International Journal of Waste Resources

Venkatraman and Ashwath, Int J Waste Resour 2016, 6:1
DOI: 10.4172/2252-5211.1000202

Research Article Open Access

Canopy Rainfall Intercepted by Nineteen Tree Species Grown on a Phytocapped Landfill

Kartik Venkatraman[1*] **and Nanjappa Ashwath**[2]

[1]*East Gippsland Shire Council, 273 Main Street, Bairnsdale, Victoria 3875, Australia*

[2]*School of Medical and Applied Science, CQ University, Rockhampton, Qld 4702, Australia*

[*]**Corresponding author:** Kartik Venkatraman, East Gippsland Shire Council, 273 Main Street, Bairnsdale, Victoria 3875, Australia, Tel: 03 5153 9500; E-mail: KartikV@egipps.vic.gov.au

Received date: December 28, 2015; **Accepted date**: March 14, 2016; **Published date**: March 21, 2016

Abstract

"Phytocapping" is an alternative landfill capping technique that consists of two components, viz. soil cover and vegetation. The soil cover stores water during rainfall events and the vegetation; in this study, trees remove stored water via transpiration and reduce the amount of rain reaching the ground surface via canopy rainfall interception. These attributes contribute significantly to hydrological balance of the phytocap thereby preventing rainwater from entering the buried waste. Canopy rainfall interception was studied for the first time in 19 tree species grown in a landfill environment. Various parameters contributing to canopy interception were monitored over 2 years using 19 tree species that were established on two types of phytocaps (Thick cap 1400 mm soil and Thin cap 700 mm soil). Stemflow and throughfall were determined during 50 rainfall events over two years. Results showed that the established species were able to intercept up to 50% of the rainfall on a per storm basis, with an overall average of 30%. Stemflow also varied between species, but its overall contribution to site water balance was only 4.5% of the total rainfall received.

Keywords: Rockhampton; Canopy rainfall interception; Landfill; Phytocap; Stemflow; Throughfall

Introduction

In a vegetated site, not all of the rain that falls on the canopy reaches the ground. Part of the rain is intercepted by the canopy which evaporates directly from the leaves, twigs, branches and bark directly into the atmosphere (Figure 1) [1]. The phenomenon by which rain is captured by the foliage and stems is termed canopy rainfall interception [2]. This has been examined predominantly in forest canopies [3] and rarely in a landfill environment.

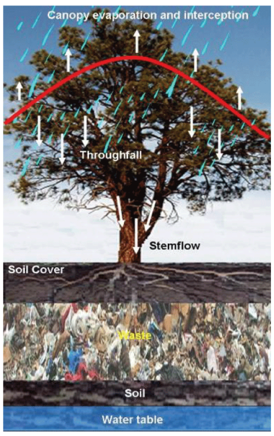

Figure 1: Conceptual model of canopy rainfall interception.

Rainfall that falls on the canopy can disperse in two ways: canopy evaporation and throughfall + stemflow. Canopy rainfall interception is the most underestimated process of rainfall analysis [4] and can be partitioned into (i) Canopy evaporation, where part of the intercepted rain directly evaporates into the atmosphere; (ii) Stemflow, where a portion of the rain that comes in contact with canopy flows through the stem, before finally reaching the ground and (iii) Throughfall, where the rain reaches the ground through gaps in the canopy or via water that drips from leaves [5]. Modeling the water balance of a site therefore requires quantification of the rainfall intercepted by vegetation as well as an estimation of the throughfall [5]. The current study was initiated to evaluate intercepting properties of different species and to understand factors that influence canopy rainfall interception. Rainfall intercepted by 19 three-year-old tree species grown on a phytocap at Rockhampton, Australia was examined.

Canopy rainfall interception has been widely studied in Australia and overseas. A number of interception studies have been completed on tropical forests [6], temperate broadleaf forests [7] and temperate conifer forests [8]. This is the first Australian study to quantify canopy rainfall interception in a landfill environment.

