SYLWAN 168 (2): 146-157, February 2024
https://doi.org/10.26202/sylwan.2024003
Journal homepage: https://sylwan-journal.pl

ORIGINAL PAPER

Water retention capacity of red-stemmed feathermoss *Pleurozium schreberi* Mitt.

Anna Klamerus-Iwan, Muhammad Owais Khan, Pranav Dev Singh, Agata Warczyk, Małgorzata Stopyra

Department of Ecological Engineering and Forest Hydrology, University of Agriculture in Krakow,
29 Listopada 46, 31-425 Kraków, Poland

ABSTRACT

The forest has a high water retention capacity, which is due to dead wood but also to a layer of moss, forming clusters in the lower forest floor. Mosses use rhizoids to collect water from the soil, but they also use their aboveground parts to collect water in the form of vapour or raindrops. The aim of the present work was to investigate the impact of initial humidity on water retention capacity of fresh samples and maximum water capacity for dry samples.

The research material used in the present study was collected in the Olkusz Forest District. The samples were cut into equal pieces of the same size. Each sample was weighed before and after rainfall simulation in laboratory conditions. The samples were divided into fractions of stems, rhizoids, and soil. The performed analyses demonstrated that the water retention capacity of moss is extremely important for the water cycle. The average sample capacity is 0.58 [g/g], which translates into 24% of the total rainfall. As much as a third of the rainfall is rainfall is retained by mosses that grow on the lower layer of the forest, which makes them an important part of the water cycle in nature.

The experiments have additionally shown that the higher the initial moisture, *i.e.* the more water in the fresh moss samples collected with the lump of earth, the higher the maximum water retention capacity. The dependence of the initial moisture on the components of the sample structure is explained by 43.22% variation. As much as 56.78% of the variability of the initial moisture content may depend on other factors that were not included in this study. These may include a different number of rhizoids, but also the degree of their binding/bonding of the soil. On the other hand, the lack of correlation of the water retention capacity, either the current one or that related to the dried weight of the sample, with the structural components of the sample tells us a lot about the complexity of the link between the moss and the soil via the rhizoids.

The results obtained in the present study are in line with the research on the hydrological properties of forest ecosystems; they also indicate that the role of moss in the forest is very important, but not yet fully understood.

KEY WORDS

current water retention, forest floor, moss, retention reservoir, storage water capacity

e-mail: anna.klamerus-iwan@urk.edu.pl

Received: 25 January 2024; Revised: 26 February 2024; Accepted: 29 February 2024; Available online: 18 April 2024

Introduction

The uptake of water by plants is considered in various aspects as a component of the water balance and as a factor influencing the water cycle in the soil. Regardless of the aspect studied, it is an important factor influencing the microclimate, which is related to air humidity (Allen *et al.*, 2020).

Factors that affect changes in the water capacity of forest ecosystem elements should not be overlooked in eco-hydrological research.

Plants retain rainwater with their entire surface, in a process known as plant interception. The amount of rainfall that reaches the forest floor depends on the direct rainfall and the relative air humidity. Tree morphology affects the amount of water reaching the lower layers of the forest (Rosado and Holder, 2013; Klamerus-Iwan and Szymański, 2017). The process of water retention on the surface of plants is influenced by plant structural features, and by precipitation characteristics (Dunkerley, 2000; Zou *et al.*, 2015). The amount of water that can be retained is treated as a constant value of a single rainfall event, which may change as a result of successive rainfall events (Chang, 2003; Klamerus-Iwan and Witek, 2018). Due to the above statements, it is very important to determine which factors can increase the amount of water retained in the stand, and which factors reduce that amount significantly.

The forest has a high water retention capacity, which is due to dead wood (Błońska *et al.*, 2020; van Stan *et al.*, 2021) but also to a layer of moss, forming clusters in the lower forest floor. A characteristic feature of these plants is their resistance to drought and the fact that they can accumulate large amounts of water (Rutten and Santarius, 1993; Xiao *et al.*, 2016). This property results from the way these organisms absorb, accumulate, transport and store water. Mosses use rhizoids to collect water from the soil, but they also use their aboveground parts to collect water in the form of vapour or raindrops. Mosses have a protective effect against soil compaction, erosion and drying out of soils (Lichner *et al.*, 2012; He *et al.*, 2016). They slow down surface runoff, thus counteracting local soil erosion (Keesstra *et al.*, 2018). Post-fire management should take into account the presence of mosses covering the soil as they significantly increase fertility (García-Carmona *et al.*, 2020). A characteristic feature of mosses is their large ecological amplitude. These organisms occupy a wide variety of habitats, with varying amounts of water available to them. Their development potential in various conditions is related to the high resistance of these organisms to long-term water shortages. Mosses can survive very long periods of drought, after which they are able to resume their physiological processes (Krupa, 1974). Mosses, like decaying wood, are an important reservoir for storing water in the ecosystem (Błońska *et al.*, 2018). Mosses and lichens can retain more rainwater than their own weigh (Porada *et al.*, 2018; Porada and Giordani, 2021) therefore their eco-hydrological importance is very high. The study focused on the common sea buckthorn *Pleurozium schreberi* (Wild. Ex Brid.) Mitt., which belongs to the division of mosses of the *Hylocomiaceae* family. This species produces extensive turfs of yellow-green or pale green colour. Sea buckthorn is a dioicous moss (Gill, 2020).

