Forest hydrology research with lysimeter in the northeast German lowlands special methods and results for the forest management

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Abstract
Broad areas of the northeast German lowlands are characterised by low precipitation, distinct periods of summer drought and sandy soils. In this region, forest hydrology research looks into the influence of differently structured forest on the landscape hydrology. The aim is to provide scientific guidance in the development of productive forests that enhance the quantity and quality of seepage water. In unconsolidated rock substrate lysimeters can be used to measure seepage and evaporation. The use of different types of lysimeters in the Eberswalde region has a tradition of more than 100 years. In 1972, nine new large-scale lysimeters with a depth of 5 m and a surface area of 100 m^2 were installed and were planted with different tree species. To investigate the impact of intensified drought on forest regeneration and tree growth special small-scale lysimeters and a field laboratory (Drylab) were constructed and used. The paper informs about the groundwater recharge under different tree species and about investigations of the water consumption of small forest trees in the face of increasingly limiting water resources arising from climate change.

Key Words
Forest lysimeter, vegetation structures, water budget, water stress.

Introduction
Given its current low precipitation levels and predominantly sandy soils with low water retention capacity, the lowlands in northeastern Germany are regarded one of the country's regions with the highest vulnerability to a climate change bringing more frequent and more intense drought periods in the future (Schröter *et al.* 2005). In northeastern Brandenburg, the long-term annual precipitation of about 570 mm is well below the overall national average of 780 mm (Müller 2002). With a forested area of 1.1 million ha, covering 35.3% of its surface area, Brandenburg, including Berlin, is the state with the fourth largest forest area in Germany (BMVEL 2008). The forest has a major effect on the landscape hydrology as a consequence of its multi-layered structure and its expanse. Therefore investigations into relationships among site, forest structure and water regime in the region are of particular interest. In view of the anticipated intensification of drought in wide areas of northern and central Germany as a consequence of climate change, the forest hydrology studies presented here may provide some direction for many other regions in Germany, particularly investigations of water consumption and forest growth in the case of declining water resources during the growing season.

Table 1. Types of lysimeters used in forest hydrology research at Eberswalde.

Year	1907	1929	1966	1972	1994	2005	2009
Site	Eberswalde "Drachenkopf"	Eberswalde "Drachenkopf"	Liepe	Britz	study sites	Britz "Postluch"	Eberswalde open field laboratory "Drylab"
Lysimeter type	smallest scale lysimeter	small-scale lysimeter	sub-surface lysimeter	large-scale lysimeter	small-scale lysimeter	groundwater lysimeter	small-scale lysimeter
Weighability	non-weighable	weighable	non-weighable	non-weighable	weighable	weighable	non-weighable
Soil	disturbed	disturbed	undisturbed	disturbed	undisturbed	undisturbed	disturbed
Surface area	500 cm^2	1 m^2	500 cm^2, 1500 cm^2	100 m^2	1 m^2	1 m^2	2 m²
Depth	1.0 m	1.5 m	5 m	5 m	1.8 m	2.0 m	1.5 m

Methods

Lysimeters are appropriate for ascertaining the water budget of individual plants and stands (Müller and Bolte 2009). Due to the existing site conditions, the use of different types of lysimeters in investigations around Eberswalde has a long tradition (Table 1).

The Drachenkopf lysimeter

In 1907, the first investigations into the water budget of young trees were conducted with very small-scale lysimeters on Drachenkopf Mountain, in Eberswalde. In 1929, these small-scale lysimeters were replaced by a larger weighable station consisting of three lysimeters, which, in 1954, were supplemented by four additional lysimeters. To our knowledge, the Drachenkopf research station is the oldest lysimeter station used for forest hydrological purposes in the world. The weighable lysimeters have a surface area of one square meter and a depth of 1.5 m.

The large-scale lysimeter at Britz

Forest hydrology research into the effect of different tree species on evaporation and groundwater recharge prompted the construction of large-scale lysimeters at the research station at Britz, near Eberswalde, in 1972 (Müller 1993). After experiences gained from using lysimeters in the past, the large-scale lysimeters were installed at a depth of 5 m, necessary for forest lysimeters, having a surface area of 100 m^2 (10x10 m) (Figure 1). Nine large-scale lysimeters were set up, and, in 1974, planted with 0.3 ha experimental stands of the tree species Scots pine (3 lysimeters), European beech (2), European larch (2) and Douglas fir (2) at plant spacings corresponding to that applied for each species in forestry practice at the time. The areas surrounding the lysimeters were planted similarly. Thus, the large-scale lysimeters at Britz are unique in Europe in their scale since, although other lysimeters planted with trees have the required area, with depths of 3 m or 3.5 m, they are too shallow.