Canopy rainfall interception varies between species and geographical location. For example [9] reported canopy rainfall interception of 18.3% in *Pinus radiata* in southeast Australia. Valente [8] found 17.1% and 10.8% in *Pinus sp.* and *E. globulus* plantations in Portugal (annual rainfall 800 mm). Singh [10] studied rainfall interception in a *Pinus wallichiana* plantation in India and found that 21% of the rain evaporated from the canopy, with stemflow contributing up to 2.7% at a site having an average rainfall of 859 mm. Opakunle [11] found interception to be 24% and stemflow to be 1.8% in a cacao plantation in Nigeria that received an annual rainfall of 1169 mm. Manokaran [12] studied the lowland tropical forest in Malaysia in

Citation: Venkatraman K, Ashwath N (2016) Canopy Rainfall Intercepted by Nineteen Tree Species Grown on a Phytocapped Landfill. Int J Waste Resour 6: 202. doi:10.4172/2252-5211.1000202

a rainfall zone of 1757 mm and found interception ranging from 0.15% to 100% on a per storm basis. Giacomin [13] measured an interception of 17% in a study of interception in a beech forest in Italy (annual rainfall 2027 mm). The Forest Science Department in British Columbia also conducted a study of rainfall interception on yellow cedar, red cedar, shore pine and Sitka spruce plantations in Smith Island (1862 mm) and Diana Lake (1943 mm), and found the interception to be 25% and 21%, respectively. A similar study by Spittlehouse [14] reported an interception of 30% by a mature coastal hemlock forest on Vancouver Island. Another study by [15] on *Pinus sylvestris* showed an interception loss of 24%. On an annual basis, the interception loss from pine plantations can be 20% to 30% of the annual rainfall, while for eucalypts the loss is evaluated at 10% to 20% [16]. Similar findings reported by various researchers are presented in Table 1.

Tree	Interception (%)	Ann. Rainfall (mm)	Location	Reference
Rain forest	12.4	2115	Columbia	[17]
Rain forest	18	800	Brunei	[3]
Laurel forest	30	733	Canary Island	[18]
Shrubs	27	230	Mexico	[19]
Ficus benjamina	59	548	Mexico	[20]
Montane forest	25 to 52	591 to 2561	Ecuador	[21]

Table 1: Rainfall intercepted by various forests.

Stemflow is often considered to be an insignificant contributor to the hydrological cycle and hence it is not accounted for in most site water balance determinations [22]. This is due to a relatively small percentage of the gross rainfall (up to 5%, in most cases) reaching the ground via stemflow [23]. However, in some forests stemflow was significant enough not to be ignored [24]. In fact, areas near the stem received 5 times more rainfall compared to places under canopy and the periphery of the canopy [25] and could even reach as high as 22 times [26]. Durocher [27] found that rainfall input at the base of some trees was 30 to 40 times higher than the mean throughfall. In Australia, stemflow has contributed significantly to soil infiltration and generated overland flow [28], with stemflow fluxes as high as 31.4 $cm^3 min^{-1}$ per cm^2 of basal area during low intensity rainfall events (2 mm min^{-1}).

There have been several practical implications of stemflow in recent years. For landfill, especially those with a phytocap, the main aim is to reduce water infiltration into the waste, stemflow that may contribute up to 5% of the total rainfall should be considered whilst calculating total hydrological balance of a site. Many stemflow studies have been conducted in the context of a large scale rainfall interception budget [8, 15, 29]. Crockford [9] found stemflow to be 4.1% of the total rainfall for eucalypts and 8.9% for pines; with the latter peaking at 13% for rainfall events greater than 25 mm. Asdak [6] found stemflow to be 1.4% in an unlogged plot in a rainforest in Indonesia, which received an annual rainfall of 3,563 mm. Large variations in stemflow of trees within species and between species are commonly observed. Lloyd [30] found in a study of 18 rainforest trees that 15 trees each contributed 14% stemflow and the remaining three trees contributed 7%, 23% and 56%. This paper reports some important finding of canopy rainfall intercepted by 19 different tree species grown on a phytocapping system which has been studied for the first time in the phytocaps.

Materials and Methods

Site establishment

An experimental site of 5000 m^2 area at the Lakes Creek Road Landfill, Rockhampton, Australia was selected for this study.

The experimental site had two soil depths treatments (Thick soil cover, 1400 mm and Thin soil cover, 700 mm; Figures 2 and 3).

Figure 2: Thick and thin soil covers.

Figure 3: Tree species planted at 2 m × 1 m spacing.

These treatments were replicated twice. In the Thin soil cover, only 300 mm of sandy loam soil and 100 mm of green waste mulch was placed over the pre-existing 400 mm un-compacted clay soil (total soil cover of 700 mm) (Figure 4).