The aim of the present work was to investigate the impact of initial humidity on water retention capacity of fresh samples (current storage capacity *S*), and maximum (full) water capacity (*Smax*) for dry samples. In eco-hydrological studies, water retention capacity of forest ecosystem elements usually refers to their fresh weight. Our research attempted to check whether other results would be obtained with regard to dry weight – as in the case of the maximum soil water retention capacity.

We have also taken into account how the structural components of the moss sample affect the initial, current and potential moisture. The water retention capacity is expressed both in grams of water per unit of the sample's weight, and as a percentage of the total rainfall.

Improving the knowledge about the water retention capacity of forest communities is most beneficial under controlled conditions, helping to provide data for the creation of mathematical models (Lorens *et al.*, 2000; Garcia-Estringana *et al.*, 2010). The issue of water retention capacity is an important problem that is being studied by hydrologists as well as by researchers dealing with forest ecosystems (Keim *et al.*, 2004; Allen *et al.*, 2020). So far, the share of mosses in the water retention of forest ecosystems is not yet sufficiently known.

Research methodology

SAMPLING LOCATION. The research material used in the present study was collected in the Olkusz Forest District (in southern Poland) where pine stands growing in fresh coniferous forests were selected. Moderate climatic factors prevail here, with the average temperature of approx. 7°C. The length of the growing season is between 200-210 days. The area of the Forest District is poor in surface waters and in rivers. Parts of the Forest District remain under a strong pressure from the mining industry, which is the result of the creation of a large number of mines, and this leads to a lowering of groundwater and disturbing water balance. Coniferous habitats predominate in a considerable part of the region. The dominant species in the Olkusz Forest District are pine *Pinus sylvestris* L., beech *Fagus sylvatica* L. and birch *Betula pendula* Roth.

DESCRIPTION OF LABORATORY WORK. The experiment began with the calibration of the sprinkler equipment. The aim of the performed calibration was to establish a constant dose of water. At each time of the application, the sample was sprinkled with a dose of 200 grams of water. A manual sprinkler was used, which had already been employed in previous studies (Klamerus-Iwan and Błońska, 2018; Klamerus-Iwan *et al.*, 2023).

The samples were cut into equal pieces of the same size (15×6×6 cm). Each selected sample (40 units) was weighed in its fresh state. The next step was to spray the sample with 200 ml of water. After the rainfall simulation, the sample was reweighed. During sprinkling, the sample was placed on a permeable pad, and the excess water flowed into a separate container. The current water retention capacity (S) was obtained from the difference in the weight of the sample after spraying with a constant dose of water, and the weight of the sample in the fresh state.

The next step was to divide the sample into fractions of stems, rhizoids, and soil. The stems were cut off with a pruner, whereas the rhizoids and the soil were separated by rinsing the fractions in water. The samples thus prepared were dried for 24 hours at the temperature of 105°C. After the samples were dried in the oven, they were again reweighed (Md).

CALCULATIONS. First, the weight of individual dried sample elements was calculated, thanks to which the dry weight of the whole sample (Md) was obtained:

$$Md = Mdg + Mdp + Mds$$

where:

Md – dry weight of the whole sample [g],
Mdg – dry weight of the leafy twigs [g],
Mdp – dry weight of the rhizoids [g],
Mds – dry weight of the soil fraction associated with the rhizoids [g].

In the next step, the initial moisture (*S*0) of the analysed samples was calculated. *S*0 is the amount of water that the sample contained before the experiment. Initial moisture content was calculated in grams of water per gram of dry weight [g/g].

$$S0 = \frac{Mf - Md}{Md}$$

where:

*S*0 – initial moisture content of the sample [g/g],
Mf – weight of the sample before the experiment – in fresh state [g],
Md – weight of the dried sample [g].

Then the maximum water retention capacity was calculated – that is the amount of water that the sample can hold in relation to its dry weight (*Smax*). The maximum retention capacity was calculated in grams of water per one gram of dry sample [g/g].

$$Smax = \frac{Mw - Md}{Md}$$

where:

Smax – maximum water capacity – related to dry weight [g/g],
Mw – weight of the sample after sprinkling [g],
Md – dry weight [g].

We have also calculated what percentage share of the total rainfall (*P*) was the maximum rainwater retention capacity. 200 grams of precipitation (*P*) was taken as 100%. *Smax* [%] was calculated from the following proportion:

$$Smax\,[\%] = \frac{Smax\,[g] \cdot 100\,[\%]}{P\,[g]}$$

where:

Smax – maximum water retention capacity expressed in [%],
Smax – maximum water retention capacity – based on dry weight [g/g],
P – the dose of water used to simulate rainfall [g].

200 grams of precipitation on the surface taken for testing resulted in a precipitation of 22.2 mm.

The current water retention capacity (*S*) is the value that reflects – as closely as possible – the amount of water retained by the moss sample with the lump of soil. It was calculated by subtracting the fresh weight of the sample from the weight after spraying. It was then referred to the weight of the fresh sample.

$$S = \frac{Mf - Mw}{Mw}$$

where:

S – current water retention capacity [g/g],
Mw – weight of the sample after sprinkling [g],
Mf – weight of the sample in the fresh state [g].

