DOI: 10.2478/frp-2014-0032

Leśne Prace Badawcze (*Forest Research Papers*), December 2014, Vol. 75 (4): 353–358

ORIGINAL RESEARCH ARTICLE

Rainfall parameters affect canopy storage capacity under controlled conditions

Anna Klamerus-Iwan

University of Agriculture in Kraków, Faculty of Forestry, Department of Forest Engineering, Al. 29 Listopada 46, 31–425 Kraków, Poland.

Tel. + 48 12 662 53 56, fax +48 12 4119715, e-mail: annaklamerus.iwan@gmail.com

Abstract. The subject of this research was the interception of precipitation, which is defined as the amount of water that can be retained by the entire surface of a tree. The aim was to measure the rate of interception under laboratory conditions in order to determine influential factors. To eliminate water absorption that would occur in living trees, we employed models of deciduous and coniferous trees enabling us to examine the effect of precipitation characteristics and the surface area individually. A sprinkler system that automatically recorded the amounts of water retained on the models was set up in the laboratory. Precipitation was simulated using 5 different intensities with 3 different raindrop sizes.

Interception rates were affected by both, the intensity of the precipitation and raindrop size. The time required to reach maximum crown filling with water was variable and depended on plant surface parameters as well as simulated precipitation. The maximum water capacity of crowns was not a constant value even within one tree model, but changed depending on precipitation characteristics.

Key words: area of trees, interception tank, mock trees, rainfall intensity, size of raindrops, sprinkler set

1. Introduction

Trees interception is a component of 'atmosphere – forest stand – soil' balance. This phenomenon concerns the phase of balance enrichment in water. The amount of water retained on plant surface lowers the reserve of water in soil (Suliński 1993; Xiao et al. 2000; Barbier et al. 2009).

In numerical terms, the interception is a significant component of water balance. Pike and Scherer (2003) even expressed an opinion that it is a crucial problem in forest hydrology. Zinke (1967) and Webb (1975) indicated on the possibility of intercepting by trees even 10–30% of whole rainfall. Calder (1999) defined the value of interception on 50%. Interception, irrespective of differences in species composition, structure and forest density and also in rain characteristics connected with different climate conditions, should be included in models simulating such processes like: evapotranspiration, water outflow from soil, soil retention and others (Chang 2003). It could also be included in water balances of special purpose, for example, in geochemical research (Hörmann et al. 1996), or in nitrogen circulation in atmosphere (Loescher et al. 2002) or in climate balances of afforestated areas (Okoński, Miler 2006).

Literature, in which data can be found from interception measurements performed in certain geographical and forest stands conditions is extensive. In Poland, a considerable source of data concerning interception of forest stands are numerous Olszewski's thesis (1965, 1975, 1984). An attempt of comparison of interception size obtained in local observations was made by Pei et al. (1993). The majority of researchers interpreted trees' interception as a difference of rainfall size over and under trees crown (Olszewski 1975, 1984; Aston et al. 1979; Jetten 1996; Feliksik et al. 1996; Calder 2001; Gomez et al. 2001; Bryant et al. 2005). Spatial and time

Received 05 March 2014, accepted after revision 20 May 2014.
© 2014, Forest Research Institute

distribution of interception is difficult to compare quantitatively. It is hard to compare obtained results due to differentiation of methods, places and time of measurements (Crockford, Richardson 2000; Jong, Jetten 2007). The role of rainfall intensity in forming of plants' interception size is significant, but this issue should be considered as poorly examined. That is why *inter alia* Asdak et al. (1998) and also Toba and Ohta (2008) postulated the need for developing study and laboratory experiments in this area.

Research studies with the use of sprinkler in laboratory were performed by Hall and Calder (1993), Garcia–Estringana et al. (2010). According to results from Calder et al. (1996) and Calder (1999), crown ability for retaining water increases when size of raindrops decrease and rain intensity decreases. Similar research of interception in laboratory conditions were conducted *inter alia*: Pei et al. (1993), Suliński et al. (2001), Keim et al. (2006).

