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Laboratory determination of potential interception of young deciduous trees during low-intense precipitation

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Abstract

The research issue focuses on potential interception, which is the maximum amount of water that can be stored on plant surface. Tests under controlled conditions remain the best way to enhance knowledge on interception determinants in forest communities. Such tests can provide data for identification of mathematical models based on ecological criteria.

The study presented in this paper concerned tree interception under simulated rain in a range from 2 to 11 mm/h. To perform the experiment a set of sprinklers was designed and built. The study included two deciduous species: beech (*Fagus sylvatica* L.) and oak (*Quercus robur* L.).

Descriptive characteristic and nonlinear estimation were suggested for the obtained data. Interdependence of potential interception, the intensity of rain and the size of raindrops were described using exponential equation.

The intensity and drop size of simulated rainfall significantly influence the obtained values of potential interception. Data analysis shows a decrease of interception value with an increase of intensity of simulated rainfall for both analysed species. Every run of the experiment that differed in the intensity and size of raindrops reached an individual level of potential interception and time needed to realize it.

The formation of ability of plants to intercept water depends both on the dynamics and the time of spraying.

Key words

deciduous trees, intensity of simulated rainfall, potential interception, size of raindrops, *Fagus sylvatica*, *Quercus robur*

Introduction

Plant interception, constituting the subject matter of the research, is examined as a component of atmosphere – forest stand – soil balance, existing in the equation for supply phase, in which the amount of water retained on the surface of plants decreases the growth of accumulation of water in soil (Suliński 1993). In water balance equations, interception is the least parameterized and computable element. Suliński (1993) proposed the following formula for discribing interception:

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$$i_d = \left[\beta i_{0d} \left(0{,}157 \sum_{j=1}^{n} D_j H_j N_j \right) \right] \times \times \left[\left(1 - e^{-\phi s}\right) \left(1 - e^{-\gamma t}\right) \right] \quad (1)$$

where:

i_d – tree interception (mm);

i_{0d} – initial interception (mm);

D_j, H_j, N_j – mean values for j – species: breast height diameter (cm) and height of a forest stand (m) and number of trees (thousands per hectare);

s – intensity (mm/h);

t – single rainfall duration (hours);

coefficients to be calculated in the process of identification of the formula:

α – characterisation of surface condition (rain adhesion);

ϕ, γ – scaling parameters.

The analysed subject matter concentrates around potential interception. It is the maximum amount of water that can be stored on the surface of plants. Typically, potential interception is considered to be a characteristic of a constant value surface, which can be illustrated by a sentence: "single rainfall – single, constant potential interception value" (Liu et al. 1997). However, there is information available in literature, on the basis of which it is possible to undermine this rule. The author in her own research on interception of simulated rainfall by forest trees concluded that potential interception should be treated as an individual value for a given rainfall (Klamerus-Iwan 2010).

Direct measurements of interception in field conditions remain a difficult task, especially due to methodical and techno-organizational limitations (Olszewski 1984; Kossowska-Cezak et al. 2000). The way to gain greater knowledge on factors shaping interception of forest communities is field research in controlled conditions (Putuhena and Cordery 1996; Anzhini et al. 2007; Toba and Ohta 2008), which could provide data for identifying mathematical models.

Pei et al. (1993) performed laboratory rainfall simulations on a constant tree surface, changing rain intensity, ranging from 47.4 to 147.6 mm/h, ten times. Similarly, Keim et al. (2006) applied the intensity ranging from 20 to 420 mm/h, also changing the size of simulated raindrops from 1.0 to 2.8 mm. From the perspective of precipitation conditions in Poland, very high intensities of simulated rainfall should be noted. In Polish climate such intensities produce the amount of rainfall which is relatively unlikely to occur.

The subject of the designed experiment was interception of trees under simulated rainfall with preservation of conditions stable over time and comparable rainfall parameters, especially the intensity and drop size.

The main aim of the research was gathering and preparation of database for identification of designed formulas related to low intensities. Secondary aim was further perfection of the research proceedings and the equipment used.