The current water retention capacity was also calculated as the percentage of water retained from all simulated precipitation.

$$S\,[\%] = \frac{S\,[g] \cdot 100\,[\%]}{P\,[g]}$$

where:

S – the amount of rainfall that was retained on the fresh moss-soil sample [%],
P – the dose of water used to simulate rainfall [g],
S – current water retention capacity [g].

STATISTICAL STUDY. The analysis was carried out using the R software, version 3.4.4. R Core Team (R Foundation for Statistical Computing, Vienna, Austria) (R Core Team, 2017). In the first step, the influence of the initial moisture on the current and maximum water retention capacity was investigated. For this purpose, univariate linear regression was used. In the second step, the impact of the share of stems, rhizoids and soil on the initial, current and potential moisture was calculated. Multivariate regression analysis was used in order to determine this correlation.

Results

IMPACT OF INITIAL MOISTURE ON THE CURRENT AND MAXIMUM WATER RETENTION CAPACITY. The influence of the initial moisture ($S0$) on the maximum water capacity ($Smax$) shows a statistically significant relationship ($p<0.005$). The regression parameter is 1.277, therefore each subsequent g/g of $S0$ increases the value of $Smax$ by an average of 1.277 g/g (Table 1).

The inverse correlation occurs in the case of the impact of the initial moisture on the current water retention capacity. This is also a statistically significant correlation, however, the regression parameter is –0.148, therefore each subsequent g/g of $S0$ decreases the value of S by an average of 0.148 g/g (Table 2).

THE DEPENDENCE OF THE INITIAL MOISTURE CONTENT ($S0$) ON THE PROPORTIONS IN THE COMPOSITION OF THE MOSS SAMPLE. As we have already established (Table 1, 2), $S0$ may affect both the current and the maximum water retention capacity, *i.e.* the capacity related to both fresh and dry weight of the twigs. It seems reasonable to investigate how individual fractions of moss collected with the soil sample influence this initial moisture. The linear regression model showed that a significant ($p<0.05$) independent predictor of the initial moisture ($S0$) is the weight of soil in the sample. The percentage and weight fraction of soil in the whole sample was the highest. For weight of soil associated with rhizoids (Mds), the regression parameter is –0.017, therefore each gram of soil weight (Mds) lowers the initial moisture ($S0$) by an average of 0.017 g/g (Table 3).

The R^2 coefficient for this model was 43.22%, which means that 43.22% of the variability of the initial moisture ($S0$) was explained by the variables adopted in the model, *i.e.* the structural components of the moss sample. The remaining 56.78% depends on the variables that were not included in the model, on random factors, or on the mutual interaction between the components of the sample structure.

Table 1.
Impact of the initial moisture on the maximum water retention capacity

Feature	Parameter	95%CI		p
$S0$ g/g	1.277	1.002	1.552	<0.001*

p – univariate linear regression; $S0$ – initial moisture; CI – confidence interval

Table 2.
Impact of the initial moisture on the current water retention capacity

Feature	Parameter	95%CI		p
$S0$ g/g	–0.148	–0.29	–0.006	0.049*

p – univariate linear regression; $S0$ – initial moisture; CI – confidence interval

The weight percentage of soil fractions in the tested samples was the highest. On average, it amounted to 78% of the total weight of the sample. The highest share of the soil fraction was 95% of the total sample volume and the lowest was 55%. *Mdg* was 9.38% of the total sample and *Mdp* accounted for 10.86%.

DEPENDENCE OF THE MAXIMUM CAPACITY (*SMAX*) ON THE STRUCTURE OF THE MOSS SAMPLE. This correlation was examined both in terms of weight, *i.e.* grams of water retained within the grams of dry weight of the entire sample, and in terms of the percentage of water retained from the total rainfall (*P*).

IMPACT OF STEM WEIGHT (*MDG*), RHIZOID WEIGHT (*MDP*), AND SOIL WEIGHT (*MDS*), EXPRESSED IN GRAMS, ON *SMAX*. The linear regression model showed that soil weight (*Mds*) is a significant (p<0.05) independent predictor of the maximum water capacity (*Smax*). Because the regression parameter is –0.028, therefore each gram of soil (*Mds*) reduces the water retention capacity – albeit related to dry matter (*Smax*) – by 0.028 g/g on average (Table 4).

The R^2 coefficient for this model was calculated as 46.37%, which means that 46.37% of the variation in the maximum water capacity (*Smax*) was explained by the variables adopted in the model.

Impact of stem weight (Mdg), rhizoid weight (Mdp), and soil weight (Mds), expressed as a percentage, on Smax

The linear regression model showed that the significant (p<0.05) independent predictors of the maximum water capacity (*Smax*), also expressed as a percentage of water retained from the whole rainfall, include:

- Stem weight (*Mdg*): The regression parameter is 0.1, therefore each additional per cent of *Mdg* increases *Smax* by an average of 0.1 g/g,
- Weight of rhizoids (*Mdp*): The regression parameter is 0.067, therefore each additional per cent of *Mdp* increases *Smax* by an average of 0.067 g/g.