2. Material and methods

The experiments were performed on two mock-ups simulating deciduous and coniferous species. The use of mock-ups for research was necessary due to recognition of interception process on areas that were not changing physical properties after wetting with water – both during single rain, measurement series but also research cycles. Material from which the models of trees were made was water resistant. For constructing, models used were available in garden stores, artificial branches out of which trees were formed similar to natural ones. In case of deciduous mock, the model was European beech and in case of coniferous mock – Scots pine. Artificial trees were 110 cm high. The area of mock-ups was defined as the sum of trunk's part surface, branches and leaves/needles. Adopted was methodology of measurements based on direct scanning of trees elements or their photographs. Analysis and calculations were made in Sigma Scan v.2 program.

When performing similar experiments in reference to live trees, water absorption by bark should be analysed. The results of experiments with the use of models of deciduous and coniferous trees were used also as control and comparison values for interception values obtained in case of live trees. Laboratory stand prepared for interception measurement of listed trees was described by Klamerus-Iwan et al. (2013).

On each of the models, two full cycles of experiments were performed. Every cycle had three series, each with different drops size from water sprinkler (0.4; 0.50; 0.60 mm). Within each series, five differing repetitions with rainfall intensity (5, 10, 15, 20, 25 mm/h) were performed. The scheme of experiments was presented in Klamerus-Iwan et al. thesis (2013a). Jointly, the cycle of experiment in one mode included 15 repetitions of experiment.

A significant assumption during all experiments was maintenance of permanent, repetitive temperature and humidity conditions in the laboratory. Thermohygrograph registered relative humidity at the level of 20–25% and temperature in the range of 19–23°C. Distilled water of temperature 21(±1)°C was used for the experiment. In natural conditions also, the temperature of rainfall is by 1–2°C lower than air temperature most frequently.

Bearing in mind small sizes of trees used for experiment, the diversity of surface had to be considered possibly scrupulously. In order to do so, measurements methodology based on direct scanning of elements on their photography (Owsiak et al. 2012) was accepted.

Statistical analysis was based on finding the factors that were responsible for the size of interception obtained for each repetition of experiment. Used were multivariate significance tests (Statistica v.10). The best predictors were compared for both models jointly and separately for deciduous and coniferous species.

3. Results

Procedures used for calculating the size of examined models area and also trees surface were labour-consuming, but they assured, however, that obtained results were very reliable and further analysis could be based on them. The surface of deciduous mock is 0.216 m^2 and coniferous mock is 0.310 m^2.

Crown projection on the horizontal plane, defined on the basis of picture made by a camera placed centrally over crown for both models was very similar (ratio of crown projection area to plane covered with sprinkling): deciduous model is 0.702 and coniferous model is 0.712.

Interception measurements were performed at 1-minute intervals. Establishing the moment of maximum interception occurrence for given experiment course was interpreted from interception curve. This curve showed increasing amount of water on models in time (t) of experiment. Values presented in Figures 1 and 2 are values of maximum water amount (*Ip*) that can be retained on models at defined rainfall characteristic. For each model and repetition of experiment, a different time (*T*) was established, which was necessary for reaching potential interception (*Ip*). All data are presented graphically in Figures 1 and 2 according to intensity of simulated rainfall and the size of raindrops in a division of deciduous and coniferous mock.

Factors that could explain why interception values obtained on trees models differ from each other in every repetition of experiment were searched. If interception was decided only by the size of the plant's surface, then the *Ip* values would be different between mock-ups and not with change of simulated rainfall parameters. Statistically searched for were the best predictors for dependent variable, that is, potential interception.

In case of woody plants occurs a qualitative diversity of assimilation apparatus and ligneous shoots surface because their covering changes with object's age.

In case of mock-ups made of plastic, it is hard to speak about influence of species characteristics, therefore the size of area (A) is a value distinguishing the deciduous mock-up from the coniferous one (Table 1).