The weighable lysimeters

Total evaporation, determined with large-scale lysimeters, provides only a general understanding of the water budget in forest stands. The separation of total evaporation into its individual components crown canopy interception, transpiration from trees and evapotranspiration of soils and ground vegetation helps clarify the interaction between the individual components.

In Scots pine ecosystems in the northeastern German lowlands, the ground vegetation and the tree and shrub regeneration represent a substantial yet, so far, difficult to measure water consumer. Special measuring systems need to be used to ascertain the evapotranspiration of the undergrowth, and hence its specific water consumption separately from transpiration of trees in the stand. Consequently, in 1994, special weighing lysimeters were designed. The new type of lysimeter developed contained an undisturbed soil monolith with sufficient size and weighability, for which the construction of a lysimeter cellar was not necessary. With it, the water budget could be balanced at low cost for different types of applications under open field conditions in the forest. Through the use of special weighing cells, the soil moisture change in the soil monolith and the amount of seepage water discharge could be recorded with an accuracy of 0.1 mm. Firstly, the lysimeters were used to measure the water consumption of ground vegetation with different species compositions. The current investigations should look into the influence of drought on the transpiration and young forest tree growth under changing climatic conditions (frequency of extreme summers) more intensively.

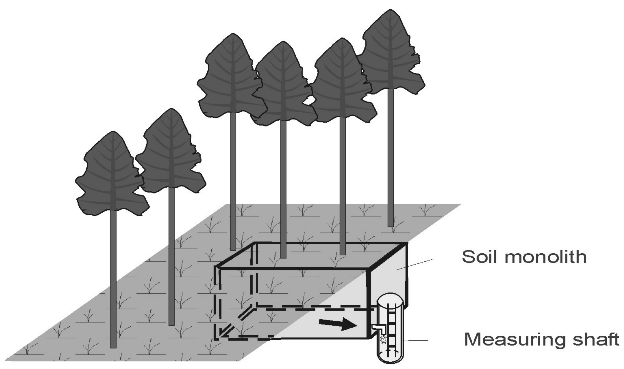

Figure 1. Diagram of a large-scale lysimeter planted with trees.

Results

The investigations at the Britz **large-scale lysimeter station** showed that tree species have an important effect on seepage under forests. The effect of differences in vegetation structure at different growth stages in a Scots pine forest, a European beech forest and a mature mixed stand with Scots pine and European beech on the amount of seepage and evaporation is shown in Figure 2. In the Scots pine stand, total evaporation increases rapidly with growth whereas seepage declines. In the polewood stage, total evaporation is about 100% so that seepage is largely absent. Scots pine growth culminates at this age, and thus the transpiration rates are high (about 60% of the annual precipitation) and, as a consequence of the dense crown cover, interception losses are also high (about 40%) (Müller 2002, 2005). The natural reduction in tree numbers and thinnings cause transpiration and interception to decline gradually, and the seepage percentage increases. However, the proportion of evapotranspiration from the ground vegetation increases relatively strongly due to the opening up of the canopy (Müller *et al*. 1998).

In the European beech stand, evaporation also increases quickly with stand growth, and, in the polewood stage, attains values of almost 80% of the annual precipitation. This value remains relatively constant over a long period up to the saw-timber stage, so that steady seepage levels of over 20% of the annual precipitation also are recorded. Transpiration increases slightly with stand growth, and interception declines as a result of the increasing stemflow (it reaches values of ca. 20% of the annual open field precipitation). Due to the low-light regime in closed European beech stands (Emborg 1998), the evaporation from the forest soil is of minor importance. Seepage is higher in European beech stands in all age phases than in Scots pine. Thus, for example, in mature European beech stands, 50 mm more precipitation seeps into the soil substrate than in mature Scots pine stands under comparable soil and weather conditions (Müller 2002, 2005).

Investigations in pine-beech mixed stands of different ages on sandy soil showed that the amount of seepage fell somewhere between that of the pure Scots pine and pure European beech stands depending on forestry operations performed, stocking density and the tree size of European beech (Müller 2007). Measurements of seepage to 5 m depth in the 28-year old pure Scots pine stand growing on the large-scale lysimeter station at Britz, which was underplanted with European beech and sessile oak in 1999, already show improvements in the groundwater recharge as a result of the Scots pine thinning.