The R^2 coefficient for this model was 61.51%, which means that 61.51% of the *Smax* variability was explained by the variables adopted in the model (Table 5).

Table 3.

Impact of the components of the moss sample including soil on the initial moisture

Feature	Parameter	95%CI		*p*
Mdg [g]	0.038	–0.026	0.101	0.253
Mdp [g]	–0.023	–0.08	0.035	0.445
Mds [g]	–0.017	–0.026	–0.009	<0.001*

p – multivariate linear regression; *statistically significant correlation (p<0.05); *Mds* – soil dry weight; *Mdp* – dry weight of rhizoids; *Mdg* – dry weight of leafy stems; CI – confidence interval

Table 4.

Impact of the sample structure components on the maximum water retention capacity

Feature	Parameter	95%CI		*p*
Mdg [g]	0.037	–0.058	0.132	0.45
Mdp [g]	0.02	–0.065	0.106	0.642
Mds [g]	–0.028	–0.04	–0.016	<0.001*

p – multivariate linear regression; *statistically significant correlation (p<0.05); *Mds* – soil dry weight; *Mdp* – dry weight of rhizoids; *Mdg* – dry weight of leafy stems; CI – confidence interval

DEPENDENCE OF THE ACTUAL WATER RETENTION CAPACITY ON THE STRUCTURAL COMPONENTS OF THE MOSS SAMPLE. The linear regression model showed that the components of the moss sample structure, each taken separately, do not constitute significant independent predictors of the actual water retention capacity (*S*) (since all values of $p>0.05$). Individually, the parts into which the samples were separated did not explain the amount of water stored in the fresh sample. The R^2 coefficient for this model was only 6.85% (Table 6).

With similar calculations applied to the percentages of water retained from total rainfall (*P*), the linear regression model showed that – likewise as regards the grams of water per gram of sample – none of the analysed features is a significant independent predictor of *S* (since all values of $p>0.05$) (Table 7).

The R^2 coefficient for this model was 8.61%, which means that 8.61% of the *S* variation was explained by the variables adopted in the model. The remaining 91.39% depends on the variables not included in the model as well as random factors.

Discussion

In the work here presented, we sought to establish the correlation between the structure of a moss sample with a lump of soil, and the impact on the sample's hydrological properties. On the one hand, it was not an easy task because the amount of soil in relation to the part of the leafy stalks and rhizoids, by weight and by percentage, was not proportional. On the other hand, it is difficult to consider the water retention capacity of moss in isolation from the soil, with which the latter is closely linked via a network of rhizoids. The presence of the soil united with the rhizoids

Table 5.

The impact of the sample structure on the percentage of water retained by the sample from the total rainfall

Feature	Parameter	95%CI		*p*
Mdg [%]	0.1	0.054	0.145	<0.001*
Mdp [%]	0.067	0.025	0.11	0.003*

p – multivariate linear regression; *statistically significant relationship ($p<0.05$); *Mdp* – dry weight of rhizoids; *Mdg* – dry weight of leafy stems; CI – confidence interval

Table 6.

The impact of the sample structure on the current water retention capacity

Feature	Parameter	95%CI		*p*
Mdg [g]	–0.006	–0.044	0.033	0.772
Mdp [g]	0.028	–0.006	0.063	0.116
Mds [g]	0	–0.005	0.005	0.984

p – multivariate linear regression; *Mds* – soil dry weight; *Mdp* – dry weight of rhizoids; *Mdg* – dry weight of leafy stems; CI – confidence interval

Table 7.

Impact of the percentage shares of sample composition on the current water retention capacity, that is capacity related to the fresh condition of the sample

Feature	Parameter	95%CI		*p*
Mdg [%]	–0.008	–0.03	0.013	0.446
Mdp [%]	0.019	–0.001	0.039	0.072

p – multivariate linear regression; *statistically significant relationship ($p<0.05$); *Mdp* – dry weight of rhizoids; *Mdg* – dry weight of leafy stems; CI – confidence interval increased the similarity of the studied sample to the actual state, and reduced the cognitive errors of the laboratory experiment (Blume *et al.*, 2017).

The performed analyses demonstrated that the water retention capacity of moss is extremely important for the water cycle. The average sample capacity is 0.58 [g/g], which translates into 24% of the total rainfall. As much as a third of the rainfall is rainfall is retained by mosses that grow on the lower layer of the forest, which makes them an important part of the water cycle in nature.

The wettability of plant material, which affects its hydrological properties, is determined by measuring the contact angle of a drop of water to a given material (Papierowska *et al.*, 2019; Holder *et al.*, 2020). In the case of lichens, such measurement was not possible due to high absorption and to the water spreading over the entire surface of the plants.

The obtained results are in line with the canon of research on the water retention properties of plant material, which indicate the range of interception from an average of 10% to as much as 50% (Gash *et al.*, 1995). 30% of the total rainfall that can be stored in the soil overgrown with moss is the amount of water that will reach the soil with some delay, but it creates a more humid microclimate and prevents excessive drying.

