

Papers published in *Hydrology and Earth System Sciences Discussions* are under open-access review for the journal *Hydrology and Earth System Sciences*

## Measuring forest floor interception in a beech forest in Luxembourg

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Received: 10 July 2006 – Accepted: 30 July 2006 – Published: 22 August 2006

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### Abstract

In hydrological models evaporation from interception is often disregarded, combined with transpiration, or taken as a fixed percentage of rainfall. In general interception is not considered to be a significant process in rainfall-runoff modelling. However, it appears that on average interception can amount to 20–50% of the precipitation. Therefore, knowledge about the process of interception is important. Traditional research on interception mainly focuses on canopy interception and almost completely denies forest floor interception, although this is an important mechanism that precedes infiltration or runoff. Forest floor interception consists partly of interception by dry soil, partly of interception by short vegetation (mosses, grasses and creeping vegetation) and partly of interception by litter. This research concentrates on litter interception: to measure its quantities at point scale and subsequently to upscale it to the scale of a hydrotape. A special measuring device has been developed, which consists of a permeable upper basin filled with forest floor and a watertight lower basin. Both are weighed continuously. The device has been tested in the Huewelerbach catchment (Luxembourg). The preliminary measuring results show that the device is working properly. For November 2004, evaporation from interception is calculated to be 34% of the throughfall in the Huewelerbach catchment.

### 1 Introduction

The process of rainfall interception and its successive evaporation is often not considered as a significant process in the hydrological cycle. This is partly due to the technical difficulties that are inherent to interception measurements (Lundberg et al., 1997; Llorens and Gallart, 2000). But also it is generally considered as a minor flux, particularly for the generation of floods, although interception strongly influences the antecedent soil moisture conditions, which are very important for the generation of floods (Roberts and Klingeman, 1970). Hence in hydrological models interception is

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regularly disregarded or taken as a fixed percentage of the precipitation. As a result, after model calibration, interception is generally compensated by another process (Savenije, 2004).

Moreover, interception measurements generally concentrate on canopy interception whereas interception by under-storey and forest floor can be as high or higher. Evaporation from interception can amount up to 20–50% of the precipitation. For example, Rutter et al. (1975) found canopy interception values of 12% of the precipitation for a defoliated oak and 48% for a Norway spruce forest in the United Kingdom. Also Bryant et al. (2005) found comparable results for a different kind of forest in the southeast of the United States. For a pine, mixed, lowland hardwood, pine plantation and upland hardwood forest Bryant et al. (2005) measured that respectively 22%, 19%, 18%, 18% and 17% of the rainfall was intercepted by canopy and successively evaporated. And Schellekens et al. (1999) found that about 50% of the gross precipitation evaporated from the canopy of a Tabonuco type forest in northeastern Puerto Rico. All these studies merely consider canopy interception. If also forest floor interception is taken into account the total amount of intercepted rainfall can be twice as much, as will be demonstrated. A remarkable difference between canopy and forest floor interception is the relatively small interception storage capacity for the canopy compared to the forest floor. On the other hand, the canopy has a larger evaporative potential compared to forest floor interception (Baird and Wilby, 1999).

### 1.1 Definition of interception

In literature interception is often defined in different ways: sometimes as a stock, sometimes as a flux or as, what is more appropriate, as the entire interception process (Savenije, 2006). If only interception storage [L] is considered, interception is defined as the amount of rainfall which is temporarily stored on the land and evaporated shortly after and during the rainfall event. Actually, this is the interception capacity or water holding capacity. Examples of interception storage measurements are by Kiss et al. (2005) and Putuhena and Cordery (1996). If the interception flux is considered, inter-

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ception is defined as the amount of intercepted water, which is evaporated in a certain time [ $L T^{-1}$ ]. In case the interception process ( $I$  [ $L T^{-1}$ ]) is considered, interception is defined as the part of the rainfall flux which is intercepted on the wetted surface after which it is fed back to the atmosphere. The Interception process equals the sum of the change of interception storage ( $S_{int}$ ) and the evaporation from this stock ( $E_{int}$ ):

$$I = \frac{dS_{int}}{dt} + E_{int} \quad (1)$$

The time scale of the interception process is in the order of one day. After one day it is justified to assume that the first term on the right hand side in Eq. (1) approximates zero, so  $I = E_{int}$ .