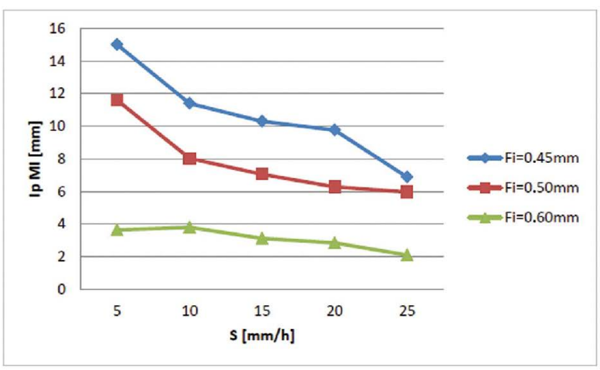

Figure 1. Relationship of potential interception (*Ip*) and rainfall intensity (*S*) and used droplet size (*F*) in the case of coniferous mock-up (*MI*)

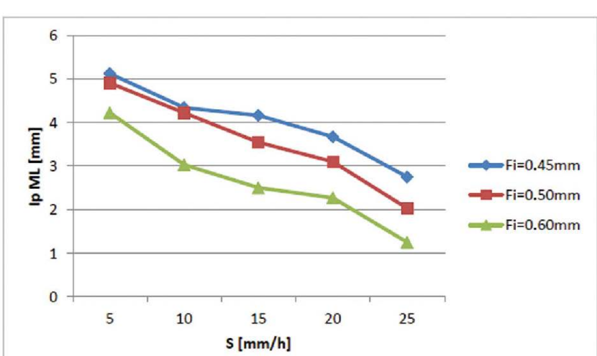

Figure 2. Relationship of potential interception (*Ip*) and rainfall intensity (*S*) and used droplet size (*F*) in the case of deciduous mock-up (*ML*)

The lack of possibility of capturing typical features of coniferous and deciduous trees (natural, morphological differences of gymno – and angiosperms) made it impossible to think about influence of species characteristics. The influence of significant factors can be analysed separately for coniferous (Table 2) and deciduous mock-ups (Table 3).

A high cognitive value would have an experiment in which both mock-ups would have the same surface and differ with features typical for coniferous and deciduous trees.

The construction and use of trees models for experiments over interception in laboratory conditions was a pioneering action. In experiment, the coniferous mock had a bigger area. In reality, such situation can only occur when comparing spruce and fir with birch. In case of the most common in Poland forest stand (pine, oak) deciduous species are the ones characterised with much greater rainfall interception area.

Table 1. Selection of the best predictors for the variable *Ip* (potential interception) for both mock-ups in total (deciduous and coniferous)

Mock-ups in total (deciduous and coniferous)	Best predictors for the variable *Ip* [mm]	
	F	*p*
A [m^2]	13.496	0.001
Fi [mm]	6.276	0.00577
T [min]	3.908	0.00575

Explantation:
A – area of artificial trees from direct measurement,
Fi – droplet size of simulated rain,
T – time necessary to achieve the maximum interception,
F – test FSnedecora,
p – significance level.

Table 2. The best predictors for the variable *Ip* for model of coniferous tree

Coniferous mock-up	Best predictors for the variable *Ip* [mm]	
	F	*p*
Fi [mm]	15.41	0.00048
T [min]	1.82	0.20496
S [mm/h]	0.679	0.62197

Explantation:
S – simulated rainfall intensity,
Other as in Table 1

Table 3. The best predictors for the variable *Ip* for model of deciduous tree

Deciduous mock-up	Best predictors for the variable *Ip* [mm]	
	F	*p*
S [mm/h]	4.8078	0.02009
Fi [mm]	2.7562	0.103514
T [min]	1.2852	0.374507

Explantation:
Other as in Tables 1, 2

4. Discussion

The process of interception of a single rainfall can be compared to filling a leaky container with water. The surface of trees used in presented mock-up experiments is an equivalent of an interception container.

Quantitative differences of interception that are dependent on surface size can be seen vividly. It can be concluded that the size of surface is, to a great degree, a determinant of water amount retained on plants (Figures 1, 2; Table 1).

Coniferous mock was bigger and retained much less water. Such summary gives reasons for considering the influence of species characteristics on the amount of retained water. With mock-ups, it is not possible to compare the properties of bark or cuticle covering the green parts of plants. It can be puzzling whether brushy setting of needles may store more water than in case of leaves. Converting interception per unit of area and then its comparison between species seems to be correct. The influence of species characteristics was discussed in Crockford and Richardson (2000) thesis, while Byrant (2000) showed very similar loss for interception in deciduous, coniferous and mixed forest stands.

On graphs (Figures 1, 2), it seen can be vividly that size of interception was influenced by both the intensity of simulated rainfall and the size of used drops.