The experiments have additionally shown that the higher the initial moisture, *i.e.* the more water in the fresh moss samples collected with the lump of earth, the higher the maximum water retention capacity. The maximum water retention capacity that has been calculated is related to the dry weight of the entire sample, given in grams. This conclusion can be compared to the water properties of soil where the wetter fresh soil is able to retain more water, and the excessively dry soil becomes hydrophobic (Doerr *et al.*, 2006).

On the other hand, the higher the initial moisture, the less water is retained in the fresh moss sample after rainfall. This situation is similar to the actual situation that occurs in natural conditions, for instance, in a forest. The research into the water retention capacity of plants has also been related to fresh weight. In summary, the more water there is in the moss samples, the higher the cell turgor, which makes the surface tighter (Jiao *et al.*, 2021). The moss absorbs water from the atmosphere, and the largest increases in water retained are recorded for drier samples, similar to desert conditions (Yuqing *et al.*, 2021). Such a situation may also result from a different external and internal structure of moss compared to vascular plants (Sikorska *et al.*, 2017). The leaves of bryophytes have characteristic vertical rows of cells in the chlorenchyma on their upper surface. This particular arrangement of cells promotes water absorption. We also know from subject literature that non-vascular plants, such as lichens, can retain water in the amount equal to up to 300% of their weight (Porada *et al.*, 2018).

The initial moisture content depends the most on the amount of soil that dominated the entire sample volume. The retention capacity of the moss must be higher than that of the soil, as each additional gram of soil reduces the initial moisture content of the samples.

The dependence of the initial moisture ($S0$) on the components of the sample structure is explained by 43.22% variation. As much as 56.78% of the variability of the initial moisture content may depend on other factors that were not included in this study. These may include a different number of rhizoids, but also the degree of their binding/bonding of the soil.

On the other hand, the lack of correlation of the water retention capacity, either the current one or that related to the dried weight of the sample, with the structural components of the sample tells us a lot about the complexity of the link between the moss and the soil via the rhizoids (Table 7, 8). In the results, we also summarized the calculations of current and potential water retention capacity, firstly in grams of water retained per gram of sample, and secondly a conversion factor was used to show how many per cent of the total rainfall was retained on the sample.

In the case of weight approach, only the increased amount of soil led to decreased *Smax*; and for the current *S*, none of the components of the sample separately constituted an explanatory predictor. For the percentage approach, none of the sample components affected the value of *S*, but an increasing numbers of stalks and rhizoids led to an increased *Smax* value.

The samples were divided into individual components in a manner similar to the separation of soil fractions when looking for analogous correlations, but nevertheless the moss sample with the soil should be treated as a joint system with high water retention capacity. This is more similar to the soil system with plant roots, which are making use of the water contained in the soil, increase its soil water repellency, and can therefore reduce slope runoff (Keesstra *et al.*, 2021; Lowe *et al.*, 2021).

An innovative approach is to relate the amount of water retained by mosses with a lump of soil both to fresh weight – as is the case in eco-hydrological research, but also to dry weight – similar to the methods used in soil science. Recording differences in the results depending on the reference to dry versus fresh weight demonstrates that when describing these phenomena, the experimental conditions should be clearly formulated.

The amounts of water, which are retained in various layers of the forest ecosystem, and which will not reach the forest floor, cannot be ignored either in the study of catchment hydrology or in the analysis of the physical properties of plant material (Limm *et al.*, 2009; Johnstone and Dawson, 2010; Sikorska *et al.*, 2017). The water retention capacity of moss and the amount of water transferred to the sub-crown zone are particularly important for areas with low water availability (Wang *et al.*, 2012). It is an important fact that mosses are pioneering plants, which often inhabit wastelands and then transform the substrate, allowing more demanding plants to settle, and that they create an environment with high water retention properties. The research should also be extended in the future to take into account the seasonal changes, similarly as it this is done for leaves (Kang *et al.*, 2018).

The results obtained in the present study are in line with the research on the hydrological properties of forest ecosystems; they also indicate that the role of moss in the forest is very important, but not yet fully understood (Porada *et al.*, 2018).

In addition, mosses are very important in nature by participating in the formation of the so-called humus layer of the soil, because in this way they also influence the soil water regime by creating a mossy layer, and thanks to their ability to retain large amounts of water, they create lowland blanket bogs.

Conclusions

- The average sample capacity is 0.58 [g/g], which is 24% of the total rainfall. As much as a third of the rainfall is retained by mosses.
- The initial moisture content is most dependent on the amount of the soil that dominated the entire sample volume.
- The water retention capacity of the moss must be higher than that of the soil, as each additional gram of soil reduces the initial moisture content of the samples.
- The initial moisture depends only in 43.22% on the structural components of the sample.

Authors' contributions

A.K-I. – conceptualization, methodology, investigation, data curation, writing parts of original draft; M.O.K., P.D.S, A.W., M.S. – investigation, writing parts of original draft, editing.

Conflicts of interest

The authors declare no conflict of interest.

Funding source

This research was financed by the Ministry of Science and Higher Education of the Republic of Poland.

References

Allen, S.T., Aubrey, D.P., Bader, M.Y., Coenders-Gerrits, M., Friesen, J., Gutmann, E.D., Guillemette, F., Jiménez-Rodríguez, C., Keim, R.F., Klamerus-Iwan, A., Mendieta-Leiva, G., 2020. Key questions on the evaporation and transport of intercepted precipitation. In: J.T. Van Stan, E. Gutmann, J. Friesen, ed. *Precipitation partitioning by vegetation: A global synthesis*. Cham: Springer, pp. 269-280. DOI: https://doi.org/10.1007/978-3-030-29702-2_16.