### 1.2 Forest floor interception review

Forest floor interception is the part of the (net) precipitation that is temporarily stored in the top layer of the forest floor and successively evaporated within a few hours or days during and after the rainfall event. The forest floor can consist of bare soil, short vegetation (like grasses, mosses, creeping vegetation, etc.) or litter (i.e. leaves, twigs, small branches).

In the literature little can be found on forest floor interception, although some researchers have tried to quantify the interception amounts. Generally these methods can be divided into two categories (Helvey and Patric, 1965):

1. Lab methods, whereby field samples are taken to the lab and successively the wetting and drying curves are determined by measuring the moisture content.
2. Field methods, whereby the forest floor is captured into trays or where sheets are placed underneath the forest floor.

An example of the first category is of Helvey (1964), who performed a drainage experiment on the forest floor after it was saturated. During drainage the samples were

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covered and after drainage had stopped (assumed 24 h), the samples were taken to the lab, where the samples were weighed and successively dried until a constant weight was reached. By knowing the oven dry weight of the litter per unit area and the drying curve, the evaporation from interception could be calculated. In this way they found that about 3% of the annual rainfall evaporated from the litter. But what they measured was not the flux, but the storage capacity. Another example of the first category was carried out by [Putuhena and Cordery \(1996\)](#). First, field measurements were carried out to determine the spatial variation of the different forest floor types. Second, the storage capacity of the different forest floor types were measured in the lab by using a rainfall simulator. Finally, the lab experiments were extrapolated to the mapping step. In this way [Putuhena and Cordery \(1996\)](#) found average storage capacities of 2.8 mm for pine and 1.7 mm for eucalypt forest floors.

Examples of the second category are for example carried out by [Pathak et al. \(1985\)](#), who measured the weight of a sample tray before and after a rainfall event. They found litter interception values of 8%–12% of the net precipitation. But also here, they measured the storage capacity, rather than the flux. [Schaap and Bouten \(1997\)](#) measured the interception flux by the use of a lysimeter and found that  $0.23 \text{ mm day}^{-1}$  evaporated from a dense Douglas fir stand in early spring and summer. Examples of measurements with sheets were done for example by [Li et al. \(2000\)](#), who found that pebble mulch intercepts 17% of the gross precipitation. [Miller et al. \(1990\)](#) found comparable results (16–18%) for a mature coniferous plantation in Scotland.

The device which is described in this paper and which is devoted to the measurement of evaporation from intercepted rainfall on the forest floor, belongs to the second category. The new device has been tested in a forest clearing in Westerbork (north-east of the Netherlands) and in a beech forest in the Huewelerbach catchment in the western part of Luxembourg. The set up in the Huewelerbach measures interception of litter and the one in Westerbork measures interception of grass and mosses. The latter device measures transpiration as well and therefore is not considered in this paper. The first objective of the measurements is to obtain knowledge about the quantities of

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forest floor interception at point scale and later to upscale it to a hydrotape.

## 2 Site description

The Huewelerbach catchment (49.7° N 5.9° E) is a hill slope area in Luxembourg, which consists mainly of sandstone and has a basin area of about  $2.7 \text{ km}^2$ . The climate in Luxembourg is modified oceanic with mild winters and temperate summers. The average annual temperature is circa  $9^\circ\text{C}$  and the yearly rainfall sum is about  $740 \text{ mm/a}$  (see Fig. 1). In the Huewelerbach catchment an experimental plot of  $0.0596 \text{ ha}$  has been set up in a 120 years old beech forest with a density of 168 trees/ha. The interception device is placed underneath the canopy, so it essentially receives throughfall ( $T \text{ [L T}^{-1}\text{]}$ ). To measure the throughfall a 3 m long gutter is placed underneath the canopy and close to the device, which drains into a tipping bucket. Next to the interception device four pluviometers are installed, from which the average is calculated ( $\bar{T}_{\text{pluvio}} \text{ [L T}^{-1}\text{]}$ ). The pluviometers are read out manually every 1 or 2 weeks. To calculate the net rainfall ( $P_{\text{net}} \text{ [L T}^{-1}\text{]}$ ) on the interception device, the event-based pattern of the tipping bucket ( $T_{\text{tb}} \text{ [L T}^{-1}\text{]}$ ) is mapped on the average cumulated precipitation in the pluviometers. In formula form for  $0 \leq t \leq i$  :