Hall and Calder (1993) conducted research over size of interception with the use of laser disdrometer and showed that parameters of wetting defying the amount of water that can be retained on plant depend on the size of raindrops. They suggested, in addition, that relation between the size of raindrops and intensity of rain should be examined further as an important factor for interception calculation.

According to results from Calder et al. (1996) and Calder (1999) thesis, the crown capacity for retaining water increases when raindrops are smaller and the intensity of rain decreases. Calder (1999) introduced a rain division to rain of first and second contact with a plant and connected it with storeys in forest stand. In later a thesis of Link et al. (2004), it was stated that the size of drops does not have such a big influence on interception of forest stands second storey because it is reached only by raindrops that have bounced from upper branches.

Calder (1999) by building stochastic models, tried to explain the loss for interception on a global scale. In zone of temperate climate, the interception in coniferous forest is very high due to small raindrops and relatively low intensity of rainfall. In tropical forests, where occur intensive rainfalls characterised by bigger drops, the interception is low because of ineffective wetting of plant's surface. The difference in the size of leaves in compared forests, generally bigger in tropical forests, also contributes to this effect. Pei et al. (1993) conducted experiments in laboratory on pine's woods of height around 4 m and crown projection 4.21 m^2. The rainfall intensity was changed 10 times from 47.4 to 147.6 mm/h. The intensity was computer-controlled. This experiment allowed to determine that the bigger the rainfall intensity, the less water remains on plant surface and the faster is reached maximum amount of retained water. The range of intensity in researches of Calder (1996, 1999) and Pei et al. (1993) did not match conditions of moderate zone. The range of intensity presented in this thesis, which is from 5 to 25 mm^{-1}, is more adjusted to the one that possibly occurs in Poland. However, noticeable are the same relations of influence of rainfall intensity and the size of its drops.

Reverse relations were observed by Keim et al (2006). They conducted an experiment in the laboratory on branches of nine different tree species.

A sprinkler was used for rain production, giving an opportunity to regulate intensity from 20 to 420 mm^{-1} and the size of drops from 1.0 to 2.8 mm. The results of measurements showed that with the increase of simulated rainfall intensity, water retention increased on branches of all species, wherein coniferous species retained more water than deciduous with the same coefficient of leaf area index (LAI). The surface of leaves turned out to be more useful equivalent of water retaining ability than biomass. The authors also suggest a need of further research with the use of lower values of rainfall intensity.

The time needed for reaching potentially highest crown filling with water (T) (Tables 1, 2, 3) confirms that interception is not a constant value. It changes vividly with each change of plants surface and simulated rainfall parameters.

Reaching higher values of potential interception, involving the use of lower rainfall intensity and smaller raindrops, also required longer time of exposure to rain. On the basis of Kuczy's (2007) research over retention properties of organic matter, a question occurs: how time (T) in research over trees interception may influence initial wetting of tree surface? It seems to be a significant determinant both of time (T) and also potential interception. It is impossible though to analyse on mock-ups made of plastic.

It is necessary to perform similar analysis on live trees of main forest species for verification of presented conclusions.

Interception is getting more meaningful in hydrological studies, especially after introducing laser measuring devices, offering wide possibilities of tracking the process of creating and transporting water drops in air.

5. Conclusions

The amount of water retained by plants depends, despite surface size, potential influence of species characteristics or surface condition, on rainfall characteristics. The bigger amount of water from rainfall may be accumulated in trees crown with low rainfall intensity and smaller raindrops.

The maximum water capacity of trees crown is not a constant value even within one tested trees model. It changes every time under influence of rainfall characteristics.

Acknowledgements

This study was completed, thanks to support of Ministry of Science and Higher Education within promoter grant No. N N309298234. I would like to thank the reviewers for valuable notes.

References

Asdak C., Jarvis P. G., Gardingen P. V. 1998. Evaporation of intercepted precipitation based on an energy balance in unlogged and logged forest areas of central Kalimantan, Indonesia. *Agricultural and Forest Meteorology*, 92: 173–180.

Aston A. R. 1979. Rainfall interception by eight small trees. *Journal of Hydrology,* 42: 383–396.

Barbier, S., Balandier P., Gosselin F. 2009. Influence of several tree traits on rainfall partitioning in temperate and boreal forests: a review. *Annals of Forest Science*, 66(6): 602p1–602p11. DOI: 10.1051/forest/2009041.