Blume, T., van Meerveld, I., Weiler, M., 2017. The role of experimental work in hydrological sciences – insights from a community survey. *Hydrological Sciences Journal*, 62 (3): 334-337. DOI: http://dx.doi.org/10.1080/02626667.2016.1230675.

Błońska, E., Klamerus-Iwan, A., Łagan, S., Lasota, J., 2018. Changes to the water repellency and storage of different species of deadwood based on decomposition rate in a temperate climate. *Ecohydrology*, 11 (8): e2023. DOI: https://doi.org/10.1002/eco.2023.

Chang, M., 2012. Forest hydrology: An introduction to water and forests. Third edition. Taylor and Francis. Available from: https://books.google.pl/books?id=Zr60yyHEdVcC.

Dunkerley, D., 2000. Measuring interception loss and canopy storage in dryland vegetation: A brief review and evaluation of available research strategies. *Hydrological Processes*, 14 (4): 669-678. DOI: https://doi.org/10.1002/(SICI)1099-1085(200003)14:4%3C669::AIDHYP965%3E3.0.CO.

Doerr, S.H., Shakesby, R.A., Dekker, L.W., Ritsema, C.J., 2006. Occurrence, prediction and hydrological effects of water repellency amongst major soil and land-use types in a humid temperate climate. *European Journal of Soil Science*, 57 (5): 741-754. DOI: https://doi.org/10.1111/j.1365-2389.2006.00818.x.

García-Carmona, M., Arcenegui, V., García-Orenes, F., Mataix-Solera, J., 2020. The role of mosses in soil stability, fertility and microbiology six years after a post-fire salvage logging management. *Journal of Environmental Management*, 262: 110287. DOI: https://doi.org/10.1016/j.jenvman.2020.110287.

Garcia-Estringana, P., Alonso-Blázquez, N., Alegre, J., 2010. Water storage capacity, stemflow and water funneling in Mediterranean shrubs. *Journal of Hydrology*, 389 (3-4): 363-372. DOI: https://doi.org/10.1016/j.jhydrol.2010.06.017.

Gash, J.H., Lloyd, C.R., Lachaud, G., 1995. Estimating sparse forest rainfall interception with an analytical model. *Journal of Hydrology*, 170 (1-4): 79-86. DOI: https://doi.org/10.1016/0022-1694(95)02697-N.

He, X., He, K.S., Hyvönen, J., 2016. Will bryophytes survive in a warming world? *Perspectives in Plant Ecology, Evolution and Systematics*, 19: 49-60. DOI: https://doi.org/10.1016/j.ppees.2016.02.005.

Holder, C.D., Lauderbaugh, L.K., Ginebra-Solanellas, R.M., Webb, R., 2020. Changes in leaf inclination angle as an indicator of progression toward leaf surface storage during the rainfall interception process. *Journal of Hydrology*, 588: 125070. DOI: https://doi.org/10.1016/j.jhydrol.2020.125070.

Johnstone, J.A., Dawson, T.E., 2010. Climatic context and ecological implications of summer fog decline in the coast redwood region. *Proceedings of the National Academy of Sciences*, 107 (10): 4533-4538. DOI: https://doi.org/10.1073/pnas.0915062107.

Jiao, Y., Du, F., Traas, J., 2021. The mechanical feedback theory of leaf lamina formation. *Trends in Plant Science*, 26 (2): 107-110. DOI: https://doi.org/10.1016/j.tplants.2020.11.005.

Keesstra, S., Mol, G., De Leeuw, J., Okx, J., De Cleen, M., Visser, S., 2018. Soil-related sustainable development goals: Four concepts to make land degradation neutrality and restoration work. *Land*, 7 (4): 133. DOI: https://www.mdpi.com/2073-445X/7/4/133.

Keim, R.F., Skaugset, A.E., Link, T.E., Iroumé, A., 2004. A stochastic model of throughfall for extreme events. *Hydrology and Earth System Sciences*, 8 (1): 23-34. DOI: https://doi.org/10.5194/hess-8-23-2004.

Klamerus-Iwan, A., Błońska, E., Lasota, J., Waligórski, P., Kalandyk, A., 2018. Seasonal variability of leaf water capacity and wettability under the influence of pollution in different city zones. *Atmospheric Pollution Research*, 9 (3): 455-463. DOI: https://doi.org/10.1016/j.apr.2017.11.006.

Klamerus-Iwan, A., Kozłowski, R., Sadowska-Rociek, A., Słowik-Opoka, E., Kupka, D., Giordani, P., Porada, P., Van Stan, J.T., 2023. Influence of polycyclic aromatic hydrocarbons on water storage capacity of two lichens species. *Journal of Hydrology and Hydromechanics*, 71 (2): 139-147. DOI: https://doi.org/10.2478/johh-2023-0010.