$$P_{\text{net}}(t) = T(t) = T_{\text{tb}}(t) * \frac{\sum_{t=0}^{t=i} \bar{T}_{\text{pluvio}}}{\sum_{t=0}^{t=i} T_{\text{tb}}} \quad (2)$$

where  $i$  is the moment where the four pluviometers are read out manually.

## 3 Research method

To measure evaporation from intercepted rainfall on the forest floor, a special device has been developed. The device consists of two aluminium basins, which are mounted above each other and are weighed accurately with 2 sets of 3 strain gauge sensors (see

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Fig. 2). One sensor consists of a metal ring where four strain gauges are mounted in the Wheatstone configuration. The upper basin is filled with forest floor and has a permeable bottom of geotextile, so water can percolate into the lower basin. In this lower basin a valve is installed, which empties every day for 10 min to avoid evaporation from the lower basin as much as possible. Also the space between the supporting structure and the aluminium basins is minimized, in order to avoid evaporation by turbulent wind fluxes. Besides the weight also the temperature is measured in one of the lower strain gauge casings. Every minute a measurement is carried out and saved on a data logger.

To calculate the amount of evaporation from interception a water balance is made of the interception device. When evaporation from the lower basin ( $E_l$  [ $L T^{-1}$ ]) is neglected and the weight of the lower basin is corrected for the drainage from the valve ( $S'_l$  [L]), evaporation of intercepted rainfall ( $E_{int}$  [ $L T^{-1}$ ]) can be calculated as:

$$E_{int}(t) = P_{net}(t) - \left( \frac{dS_u}{dt} + \frac{dS'_l}{dt} \right) \quad (3)$$

where  $S_u$  and  $S_l$  are respectively the storage of the upper and the lower basin [L], which are obtained by dividing the weight of the basins [M] by the density of water [ $M L^{-3}$ ] and the surface area [ $L^2$ ] of the basin.

In the Huewelerbach the rectangular basins have a surface area of  $1.00 m^2$  and the upper basin is filled only with leaves (no soil) from the beech canopy (i.e. litter interception). A photo of the set up in the Huewelerbach can be seen in Fig. 3.

#### 4 Results and discussion

In Fig. 4 the first results of the interception device of the Huewelerbach are presented. The data have been first aggregated from a one minute time step to a 15 min time step by the use of the moving average method to cancel out measuring noise. The

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raw measuring data of the interception device (with a time step of one minute) and the meteo data can be obtained from the DARELUX-repository (<http://devcms.library.tudelft.nl/DLUI2/hessd001.html>).

From the graph it can be seen that the device is working properly. After a rainfall event the weight of the upper basin increases and next also the weight of the lower basin increases if the rainfall event is large enough to saturate the upper basin. Also the working of the valve can clearly be seen by the sudden drop of the weight of the lower basin. As a check, it is possible to do a water balance verification by summing up all increases in both basins, which should be equal to the sum of the net precipitation. Most of the time there is a small difference between the two, caused by for example evaporation during the rainfall event, measuring noise, falling branches and/or leaves, dew, heterogeneity of throughfall (due to canopy structure), passing of small animals (like birds or rabbits) on the upper basin, etc.

In Fig. 4c the amount of evaporated interception is calculated for the Huewelerbach by Eq. (3). For November 2004 34% of the net rainfall (i.e. throughfall) has evaporated from the litter. Because we want to compare the results with storage capacity estimates from literature, we apply a simple threshold model described by Savenije (1997):

$$E_{int} = \min(P_d, D) \quad (4)$$

This model describes the daily interception as a threshold process with  $P_d$  the daily rainfall [ $L T^{-1}$ ] and  $D$  the daily interception threshold [ $L T^{-1}$ ]. The calibration of the threshold  $D$  is done in such a way that the monthly interception sum of the threshold model is equal to the intercepted month sum of the observed interception. The calibrated estimate for  $D$  of  $1.5 mm day^{-1}$  compares well with the estimate of  $1.7 mm$  for an eucalypt floor from Putuhena and Cordery (1996). The large difference with the results of Helvey (1964), who found that only 3% of the annual rainfall evaporated by the litter, can be explained by the fact that only events, which are large enough to saturate the forest floor were taken into account. In this way a large part of the litter interception is neglected, especially in temperate climates. Secondly, it is quite difficult to not disturb field samples when taking them to the lab. Thirdly, evaporation during the rainfall