Material and methods

The present study concerns research on interception of trees sprayed with simulated rainfall ranging from 2 to 11 mm/h. To perform the experiments a set of sprinklers (Klamerus-Iwan et al. 2013) was designed and built. The difficulties in reaching low intensities were taken into account. Gravitational discharge of water from specially adjusted needles was exchanged for the one forced by a hydrophore pump. The sole needles were replaced by garden micro sprinkler nozzles. Parameters of the obtained precipitation were results of the accurate calculations of discharge of water on the sprayed area. Control measurements were also made to establish constancy and repeatability of the assumed parameters. This issue plays a significant role in specifying the relation of potential interception to rain intensity. The problem of retention of water on the tunnel protecting the tree was eliminated. Installing additional scales under the ceiling and hooking it to the aforementioned tunnel made it possible to continuously register the amount of water retained by the tunnel. The experiments were conducted on 2 species of deciduous trees: *Fagus sylvatica* L. and *Quercus robur* L. The trees chosen for the experiment had properly developed crowns. They were collected with a lump of soil, replanted into pots of suitable size and regularly watered. After making sure that life processes were not stopped, the actual measurements began. During the subsequent runs of the experiment the results were analysed on a current basis, with reference to factors shaping the measured interception, especially drop size of the simulated rain and its intensity. The scheme of the experiment included factors that the author considered relevant, based on her previous research.

Ten runs of the experiment, varying in the intensity of simulated rain and drop size, were made on every tree. Drop size was changed twice and equalled 0.1 and 0.2 mm. For every size 5 changes of rainfall intensity were implemented: 2, 4, 6, 8, 11 mm/h. Henceforth, every rainfall with individual parameters is called the run of the experiment. Values for actual interception were automatically measured and recorded at 5 second time step in a computer database using *Pomiarwin* v5 software. All interception values were given in millimetres of the water layer.

Spraying lasted until the amount of water retained on the whole tree was stable. The point of potential interception, i.e. the maximum possible interception for a given run of the experiment, was determined only later on the basis of actual interception curve. Actual interception was introduced to distinguish it from potential interception I_p. It is the amount of water that remains on the tree surface during every second of spraying.

The determined point of potential interception is closely connected with time T necessary to reach potential interception in a given run of the experiment.

Every run, varying in the intensity and drop size, reached individual levels of potential interception and time needed to its realization. It can be said that by conducting 10 rain simulations on every tree we obtained 10 I_p and T values. Thusly created database was used for further analyses.

Results

Values of potential interception I_p and time T needed for reaching it were read from interception curve $Irz = f(t)$ as shown in figure 1.

After time T, further spraying no longer caused gain in water mass measured on scales. T and I_p values for all 20 runs of the experiment are presented in table 1, including rain intensity S and drop size F_i.

The analysis of potential interception shows that values of this interception for both species correlate well with values of their corresponding time T, as well as with rain intensity values S and drop size F_i (fig. 2 and 4). At the same time it was found that there is a strong correlation between time T needed to reach potential interception I_p, intensity S and drop size F_i.

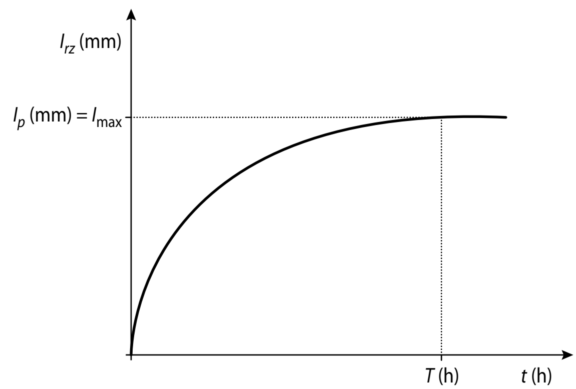

Fig. 1. Example of interception curve

Tab. 1. Values of potential interception for *Fagus sylvatica L.* and *Quercus robur L.*

Species	F_i (mm)	S (mm/h)	T (h)	I_p (mm)
Oak	0.1	2	13.2	22.5
	0.1	4	10.5	18.8
	0.1	6	8.9	15.4
	0.1	8	7.2	14.0
	0.1	11	5.4	13.2
	0.2	2	7.8	16.5
	0.2	4	6.4	15.0
	0.2	6	5.5	13.8
	0.2	8	4.8	11.8
	0.2	11	3.8	10.8
Beech	0.1	2	14.6	26.4
	0.1	4	13.8	24.8
	0.1	6	10.8	22.5
	0.1	8	9.5	19.9
	0.1	11	8.2	18.8
	0.2	2	8.8	22.0
	0.2	4	7,2	21.2
	0.2	6	6.4	19.8
	0.2	8	4.8	19.0
	0.2	11	3.6	18.5

T – time required to achieve potential interception; S – rain intensity and F_i – the size of drops of the simulated rainfall

The analysis of curves presented in figure 2 and in figure 4 shows a decrease in interception value with an increase of the intensity of simulated rain for both tested species. The influence of drop size on potential interception is equally apparent, therefore has to be accounted for in studies on interception process together with rainfall intensity.