The **weighable lysimeters** were installed in Scots pine stands with a typical ground cover in the northeastern lowlands to determine the water consumption of these ground vegetation types. The typical ground cover consisted of wood small-reed (*Calamagrostis epigejos*), wawy hair grass (*Deschampsia flexuosa*), wawy hair grass/raspberry *(Deschampsia flexuosa / Rubus idaeus*) and blueberry (*Vaccinium myrtillus)*. Investigations showed that evapotranspiration increased with increasing grass cover. The low shrub layer consumed less water. Thus, closed wood small-reed cover consumed more than one third, and the wavy hair grass almost 30% of the annual precipitation of 620 mm. Where a low shrub layer was present, the evaporation from the wawy hair grass/raspberry layer, a little more than 25%, and the blueberry/wawy hair grass layer, with almost 20% of the annual precipitation, was sometimes distinctly lower than the pure grass cover. In addition to the evaporation from the ground vegetation layer, for which the annual sum varied, the seasonal development

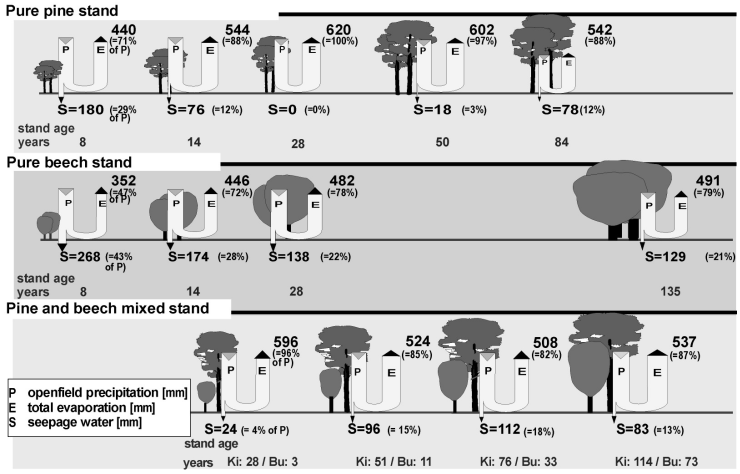

Figure 2. Influence of vegetation structures of Scots pine and European beech at different growth stages on the water budget parameters, evaporation and seepage - (Finowtaler sandy brown earth, 620 mm annual precipitation).

of evapotranspiration during the growing season is also ecologically meaningful. In water limiting periods, the higher water consumption by grass cover leads to a reduction in the amount of plant available soil water, enhancing the water limitation for trees, and thereby impacting upon tree growth (Müller *et al.* 1998). The composition and cover of the ground vegetation influence considerably the amount of water consumed by trees.

Conclusion

Often a major problem of hydrological investigations in different types of ecosystems is the dissimilar conditions, or inability to control sufficiently the environmental conditions in the study sites. Thus, the effects of the parameters of interest may be blurred or false in the results. If one aims to determine the effect of the vegetation on hydrology in the unconsolidated rock substrate, then lysimeter measurements are appropriate for excluding conditions, which are not relevant. Assuming the lysimeters were constructed correctly and adequate in size, they can also be applied for forest ecosystems. Only by considering the special features of the forest structure can one accurately evaluate the hydro-ecological effects. Thus, with the assistance of large-scale lysimeters, the influence of tree species on seepage and evaporation in mature stands can be quantified. It shows that the crown canopy structure considerably influences the amount of seepage and the distribution of the precipitation in the stand as it affects the soil water availability. Total evaporation provides only a general understanding of the water budget in forest stands. The separation of total evaporation into its individual components leads to more meaningful explanations of the interactions between the compartments. During the growing season, the water consumption of the individual vegetation layers is important in the assessment of possible occurrence of water stress.

The main advantage of lysimeter techniques is the opportunity to balance energy and nutrient flows at a high temporal resolution under carefully differentiated conditions. This makes the lysimeter increasingly more interesting for both scientific and practical applications in very different disciplines. Due to their innovative measurement techniques, e.g. weighing cells for determining moisture changes and seepage flows as well as soil moisture sensors and tensiometers for observing seepage water movement, lysimeters are an important instrument for the parameterisation of process models for modelling energy and nutrient cycling. This also applies to forest hydrology research. Lysimeters are indispensable in investigations of water consumption of small forest trees of different origin in the face of increasingly limiting water resources arising from climate change.

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