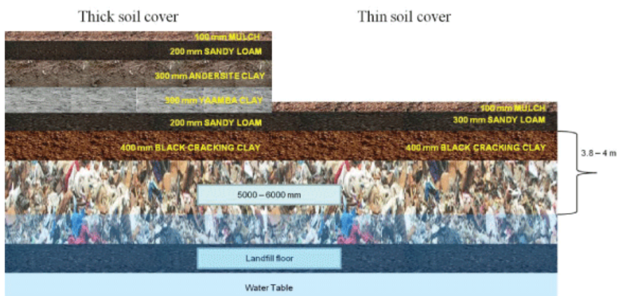

Figure 4: Different types of soils and their depths used in Thick (left) and Thin (right) phytocaps.

In the Thick soil cover, four layers of soil were placed over the pre-existing 400 mm clay soil. This consisted of 200 mm of sandy loam, 300 mm of Yaamba clay and 300 mm of Andersite clay, 200 mm of sandy loam soil and 100 mm of green waste mulch (soil cover of 1400

Citation: Venkatraman K, Ashwath N (2016) Canopy Rainfall Intercepted by Nineteen Tree Species Grown on a Phytocapped Landfill. Int J Waste Resour 6: 202. doi:10.4172/2252-5211.1000202

mm) (Figure 4). Both Thick and Thin soil cover treatments were mulched with a layer of shredded green waste (100 mm). Eighteen seedlings of 21 species were planted at 2 m × 1 m spacing in each plot (Figure 3). Two tree species out of the 21 grown did not survive.

Throughfall

Throughfall was determined using a standard rain gauge (4 cm wide and 51 cm high) (Figure 5) [31].

Figure 5: Standard rain gauge used in measuring throughfall.

Four randomly selected plants of a species in Thick and Thin phytocaps were monitored by placing the rain gauges under the canopy of each tree at 30 cm, 40 cm and 50 cm from the main stem. Trees from one replication of each capping system were monitored and a total of 456 rain gauges were used within an area of 2500 m^2. An additional 20 rain gauges were placed around the experimental plot in an open area to record total rainfall received at the site. The rain gauge readings were recorded for almost all rainfall events during a 24 month period (50 rainfall events). The canopy rainfall interception was calculated as follows:

$$\text{Canopy rainfall interception (\%)} = \frac{\text{Total rainfall} - \text{Throughfall} - \text{Stemflow}}{\text{Total rainfall}} \times 100$$

Stemflow measurement

To measure stemflow, a split plastic hose was stapled around the tree using galvanised staple pins with one of its ends tapering downwards to discharge water into a graduated jar (Figure 6) [31].

$$\text{Stemflow (mm)} = \frac{\text{Volume of rainwater collected (L) in a rainfall event}}{\text{Canopy area of that tree } \left(\text{m}^2\right)}$$

Figure 6: Stem flow collar.

The gaps between the hose and the bark were sealed with neutral silicon sealant and the sealant was left to dry for 24 hours before measurement. Once dried completely, the tapering end was inserted into the jar through the lid (Figure 6). The measuring jar was closed and anchored to the stem to restrict movement and to prevent evaporation. During rain events, the water flowing through the stem entered the cup shaped split hose and ran through the tapering end into the jar. Three such stemflow gauges were installed per species in each of the Thick and Thin capping systems, and measurements were taken over several rainfall events that spanned over a year. Stemflow was calculated as follows:

In most species that were studied for canopy interception, the canopy was not fully closed at one year or at one and half years after establishment. Canopy area was recorded each year for each species and the stemflow was calculated based on canopy area. Stemflow collars were installed 9 months after the beginning of the collection of rainfall interception data. Thus the stem flow values for the early part were estimated based on the values obtained from the later measurements (based on the rainfall received per event and its intensity) so that both stem flow and interception data were derived for the entire measurement period. Stemflow values for the period January 2005 to September 2005 therefore include extrapolated values according to rainfall intensity and duration.

Statistical analysis

Data was analysed (ANOVA) using Genstat ver. 8.0. Least significance differences (l.s.d.) are presented in figures where the F values of the treatment, capping, species or their interactions were significant ($P<0.05$). Regression analysis was carried out to determine interrelationships between tree traits and interception data using GraphPad Prism v 4.03. A polynomial equation was chosen for all graphs as this produced the highest r2.

Citation: Venkatraman K, Ashwath N (2016) Canopy Rainfall Intercepted by Nineteen Tree Species Grown on a Phytocapped Landfill. Int J Waste Resour 6: 202. doi:10.4172/2252-5211.1000202

Results and Discussion

Canopy rainfall interception

The 3-year-old trees that were established on Thick and Thin phytocaps were able to intercept up to 50% of the rainfall on a per storm basis, with an overall average of 30% of the total rainfall received at Rockhampton (Figure 7).