Due to different surfaces of the used trees and different values of the retained water, statistical analyses were performed separately for each species.

Using nonlinear estimation, an exponential model was proposed for data obtained for oak:

$$I_p = 9.834 + \exp(3.481 - 5.965S - 0.177F_i) \quad (2)$$

where:

I_p – potential interception,
S – intensity of the simulated rainfall,
F_i – drop size.

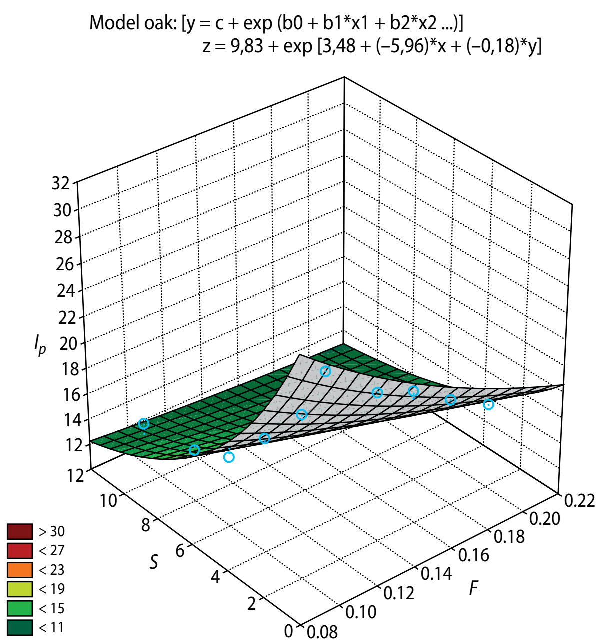

Fig. 2. Illustration of relation of potential interception to rain intensity and drop size based on proposed exponential model for simulation of rainfall for oak

For this model, there is a linear correlation between the observed and the predicted values (fig. 3).

Nonlinear estimation model for beech is:

$$I_p = 16.762 + \exp(3.189 - 5.767S - 0.156F_i) \quad (3)$$

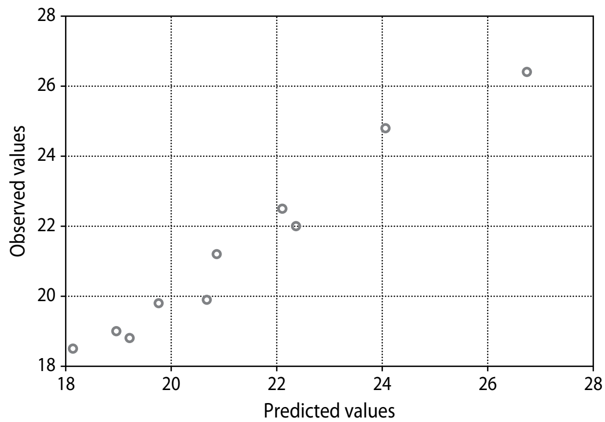

Fig. 3. Linear correlation between observed and predicted values for beech

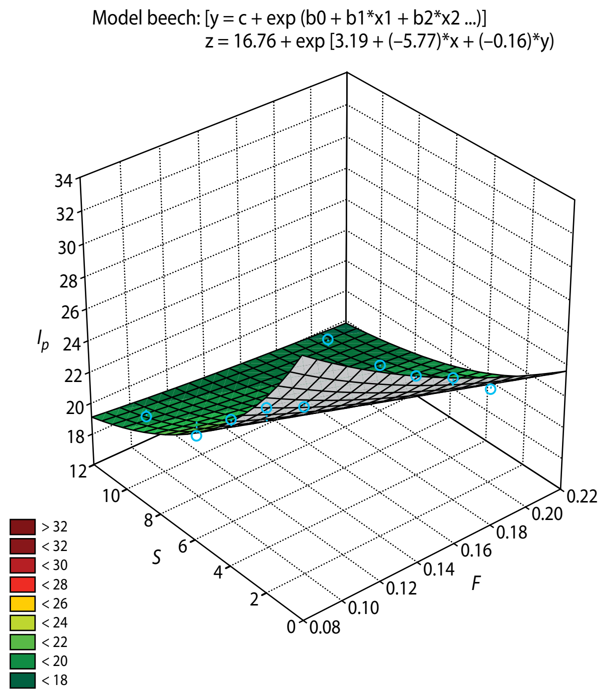

Fig. 4. Relationship between potential interception Ip and the intensity and size of raindrops obtained using proposed exponential model for simulated rainfall for beech

For this model, there is a linear correlation between the observed and the predicted values (fig. 5).