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events is not taken into account, which is also the case for the method of Pathak et al. (1985), who measured that 8–12% of the net precipitation was evaporated. Despite these arguments Helvey and Patric (1965) stress that the difference is caused by the “interface effect”. This is probably not the case for this measuring setup, because the used geotextile is very permeable and has just as in reality atmospheric pressure conditions between litter and soil. A comparison with the results of Schaap and Bouten (1997) and Li et al. (2000) is quite difficult, because they measured respectively pine and pebbles, which do not have the storage capacity of leaves, which explains their lower estimates.

#### 4.1 Temperature correction

Although the interception device works generally well, there are unfortunately some minor problems. As can be clearly seen in Fig. 5 during a dry period (for example the last week of June or the second week in July) there are some daily decreases in the upper basins, which are not caused by rainfall. This daily pattern can be partly explained by dew. However the observed increases are of a higher magnitude. Another explanation is the effect of temperature variation on the sensors. Because the strain gauges are mounted on a metal ring, which expands when the temperature increases and which reacts similar to a decrease in weight, the sensors measure a lower weight than in reality. To correct the observed data for this effect, the relation between temperature and the output of the sensor should be found. Therefore, a linear regression has been applied for a dry period, to be sure that the variation in observed weight is only due to temperature variation. It appears that a linear relation exists, however a time lag  $\rho$  [T] occurs between temperature change and the reaction on the sensors. In Table 1 the found regression values are presented, which are successively used to correct the data with Eq. (5), where  $S_{\text{cor}}$  is the weight after the correction for temperature [M] and  $S_{\text{obs}}$  the sensor output [M]. The differences between the time lags are partly due to the fact that the temperature sensor is not mounted on the metal ring itself, but close to it,

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and partly because the sensors do not all receive the same amount of radiation.

$$S_{\text{cor}}(t) = S_{\text{obs}}(t) - S_{\text{obs}}(t - 1) + S_{\text{cor}}(t - 1) - \alpha(T(t + \rho) - T(t - 1 + \rho)) \quad (5)$$

After the correction has been applied on the data, only a slight improvement could be observed. Hence for the future new sensors will be built, which are less temperature sensitive. The new sensors will also be tested in a climate room to know the relation between temperature and sensor output. Second also an extra sensor (dummy) will be installed on which a fixed weight is mounted, so the relation between temperature and sensor output is always known.

#### 4.2 Improvements of the device

For the future, it would be interesting to look after the long term behaviour of the interception device. At the moment this is unfortunately not yet possible due to different kinds of equipment failures, which cause gaps in the time series. A lot of data has been lost due to congested valves by sand, leaves, etc. This causes the amount of percolated water not to be registered. This malfunction has been solved by installing a new valve with a larger diameter and by placing a filter before the valve entrance, hence the chance of congestion is lowered. The first results look promising, so research can be done on interception throughout the seasons, to study the effect of oxidation of the leaves and vegetation growth.

## 5 Conclusions

The preliminary measurements of the interception device look very promising. However, for the future some fine tuning on for example the working of the valve and on the temperature influence will still be necessary. Although the new valve, the dummy and the new sensors will solve most of the problems.

The obtained result for evaporation from beech litter interception (34% of the net precipitation) in the Huewelerbach catchment is quite high compared to the literature.

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Particularly if we realise that it was during the European autumn (November). However, these values can be explained by 1) taking the rainfall events into account which are not large enough to saturate the litter, 2) by not disturbing the local water content conditions by working in the field and 3) lastly by taking evaporation during the rainfall event into account.