Klamerus-Iwan, A., Szymański, W., 2017. Przestrzenno-czasowe zróżnicowanie pojemności wodnej koron drzew leśnych na przykładzie buka zwyczajnego. (Spatio-temporal variability of water storage capacity in forest canopies of European beech). *Sylwan*, 161 (02): 142-148. DOI: https://doi.org/10.26202/sylwan.2016027.

Klamerus-Iwan, A., Witek, W., 2018. Variability in the wettability and water storage capacity of common oak leaves (*Quercus robur* L.). *Water*, 10 (6): 695. DOI: https://www.mdpi.com/2073-4441/10/6/695.

Kang, H., Graybill, P.M., Fleetwood, S., Boreyko, J.B., Jung, S., 2018. Seasonal changes in morphology govern wettability of Katsura leaves. *PloS One*, 13 (9): e0202900. DOI: https://doi.org/10.1371/journal.pone.0202900.

Krupa, J., 1974. Struktura anatomiczna liści mchów a ich aktywność fizjologiczna. Kraków: Wydawnictwo Naukowe Wyższej Szkoły Pedagogicznej, 59 pp.

Leelamanie, D.A.L., Piyaruwan, H.I.G.S., Jayasinghe, P.K.S.C., Senevirathne, P.A.N.R., 2021. Hydrophysical characteristics in water-repellent tropical Eucalyptus, Pine, and Casuarina plantation forest soils. *Journal of Hydrology and Hydromechanics*, 69 (4): 447-455. DOI: https://doi.org/10.2478/johh-2021-0027.

Yuqing, L., Xiaoshuang, L., Jing, Z., Lu, Z., Xiaojie, L., Ruirui, Y., Daoyuan, Z., 2021. Dehydration rates impact physiological, biochemical and molecular responses in desert moss *Bryum argenteum*. *Environmental and Experimental Botany*, 183: 104346. DOI: https://doi.org/10.1016/j.envexpbot.2020.104346.

Lichner, L., Holko, L., Zhukova, N., Schacht, K., Rajkai, K., Fodor, N., Sándor, R., 2012. Plants and biological soil crust influence the hydrophysical parameters and water flow in an aeolian sandy soil. *Journal of Hydrology and Hydromechanics*, 60 (4): 309-318. DOI: https://doi.org/10.2478/v10098-012-0027-y.

Limm, E.B., Dawson, T.E., 2010. *Polystichum munitum* (Dryopteridaceae) varies geographically in its capacity to absorb fog water by foliar uptake within the redwood forest ecosystem. *American Journal of Botany*, 97 (7): 1121-1128. DOI: https://doi.org/10.3732/ajb.1000081.

Llorens, P., Gallart, F., 2000. A simplified method for forest water storage capacity measurement. *Journal of Hydrology*, 240 (1-2): 131-144. DOI: https://doi.org/10.1016/S0022-1694(00)00339-5.

Lowe, M.A., McGrath, G., Leopold, M., 2021. The impact of soil water repellency and slope upon runoff and erosion. *Soil and Tillage Research*, 205: 104756. DOI: https://doi.org/10.1016/j.still.2020.104756.

Papierowska, E., Mazur, R., Stańczyk, T., Beczek, M., Szewińska, J., Sochan, A., Ryżak, M., Szatyłowicz, J., Bieganowski, A., 2019. Influence of leaf surface wettability on the drop splash phenomenon. *Agricultural and Forest Meteorology*, 279: 107762. DOI: https://doi.org/10.1016/j.agrformet.2019.107762.

Porada, P., Giordani, P., 2021. Bark water storage plays key role for growth of Mediterranean epiphytic lichens. *Frontiers in Forests and Global Change*, 4: 668682. DOI: https://doi.org/10.3389/ffgc.2021.668682.

Porada, P., Van Stan, J.T., Kleidon, A., 2018. Significant contribution of non-vascular vegetation to global rainfall interception. *Nature Geoscience*, 11 (8): 563-567. DOI: https://www.nature.com/articles/s41561-018-0176-7.

R Core Team, 2017. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing, 2014. Available from: https://www.r-project.org/.

Rosado, B.H., Holder, C.D., 2013. The significance of leaf water repellency in ecohydrological research: A review. *Ecohydrology*, 6 (1): 150-161. DOI: https://doi.org/10.1002/eco.1340.

Rütten, D., Santarius, K.A., 1993. Osmotic potentials of water-saturated mosses. *Journal of Plant Physiology*, 141 (6): 739-744. DOI: https://doi.org/10.1016/S0176-1617(11)81584-1.

Sikorska, D., Papierowska, E., Szatyłowicz, J., Sikorski, P., Suprun, K., Hopkins, R.J., 2017. Variation in leaf surface hydrophobicity of wetland plants: the role of plant traits in water retention. *Wetlands*, 37: 997-1002. DOI: https://doi.org/10.1007/s13157-017-0924-2.

Van Stan, J.T., Dymond, S.F., Klamerus-Iwan, A., 2021. Bark-water interactions across ecosystem states and fluxes. *Frontiers in Forests and Global Change*, 4: 660662. DOI: https://doi.org/10.3389/ffgc.2021.660662.

Wang, X.P., Zhang, Y.F., Hu, R., Pan, Y.X., Berndtsson, R., 2012. Canopy storage capacity of xerophytic shrubs in Northwestern China. *Journal of Hydrology*, 454: 152-159. DOI: https://doi.org/10.1002/hyp.11157.