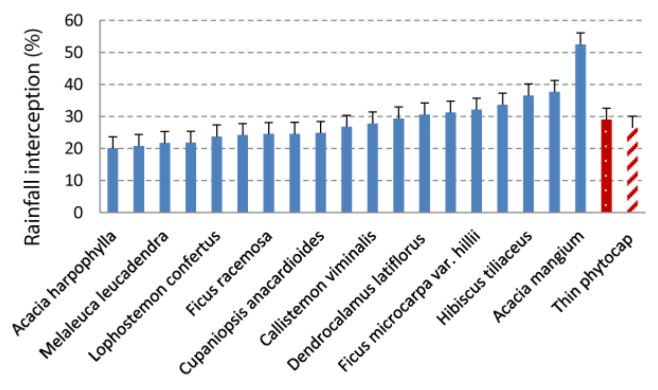

Figure 7: Canopy rainfall interception by 19 species grown in a phytocapping system.

Data are means of 50 measurements taken over a period of 26 months (Bars represent l.s.d. 3.587)

Data represent the average performance of trees across a variety of rainfall events ranging from 0.6 mm to 80 mm. Furthermore, data was recorded over 26 months representing winter, spring, and summer seasons and windy, still and humid climates. With current performance of trees, only 546 mm of the total rainfall would reach the ground surface, and this does not include the rainfall intercepted by leaf litter. This effective reduction of rainfall from 780 mm to 546 mm will have practical implications. This is quite a significant contribution towards the hydrological balance of the phytocapping system. For example, a reduction in effective rainfall could mean the use of shallower depths of soil caps. The use of shallow depths of soil in Thick and Thin caps will eventually contribute to reduced costs for landfill construction.

Effect of species on canopy rainfall interception

The species used in this study showed a significant ($P < 0.001$) difference in rainfall interception between species (Figure 7) which can be attributed to the differences in leaf characteristics. Few species had needle shaped leaves (e.g. *Casuarina spp.*), a few had broad leaves (e.g. *Hibiscus tiliaceus*) and most species had medium sized leaves (Table 2). The list of species examined and their leaf type and their rainfall intercepting capabilities are given in Table 2.

Trees grown on the phytocaps were of varied nature, shape and size. A few were fast growing such as *A. mangium*, *Eucalyptus sp.*, *H. tiliaceus* and *Casuarina spp.*, while some were moderately fast-growing such as *F. racemosa* and *P. pinnata* and the others were slow growing, such as *A. harpophylla* and *C. viminalis*. Yet, a few slow and moderately growing species such as *A. harpophylla* and *S. australis* intercepted rain better than some fast growing species like eucalypts, *C. glauca* and *D. latiflorus*.

Species	Leaf type/size	Canopy rainfall interception (%)
Acacia harpophylla	Medium	20.1
Acacia mangium	Broad	52.5
Callistemon viminalis	Narrow	27.82
Casuarina cunninghamiana	Needle	37.68
Casuarina glauca	Needle	24.22
Cupaniopsis anacardioides	Medium	24.87
Dendrocalamus latiflorus	Broad	30.6
Eucalyptus grandis	Medium	26.8
Eucalyptus raveretiana	Medium	24.62
Eucalyptus tereticornis	Medium	20.78
Ficus microcarpa var. hillii	Medium	32.14
Ficus racemosa	Medium	24.56
Glochidion lobocarpum	Medium	33.68
Hibiscus tiliaceus	Broad	36.54
Lophostemon confertus	Narrow	23.78
Melaleuca leucadendra	Medium	21.74
Melaleuca linariifolia	Narrow	29.36
Pongamia pinnata	Medium	21.82
Syzigium australis	Narrow	31.24

Table 2: Rainfall intercepted by 19 tree species with different leaf size and shape.

Stemflow

Variability ($P < 0.001$) in stemflow between species (Figure 8) was associated with a variety of factors such as stem diameter, canopy morphology and other features such as branch angle, rain intensity and bark texture [2,18].