From these results it can be concluded that forest floor interception is a significant process in the hydrological cycle and therefore should be included in hydrological models. Especially because interception has an effect on the antecedent moisture conditions, which are important for the generation of floods. If interception is not properly accounted for in a model, the model can of course be adjusted by calibration, but then the internal state variables are wrong and not physically based. In that case most likely the interception process is compensated by another process such as for example transpiration or soil evaporation by increasing the soil moisture storage capacity. As a result the function describing the transpiration as a function of the soil moisture is wrong.

For the future it will be interesting to look into the long term behaviour of the interception process to know for example how the process of interception changes over the seasons, how large the influence is of falling leaves and oxidation, how vegetation growth influences the measurements, etc. Furthermore it would be interesting to investigate the effect of rainfall intensity on the amount of intercepted rainfall.

*Acknowledgements.* The authors would like to thank the Ministry of Culture, Higher Education and Research of Luxembourg and Delft Cluster, the Netherlands, for their support on this research. Furthermore we thank the DARELUX-project for making the measuring data publicly available for verification and further research.

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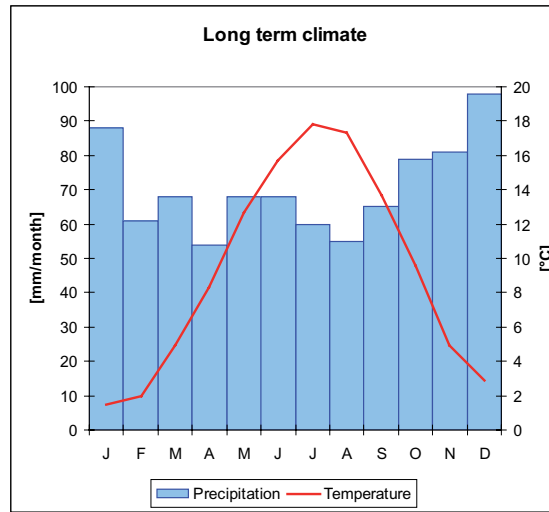
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**Table 1.** Linear regression results with time lag.

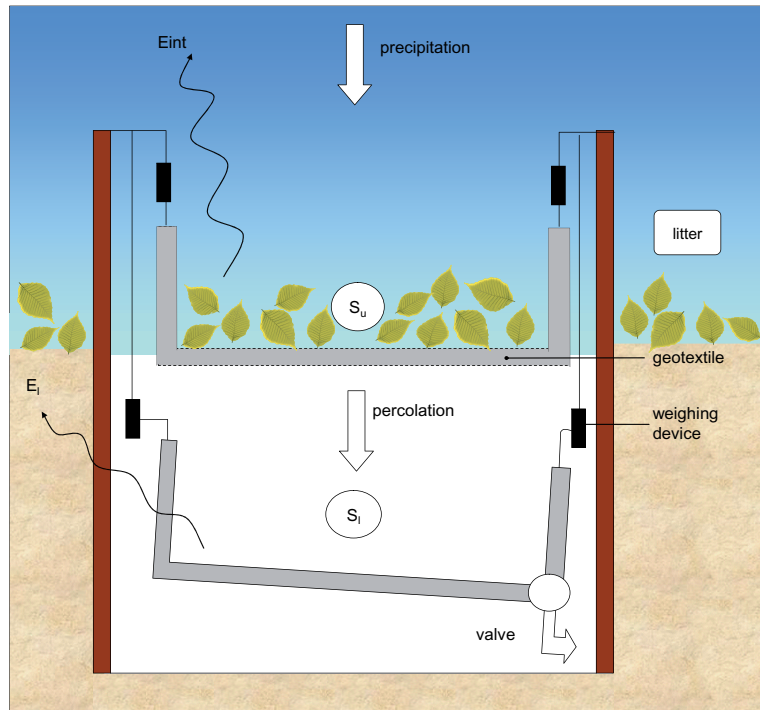
Sensor	$\alpha$ [gr°C <sup>-1</sup> ]	$\rho$ [min]
upper 1	-0.047	-131
upper 2	-0.071	-38
upper 3	-0.074	-34
lower 4	-0.277	-25
lower 5	-0.212	-23
lower 6	-0.150	-46

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**Fig. 1.** Long-term climate for the Huewelerbach in period 1971–2000 (Pfister et al., 2005). The precipitation is obtained from a station in Calmus-Saeul (49.7° N 6.0° E) and the temperature is measured at Ettelbruck (49.8° N 6.1° E).