Figure 2 generated on the basis of the proposed formula (2) and figure 4 generated on the basis of the proposed formula (3) confirms that the increase in drop size and the intensity of rain causes the tree crown to lose its ability to intercept rainfall, in other words, the values of potential interception decrease.

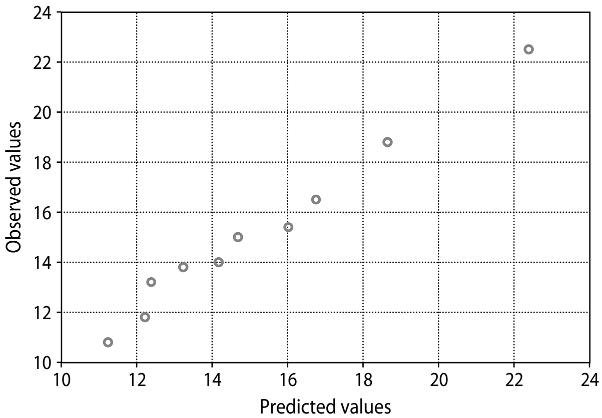

Fig. 5. Linear correlation between observed and predicted values for beech

The results of the identification of the formula for 20 runs of the experiment (R^2 = 0.98 and variance 96) lead us to believe that potential interception of trees is a process that can be depicted with mathematical formulas.

Discussion

Potential interception can be figuratively called "interception reservoir volume". In compliance with Czarnowski concept (1978), developed further by Suliński (1993), an assumption was made that "the reservoir is leaky", i.e. its filling requires rain of appropriate intensity and duration. At the same time there is a big possibility that surface of plants may change its water retention potential in time like retention capacity of forest areas in the work of Grajewski (2006). This applies particularly to shoots covered with old bark which may be subject to this phenomenon, which can be easily observed only on the surface of dead parts of a plant (Kucza 2007).

Considering these correlations in terms of nature, it is worth to ask the following question: does "interception reservoir volume" increase as a result of changes taking place on the surface of plants – related to rain duration – or does it depend on the way of filling the reservoir, i.e. the intensity of rain and the size of raindrops. It is impossible to determine a priori the time T necessary to reach potential interception, as it can be done in case of other rain parameters. It can only be determined from the interception curve after spraying with rain possessing specified characteristics. The correlation $T = f(S, F_i)$ can prove helpful in potential prediction of time T at the specified intensity S and drop size F_i. However, what has to be considered is the fact that interception values are largely the result of sorptive changes of the surface of a tree – the numerical equivalent of which is time T of exposure to rainfall.

We are not able to determine a possible influence of species on interception, because the trees used for the experiment had different surface areas. In order to draw conclusions about the influence of species, it is necessary to precisely determine the surface area and to examine the analysed interception in relation to identical unit of this area. The sole size of the surface area has key significance for the amount of intercepted water (Gomez 2001; Hall 2003).

Pei et al. (1993) performed laboratory rainfall simulations on a constant tree surface, changing rain intensity, ranging from 47.4 to 147.6 mm/h, and also Keim et al. (2006) applied intensity ranging from 20 to 420 mm/h. In Polish climate such intensities produce the amount of rainfall which is relatively unlikely to occur. This was the reason why rain simulations under much lower intensities were carried out. Large variations in implemented intensities make it difficult to compare the results of the present study with those available in literature. However, similar tendencies can be observed. The amount of retained water (interception) increases with decreasing rainfall intensity.

The issue of rain intensity is relevant to interpretation, because, as stated by Toba and Ohta (2008), who measured interception of 24 trees under controlled conditions, the role of rain intensity is important and it takes the same form as in the present research.

In the summary of the present research material it should be stated that the constructed set of sprinklers and the proposed methodology let us obtain comparative and analysable statistical data. The received results correspond with the stream of research on interception of forest communities. The intensity and drop size of the simulated rainfall significantly influence the received values of potential interception. The phenomenon of formation of ability of plants to intercept water depends both on the dynamics and duration of sprinkling.

Conclusions

1. The intensity and size of simulated rainfall droplets has a significant impact on the amount of potential interception.
2. Plant capacity to retain water depends on both the dynamics of spraying, as well as the duration of the spray.

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