eliáš, 1982, 1992). Some steps to review and/or synthesise the results were made (cf. Eliáš, 1992). Partial syntheses were published for water balance of the oak-hornbeam forest by Intribus (1977), soil water regime by Tužinský (1976, 2004) and water regime of the plants by Eliáš (1980, 1982, 1992).

Aerodynamic properties of the forest canopy, subcanopies as well as forest understory determine several components of the water balance and ecological functions of the forest. Multi-layer structured stand model to estimate canopy-layer and „surface“ resistance of the oak-hornbeam stand was , therefore, developed and applied by Eliáš (1980, 2008). Actual canopy conductance and canopy transpiration was estimated. Forest stratification was performed on the basis of vertical leaf distribution in the stand. Four layers were distinguished: above-canopy layer (19-22 m), the canopy layer (15-19 m), subcanopy layer (9-15 m) and the bottom layer (6-9 m). Data of porometric measurements of stomatal conductance to transpiration of four tree species were used for the calculations. Conductance of each layer was calculated by multiplying stomatal conductances of each tree species in the layer by its leaf area index and by summing up the results. The canopy conductance makes the sum of the total conductances of all the vertical layers (Elias 1980, 2008). The total conductance of the stand was most contributed to by predominant tree species (stand dominant) with the highest leaf area index. The main evaporation source of the stand was represented by the leaves in the canopy layer (15-19 m) in which the most leaves were found and their stomatal conductance being relatively low (Eliáš, 2008).

Organic layer biomass on the soil surface (litterfall) was estimated in monthly interval in plots 0.5x0.5 m and the dry mass in given in $g.m^{-2}$.

The following hydric ecological functions were quantified: interception and stemflow, water storage capacity (retention capacity), loss of water from the stand (forest evapotranspiration, transpiration, transpiration flow), surface storage capacity/soil surface capacity, infiltration, soil water storage and soil water content recharge.

RESULTS AND DISCUSSION

Hydric ecological functions were preliminary quantified. Annual precipitation ranged from 450 to 660 mm. Distribution of rainfall in the oak-hornbeam forest was determined by stand structure (horizontal and vertical) and by the presence/absence of leaves in the canopy (Fig. 1).

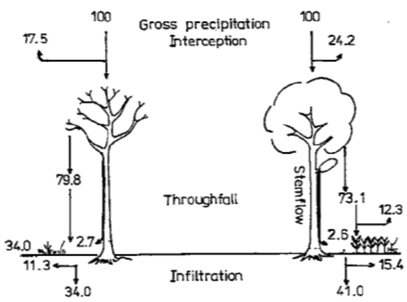

Fig. 1 Rainfall distribution in the oak-hornbeam forest at Báb, SW Slovakia (Eliáš, 1992). The winter period (left) and the growing season (right) are shown.

Interception and stemflow

In summer, leaf canopy interception varied from 20 to 50 % of gross precipitation. Rainfalls up to 1 mm (Intribus, 1977) were fully intercepted, it means they were storied in main canopy (wetting the surface of tree organs – leaves, branches, twigs, as wells as trunks) and were evaporated to atmosphere. During the growing season/hydrological year 8.5 % of precipitation is intercepted by tree canopy (Tužinský, 2004). Interception of understorey vegetation and organic litter on the soil surface (litter) can be also important.

Stemflow varied from 5.3 % in *Carpinus* to 2.0 % in *Quercus cerris* or 0.9 % in *Q. petraea* (cf. Intribus, 1977). Ground water and lateral flow were considered to be not importan here (Eliáš, 1992).

Water storage capacity (retention capacity)

Storage of water in the forest ecosystem has been evidently changed in the course of a day, or a season, as well as from year to year. Water storage in the soil varied from field capacity in spring (it was ca 300 mm in the soil horizon 0.0 to 1.0 m) to wilting point in summer (ca 130 mm) (Tužinský, 1976, 2004).

Water storage of the tree foliage and leaves of herbaceous undergrowth was larger than 40 mm and 5 mm, respectively (Eliáš, 1980, 1982, 1992). In summer, during periods of long-term droughts, the water content in leaf tissues of many plant species decreased to sublethal values (Eliáš, 1978,1980, 2013).

Forest evapotranspiration

The most important output component of the water balance of the ecosystem is evapotranspiration. The evapotranspiration rate of the stand varied considerably between 0.3 and 6.8 mm per day (but cf. also Tužinský, 2004). Miklánek (1985) calculated daily course of potential evapotranspiration of the oak-hornbeam forest in Báb with maximal hourly values in June close to $0.7\ mm.h^{-1}$.