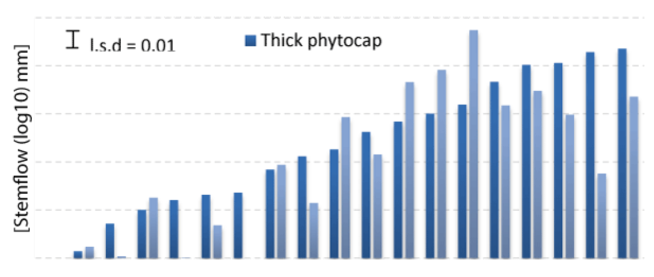

Figure 8: Stemflow in 19 species grown on thick and thin phytocaps. Note: (Bar represented species.cap interaction)

The stemflow in these species contributed up to 4.5% of the total rainfall and is similar to the 5% reported by [23] in hardwood species in the US. Studies in the past have shown that stemflow may not start in many species until 1.27 mm to 22.86 mm of rain has fallen [2]. Hence variation in stemflow could also make a significant contribution to variation in canopy interception.

There was a significant difference ($P < 0.001$) in stemflow generated by the same species in the Thick and Thin phytocaps and this can be attributed to tree shape and angle from the ground, as well as tree spacing and canopy dimension. Stemflow was higher in the Thick phytocap (Figure 9) due to better tree growth, which could be due to availability of resources such as nutrients, better root development and water availability.

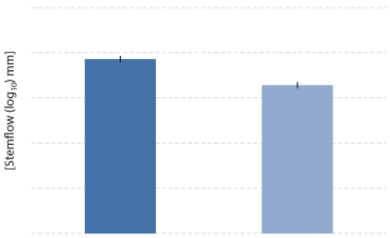

Figure 9: Comparison of stemflow generated in Thick and Thin phytocaps.

Note: (Bar represents l.s.d. 0.002)

More importantly, the thick phytocap had 300 mm of black cracking clay with 600 mm of clay soil, which was more fertile than the soil present in the thin phytocap. High fertility leads to tougher leaves, which in turn gives strength to the leaves to hold more water on their surface. If the leaf is not tough then they drop water quickly thereby allowing more water to reach the ground surface.

Conclusions

The 3 year-old trees that were established on Thick and Thin phytocaps were able to intercept up to 50% of the rainfall on a per storm basis, with an overall average of 30%. This is a significant contribution towards hydrological balance of the phytocapping system. A study conducted showed that a pine leaf litter can hold 0.97 mm kg^{-1} m^2 while eucalypt leaf litter can hold 1.13 mm kg^{-1} m^2. The present study also demonstrated that canopy rainfall interception, including stem flow, varied significantly between species due to various factors such as their growth habit, leaf characteristics, canopy characteristics, bark texture, tree position and rainfall patterns. Canopy rainfall interception also varied between Thick and Thin phytocaps. The species that were established in the Thick phytocap intercepted more rain than the same species grown in Thin phytocap. This was due to better growth of trees in the thick phytocap with respect to height, stem diameter, larger canopy area and biomass. This is most likely as a result of deeper soil and better quality of soil in the thick phytocap compared to the thin phytocap.

The stemflow was estimated at 4.5% of the total rainfall and is similar to previous reports (e.g. 5% – [23]). Overall, the results clearly demonstrate the need to consider plant canopy interception as an essential parameter in modeling water balance for sensitive sites such as landfills. Consideration of canopy interception when modeling the cost of constructing landfills can help reduce the gross costs. This is because volume of soil required to be used for phytocaps can be reduced considerably due to reduction in the effective rainfall reaching the surface.