Bryant M. L., Bhat S., Jacobs J. M. 2005. Measurements and modeling of throughfall variability for five forest communities in the southeastern US. *Journal of Hydrology,* 312: 95–108. DOI:10.1016/j.jhydrol.2005.02.012.

Calder I. R. 1999. Dependence of rainfall interception on drop size - a reply to the comment by Uijlenhoet and Stricker. *Journal of Hydrology*, 217: 164–165. DOI: 10.1016/S0022-1694(99)00003-7.

Calder I. R. 2001 Canopy processes: implications for transpiration, interception and splash induced erosion, ultimately for forest management and water resources. *Plant Ecology*, 153: 203–214. DOI: 10.1007/978-94-017-3606-0_16.

Calder I. R., Hall R. L., Rosier P. T. W., Bastable H. G., Prasanna K. T. 1996. Dependence of rainfall interception on drops size: 2. Experimental determination of the wetting functions and two-layer stochastic model parameters for five tropical tree species. *Journal of Hydrology*, 185: 379–388. DOI: 10.1016/0022-1694(95)02999-0.

Chang M. 2003. Forest Hydrology: an introduction to water and forest. Boca Raton, London, New York Washington, D.C. CRC Press. ISBN 143987994X.

Crockford R. H., Richardson D. P. 2000. Partitioning of rainfall into throughfall, stemflow and interception: Effect of forest type, ground cover and climate. *Hydrological Processes*, 14: 2903–2920. DOI: 10.1002/1099-1085(200011/12)14:16/17<2903::AID-HYP126>3.0.CO;2-6.

Feliksik E., Durło G., Wilczyński S. 1996. The interception of rainfall in mixed forest stands. *Zeszyty Naukowe AR Kraków*, 5: 15–22.

Garcia-Estringana P, Alonso-Blazquez N, Alegre J. 2010 Water storage capacity, stemflow and water funneling in Mediterranean shrubs. *Journal of Hydrology*, 389: 363–372. DOI: 10.1016/j.jhydrol.2010.06.017.

Gomez J. A., Giraldez J. V., Fereres E. 2001. Rainfall interception by Olive trees in relation to leaf area. *Applied Water Management*, 49: 65–76. DOI: 10.1016/j.agwat.2006.05.011.

Hall R. L., Calder I. R. 1993. Drop size modification by forest canopies-measurements using a disdrometer. *Journal of Geophysical Research*, 90: 465–470. DOI: 10.1029/93JD01498.

Hormann G., Branding A., Clemen T., Herbst M., Hinrichs A., Thamm F. 1996. Calculation and simulation of wind controlled canopy interception of a beech forest in Northern Germany. *Agricultural and Forest Meteorology,* 79 (3): 131–148.

Jetten V. G., 1996. Interception of tropical rain forest, performance of a canopy water balance model. *Hydrological Processes,* 10: 671–685. DOI: 10.1002/(SICI)1099-1085(199605)10:5<671::AID-HYP310>3.0.CO;2-A.

Jong de S. M., Jetten V. G. 2007. Estimating spatial patterns of rainfall interception from remotely sensed vegetation indices and spectral mixture analysis. *International Journal of*

Geographical Information Science, 21(5): 529–545. DOI: 10.1080/13658810601064884.

Keim R. F., Skaugset A. E., Weiler M. 2006. Storage of water on vegetation under simulated rainfall of varying intensity. *Advances in Water Resources*, 29: 974–986. DOI: 10.1016/j.advwatres.2005.07.017.

Klamerus-Iwan A., Owsiak K. 2013. Ocena konstrukcji prototypowego stanowiska do badań nad intercepcją drzew leśnych w warunkach laboratoryjnych [Assessment of the design of the prototype experimental station for the research on forest trees interception in the laboratory conditions]. *Sylwan*, 157(6):464–469.

Klamerus-Iwan A., Owsiak K., Szczuka M. 2013a. Zmodyfikowana metodyka badania intercepcji drzew w warunkach laboratoryjnych [Modified methodology of trees interception research under laboratory condition]. *Infrastruktura i Ekologia Terenów Wiejskich*, 4(1): 45–57.