Potential transpiration of trees may be 12 mm per day, but maximum transpiration rate estimated for the stand was $9.9\ mm.d^{-1}$ only (Huzulák, Eliáš, 1976, Huzulák, 1981). In summer, total amount of water transpired by trees in the oak-hornbeam forest in a month varied between 1500 to $1950\ m^3$ (cf. Huzulák, 1981).

Huzulák and Eliáš (1976) estimated the quantity of the transpirated water for *Quercus cerris*, and Huzulák (1981) for three forest trees oak, hornbeam, maple. Temperature balance methods with direct electrical heating of the xylem was used (Penka, 1985).

Transpiration intensity is very dynamic variable which varied during a day, between days and seasons. Daily maxima of the transpiration rate of two adult (tall) trees of *Acer campestre* and *Quercus cerris*, reached in a typical hot summer day, were above $20\ mg.g^{-1}.min^{-1}$ (Huzulák, Eliáš, 1975).

Transpiration rate of understorey herbaceous species was studied by Eliáš (1975a,b). The transpiration rate of two herbs *Galium odoratum* and *Pulmonaria officinalis* varied from ca $6\ mg.g^{-1}$ fresh mass min^{-1} in warm, sunny days to 1 to $2\ mg.g^{-1}.min^{-1}$ in cloudy days.

Based on the water balance method the water loss by transpiration and evaporation was 63.5 % of gross precipitation (Intribus, 1977, Tužinský, 2004). During the growing season losses of water from the stand usually exceeded the amount of gross precipitation, the forest stand has also used the water from winter and early spring rainfalls (Eliáš, 1992).

Surface storage capacity

A thick organic layer, which is formed in the deciduous forest on the soil surface (100 % cover during late autumn, winter and spring periods), intercepts precipitation and minimizes soil evaporation (2007). In spring the litter biomass varied between 200 and 400 $g.m^{-2}$, with maximum close to 500 $g.m^{-2}$. Tree litter dominated (leaves of tall trees) (Fig.).

Fig. 2 Litterfall was accumulated on soil surface during the winter periods in the deciduous forest. The Báb Forest Research Site, January 2014, Photo: P. Eliáš sen.

Soil water content recharge

The high soil moisture in the entire soil profile was estimated in April, which is in strong contrast with the low soil moisture in June and July. Even heavy rains in the summer months did not saturate the whole soil profile and the deeper horizons continued to be dry (cf. Eliáš, 1978).

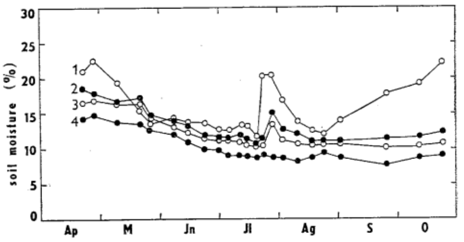

Fig. 3 Changes of soil moisture (soil water content in % of fresch mass) at four different depths under the oak-hornbeam forest at Báb during a growing period (Eliáš, 1978). Soil depths indication: 1 – 01 to 0.2 m, 2 – 0.3 to 0.4 m, 3 – 0.5 to 0.6 m, 4 – 0.7 tro 0.8 m.

The hydric ecological functions are closely related to water and wind erosion protection/to reduction of water erosion of soils in hilly landscape of SW Slovakia, to protection of quantity and quality of surface waters resources (Papánek, 1978, Chang, 2006, Bond et al., 2008, Konôpka, 2012).

Management of hydric functions of forests

Management of hydric function of forests according to Papánek (1978) means natural effect of a forest with regard to the ability to retain water from snow and rains, with a delayed runoff to lowlands till growing period, creating the water supply for management and drinking purposes. The main aim of water supplies management function of forests is to secure constant water supply in rivers so the maximal amount of disponible water is secured. Qualitative management of water supplies lies in influencing the precipitation water run-off manner and its transformation to underground run-off. Quantitative management of water supplies lies in securing the sufficient amount of disponible water (Konôpka, Konôpka, 2003, Tužinský, 2006).

Hydric ecological functions can be used for improving management of forest ecosystems in forested and/or agricultural landscape. Konôpka (2012) proposed to optimize the spatial distribution of ecosystems in a landscape, particulary in terms of flood protection of the area/landscape. Švihla et al. (2014) confirmed that retention capacity of forest soil was of great importance for a flood-event buffering in an experimental catchment, the Orlické hory Mountains (Czech Republic) (Kantor et al., 2003).

CONCLUSION

Hydric ecological functions of forests can be estimated and quantified on the basis of field research of forest ecosystems (structure and dynamics of the ecosystems).

Contribution of forest ecosystem components to the function depends on species diversity and abundance, their dynamics during growing seasons, years and centuries.

The complex ecosystem research can help to evaluate of the hydrological role of forests and forest (water) management in protecting water quality, managing water resources for the quantity of waters, flood reduction (alleviation), elimination desertification and support soil protection.

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