Xiao, B., Hu, K., Ren, T., Li, B., 2016. Moss-dominated biological soil crusts significantly influence soil moisture and temperature regimes in semiarid ecosystems. *Geoderma*, 263: 35-46. DOI: https://doi.org/10.1016/j.geoderma.2015.09.012.

Zou, C.B., Caterina, G.L., Will, R.E., Stebler, E., Turton, D., 2015. Canopy interception for a tallgrass prairie under juniper encroachment. *PloS One*, 10 (11): e0141422. DOI: https://doi.org/10.1371/journal.pone.0141422.

STRESZCZENIE

Pojemność wodna rokietnika pospolitego *Pleurozium schreberi* Mitt.

Cechą charakterystyczną mchów jest odporność na suszę i umiejętność gromadzenia dużych ilości wody. Mchy za pomocą chwytników pobierają wodę z gleby, ale wykorzystują również części nad-

ziemne, by pobierać wodę w postaci pary wodnej lub kropel z opadów. Mchy, podobnie jak rozkładające się drewno, stanowią ważne miejsce magazynowania wody.

Do badań wykorzystano rokietnik pospolity *Pleurozium schreberi* (Wild. ex Brid.) Mitt., który należy do gromady mchów i rodziny gajnikowatych. Gatunek ten tworzy rozległe darnie w kolorze żółtozielonym lub bladozielonym. Materiał badawczy wykorzystany w pracy zebrano w Nadleśnictwie Olkusz (południowa Polska). Celem pracy było zbadanie wpływu wilgotności początkowej na pojemność wodną próbek w stanie świeżym (pojemność aktualna *Sa*) i pojemność wodną maksymalną (*Smax*) dla próbek wysuszonych. W badaniach ekohydrologicznych pojemność wodna elementów ekosystemu leśnego odnosi się zwykle do świeżej masy. W niniejszych badaniach podjęto próbę sprawdzenia, czy w przypadku suchej masy zostaną uzyskane inne wyniki (podobnie jak w przypadku pojemności maksymalnej gleby) (tab. 1 i 2). Badano również, jak składowe budowy próbki mchu wpływają na wilgotność początkową, aktualną i potencjalną.

W prezentowanej pracy poszukiwano zależności pomiędzy budową próbki mchu z bryłką ziemi a jej właściwościami hydrologicznymi (tab. 3 i 4). Ilość ziemi w stosunku do części ulistnionych łodyżek i chwytników nie była proporcjonalna masowo i procentowo (tab. 5). Trudno jednak rozpatrywać zdolności retencyjne mchu w oderwaniu od gleby, z którą jest ściśle powiązany za pomocą sieci chwytników (tab. 6 i 7). Średnia pojemność całej próbki wynosiła 0,58 [g/g], co stanowi 24% całości opadu. Aż $^1/_3$ opadu zostaje zatrzymana przez mchy, które porastają dolne piętro lasu i stanowią ważny element obiegu wody w przyrodzie.

Doświadczenia wykazały też, że im wyższa wilgotność początkowa, czyli im większa jest zawartość wody w świeżych próbkach mchu pobranego wraz z bryłką ziemi, tym wyższa pojemność maksymalna (tab. 1 i 2). Nasuwa się tu analogia do właściwości wodnych gleby: gleba wilgotniejsza w stanie świeżym jest w stanie zatrzymać więcej wody, a gleba nadmiernie przesuszona staje się hydrofobowa. Zależność wilgotności początkowej (*S*0) od składowych budowy próbki jest wyjaśniona przez 43,22% zmienności. Aż 56,78% zmienności wilgotności początkowej może zależeć od innych czynników, które nie zostały ujęte w tym badaniu (tab. 3 i 4). Może to być nie sama ilość chwytników, ale także stopień związania/spajania przez nie gleby. Natomiast brak zależności pojemności wodnej – zarówno aktualnej, jak i odniesionej do wysuszonej masy próbki – od składowych budowy próbki dużo mówi o złożoności układu pomiędzy mchem związanym chwytnikami a glebą (tab. 5 i 6).

Nowatorskim spojrzeniem jest odniesienie ilości zatrzymanej wody przez mchy z bryłką ziemi zarówno do świeżej masy (jak ma to miejsce w badaniach ekohydrologicznych), ale także do wysuszonej masy, na wzór metod stosowanych w gleboznawstwie. Zarejestrowanie różnic w wynikach w zależności od odniesienia do suchej czy świeżej masy pokazuje, że opisując te zjawiska, należy jasno sformułować warunki doświadczenia (tab. 7).

Mchy to rośliny pionierskie i często zasiedlają nieużytki, a następnie przekształcają podłoże, umożliwiając osiedlenie się bardziej wymagającym roślinom i tworząc środowisko o wysokich właściwościach retencyjnych. W przyszłości należałoby rozszerzyć badania i uwzględnić zmiany sezonowe, podobnie jak dla liści. Uzyskane wyniki wpisują się w badania nad hydrologicznymi właściwościami ekosystemów leśnych i pokazują, że rola mchu w lesie jest bardzo istotna, ale jeszcze nie do końca poznana.