Kucza J. 2007. Właściwości hydrologiczne materii organicznej gleb leśnych na przykładzie gleb pod świerczynami istebniańskimi [Hydrological properties of organic matter of forest soils as exemplified by soils under Istebna stands of Norway spruce]. *Zeszyty Naukowe Akademii Rolniczej im. Hugona Kołłątaja w Krakowie* 442. *Rozprawy,* 320: 1–176.

Link T. E., Unsworth M., Marks D. 2004. The dynamics of rainfall interception by a seasonal temperate rainforest. *Agricultural and Forest Meteorology,* 124(3-4): 171–191. DOI: 10.1016/j.agrformet.2004.01.010.

Loescher H. W., Powers J. S., Oberbauer S. F. 2002. Spatial variation of throughfall volume in an old growth tropical rain forest. *Journal of Tropical Ecology*, 18(3): 397–407.

Okoński B., Miler A.T. 2006. Klimatyczny bilans wodny terenów zalesionych Wielkopolski na przykładzie Puszczy Zielonka [Climatic water balance for forested areas of Wielkopolska region as exemplified by Zielonka Forest]. *Acta Scientiarum Polonorum, Ser. Formatio Circumiectus*, 5(2): 73–81. ISBN 978-83-89263-24-7.

Olszewski J. 1965. Pomiary opadu deszczu w grądzie (*Querco-Carpinetum medioeuropaeum* Tuxen 1936) w Białowieskim Parku Narodowym [Rainfall measurements in *Querco-Carpinetum medioeuropaeum* Tuxen 1936 in Białowieża National Park]. *Sylwan*, 109(3): 27–32.

Olszewski J. 1984. Intercepcja i jej wpływ na wysokość opadów atmosferycznych docierających do powierzchni gruntu w lesie. *Zeszyty Problemowe Postępów Nauk Rolniczych*, 288: 245–270**.**

Olszewski J., Orzeł W. 1975. Intercepcja opadowa buka i sosny w Bieszczadach [Precipitation interception by beech and pine in Bieszczady Mts.]. *Sylwan,* 10: 45–53.

Owsiak K., Klamerus-Iwan A., Kostrzewa E. 2012. Wybrane cechy morfologiczne igieł i pędów sosny zwyczajnej w kontekście obliczania potencjalnej intercepcji pojedynczych drzew [Morphological characteristics of pine needles and branch in the context of calculating potential interception]. *Infrastruktura i Ekologia Terenów Wiejskich,* 3(4): 203–213.

Pei T. F., Fan S. X., Han S. W. 1993. Simulation experiment analysis on rainfall distribution process in forest canopy, Chin. *Journal of Applied Ecology*, 4: 250–255.

Pike R. G., Scherer R. 2003. Overview of the Potential Effects of Forest Management on Low Flows in Snowmelt-dominated Hydrologic Regimes. *BC Journal of Ecosystems and Management,* 3(1): 44–60.

Suliński J. 1993. Modelowanie bilansu wodnego w wymianie między atmosferą, drzewostanem i gruntem przy użyciu kryteriów ekologicznych [Modelling water balance in the exchange between atmosphere, tree stand and soil using ecological criteria]. *Zeszyty Naukowe Akademii Rolniczej im. Hugona Kołłątaja w Krakowie*, Rozpr. hab. 179 s.

Suliński J., Starzak R., Kucza J. 2001. Weryfikacja wzoru wyrażającego intercepcję drzew w zależności od natężenia i czasu trwania opadu deszczu, w warunkach eksperymentalnych. *Acta Agraria et Silvestria*, 39: 3–16.

Toba T, Ohta T. 2008. Factors affecting rainfall interception determined by a forest simulator and numerical model. *Hydrological Processes,* 22(14): 2634–2643. DOI: 10.1002/hyp.6859.

Webb E. K. 1975. The interception process, in: Prediction in Catchment Hydrology (eds. T.G. Chapman, R.X. Dunin), Netley, Australian Academy of Science: 203–236.

Zinke P. J. 1967. Forest interception studies in the United States, in: International Symposium on Forest Hydrology (eds. W. E. Sopper, H. W. Hull). Pergamon, Oxford.

Xiao Q.-F., McPherson E.G., Ustin S.L., Grismer M.E. 2000. A new approach to modeling tree rainfall interception. *Journal Geophysical Research,* 105(ND23): 29173–29188.

Translated by: Anna Wyszyńska