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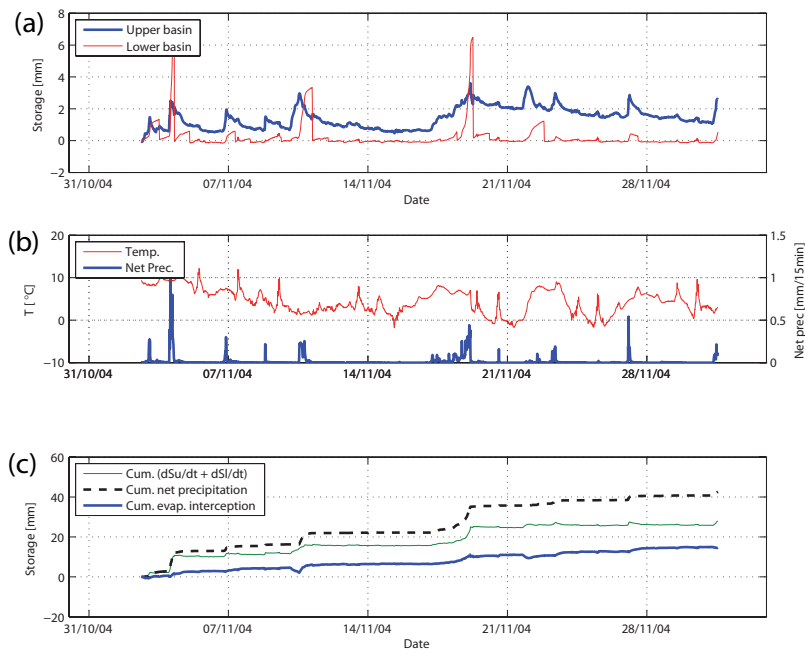
**Fig. 2.** Schematic drawing of the interception device in the Huewelerbach with  $E_{int}$  the evaporation from interception,  $E_l$  the evaporation from the lower basin and  $S_u$  and  $S_l$  the storage in respectively the upper and lower basin.

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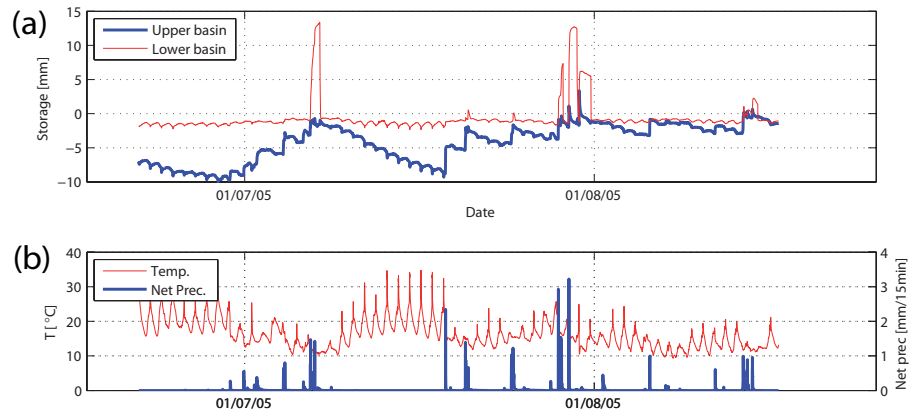
**Fig. 3.** Interception device in the Huewelerbach catchment on January 2006. The upper basin is filled with leave litter.

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**Fig. 4.** Measuring results of the Huewelerbach catchment for November 2004. **(a)** Storage in the upper and lower basin; **(b)** Meteorological data (net rainfall and temperature); **(c)** Cumulated evaporation from interception compared to total net rainfall.

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**Fig. 5.** Measuring results of the Huewelerbach from 21 June until 17 August 2005. **(a)** Storage in the upper and lower basin; **(b)** Meteo data (net rainfall and temperature).