References

1. Tate KW (1995) Interception on Rangeland Watersheds. Department of Agronomy and Range Science 36 California pp. 1-4.
2. Steinbuck E (2002) The influence of tree morphology on stemflow in a redwood region second growth forest. California State University Chico pp. 1-51.
3. Dykes AP (1997) Rainfall interception from a lowland tropical rainforest in Brunie. Journal of Hydrology 200: 260-279.
4. Savenije HHG (2004) The importance of importance and why we should delete the term evapotranspiration from our vocabulary. Hydrological Process 18: 1507-1511.
5. Crockford H, Richardson DP (1983) Some errors in the measurement of precipitation, throughfall and stemflow and the implications for estimation of interception. Hydrology and water resources pp. 1-7.
6. Asdak C, Jarvis PG, Gardingen PV (1998) Evaporation of intercepted precipitation based on an energy balance in logged and unlogged forest areas of Central Kalimantan, Indonesia. Agric For Meteorol 92: 173-180.
7. Hormann G, Branding A, Clemen T, Herbst M, Hinirchs A, et al. (1996) Calculation and simulation of wind controlled canopy interception of a beech forest in Northern Germany. Agriculture and Forest Meteorology 79: 131-148.
8. Valente F, David J S, Gash, JHC (1997) Modeling interception loss for two sparse eucalypt and pine forests in central Portugal using reformulated Rutter and Gash analytical methods. Journal of Hydrology 190: 389-395.
9. Crockford H, Richardson DP (1990) Partitioning of rainfall in a eucalypt forest and pine plantation in south eastern Australia: ii stemflow and factors affecting stemflow in a dry sclerophyll eucalypt forest and Pinus radiata plantation. Hydrological Process 4: 145-155.
10. Singh RP (1987) Rainfall interception by Pinus Wallichiana plantation in temperate region of Himachal Pradesh, India. Indian Forester pp. 559-566.
11. Manokaran N (1979) Stemflow, throughfall and rainfall interception in a lowland tropical rain forest in peninsular Malaysia. The Malaysian Forester 42: 174-201.
12. Giacomin A, Trucchi P (1992) Rainfall interception in a beech coppice (Acquerino, Italy). Journal of Hydrology 137: 141-147.
13. Spittlehouse D (1998) Rainfall interception in young and mature conifer forest in British Columbia. In 23rd Conference on Agricultural and Forest Meteorology: Weather data requirements for integrated pest management.
14. Llorens P, Poch R, Latron J, Gallart F (1997) Rainfall interception by a Pinus sylvestris forest patch overgrown in a Mediterranean mountainous abandoned area I. Monitoring design and results down to be even scale. Journal of Hydrology 199: 331-345.
15. Nambiar EKS, Loughlin OE (2001) Plantations, farm forestry and water, Water and Salinity issues in agro forestry. Rural Industries Research and Development Corporation.
16. Veneklaas EJ, Vanek R (1990) Rainfall interception in two tropical Montana rain forests, Colombia. Hydrological Processes 4: 311-326.
17. Aboal JR, Jimenez MS, Morales D, Hernandez M (1999) Rainfall interception in the Canary Islands. Agric For Meteorol 97: 73-86.

18. Jose N, Rorke B (2005) erception loss and rainfall redistribution by three semi-arid growing shrubs in north eastern Mexico. Journal of Hydrology 115: 51-63
19. Guevara-Escobar A, Gonzalez-Sosa E, Veliz-Chavez C, Ventura RW, Eramos SM (2007) Rainfall interception and distribution patterns of gross precipitation around an isolated Ficus benjamina tree in an urban area. Journal of Hydrology 333: 532-541.
20. Katrin F, Wolfgang W, Rainer G, Jens B, Carlos V, et al. (2005) Rainfall interception in a lower montane forest in Ecuador: effects of canopy properties. Hydrological Process 19: 1355-1371.
21. Liu S (1997) A new model for the prediction of rainfall interception in the forest canopies. Ecological Modelling 99: 151-159.
22. Zinke PJ (1966) Forest interception studies in the United States. In Forest Hydrology.
23. Kovda VA, Samoilova EM, Charley JL, Skujins JJ (1979) Soil processes in arid lands. In: Goodal D, Perry R (eds.) Arid lands ecosystems: their structure, functioning and management. Cambridge University Press, London, pp. 439-470.
24. Navar J, Bryan RB (1990) Rainfall interception and redistribution by three semi-arid growing shrubs in northeastern Mexico. Journal of Hydrology 115: 51-63.
25. Matsubayashi U, Velasquez GT, Sasuga H, Sumi T, Takagi F (1995) On the physical and chemical properties of throughfall and stemflow. Journals of Hydroscience and Hydraulic Engineering 13: 69-81.
26. Durocher MG (1990) Monitoring spatial variability of forest interception. Hydrological Process 4: 215-229.
27. Herwitz SR (1986) Infiltration-ecxess caused by stemflow in a cyclone prone tropical rainforest. Earth Surface and Process Landforms 11: 401-412.
28. Klaassen W, Bosveld F, De Water E (1998) Water storage and evaporation as constituents of rainfall interception. Journal of Hydrology 212-213: 36-50.
29. Lloyd CR, Marques A (1988) Spatial variability of throughfall and stemflow measurements in Amazonian rain forests. Journal of Agricultural and Forest Meteorology 42: 63-73.
30. Crockford H, Richardson DP (2000) Partitioning of rainfall into throughfall, stemflow and interception: effect of forest type, ground cover and climate. Hydrological Process 14: 2903–2920.
31. Eamus DT, Hatton P, Cook, Christine C (2006) Water relations of plants. Ecohydrology Collingwood, Victoria, Australia, CSIRO Publishing.