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Modified wick lysimeters for critical water use efficiency evaluation and yield crop modelling

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Summary

Short-rotation plantation for bioenergy production could be a valuable land management alternative for marginal land. Often extreme edaphic condition and aridity are characterizing these areas, thus conventional crops systems are in general economically not profitable. For the development of sustainable crop production detailed information about water consumption of bioenergy plants is required. For water use efficiency and fertilization regime evaluation of various potential bioenergy plants, a lysimeters system has been developed. Because it is crucial to maintain unsaturated conditions at the lysimeter bottom layer, a modified wick lysimeters (WL) prototype has been developed. Improved seepage and thus unsaturated condition at the bottom layer have been confirm for rockwool wick lysimeter (RWL), compared to a Pam lysimeter (PL).

Keywords: Bioenergy production, fast-growing trees, high conductive drainage extension, unsaturated conditions, yield-transpiration relation

Introduction

Climate change and alternative energy generation have become worldwide central topics in the last decades. They are moving up the European political agenda to encourage and promote an environmentally sustainable economy (EUROPEAN COMMISSION 2005). In particular the German Government has set itself the target of increasing the proportion of renewable energies in the electricity sector by 25 to 30 % by the year 2020. The cultivation of fast-growing plantations for energetic usage is especially attractive for post- mining areas (BÖHM et al. 2009) where soil reclamation practices are needed to re-establish soil productivity. Furthermore, due to the initial succession, woody species have a high benefit for restoration of landscapes (QUICKENSTEIN et al. 2009, DILLY et al. 2010, VESTE et al. 2010).

As the availability of water and nutrition is limiting the primary production (SINCLAIR et al. 2005), the optimization of these processes and interrelations with yield play a key role in agricultural systems. Currently, various simulation models have been developed for land management and crop production (e.g. STÖCKLE et al. 2003, JANSSON and KARLBERG 2001). However, to improve their applicability and efficiency in existent situations, more tests are needed and experimental verification must be successfully applied under different environmental conditions. Lysimeter studies offer an appropriate way to describe and quantify the complexity of process involved in the soil-plant-atmosphere system. They are befitting for yield-transpiration relations determination and can be even use for woody species (BEN GAL et al. 2010). Furthermore, since the environmental condition of the lysimeter can be controlled, it can offer valuable information for model calibration and improvement (RAMSBECK et al. 1997, SCHOEN et al. 1999). At present, several lysimeter designs have been tested and satisfactory reviews of the different materials and methods have been done by WEIHERMÜLLER et al. (2007). As emphasized by BEN-GAL and SHANI (2002), a critical problem is that the saturation at the lysimeter bottom boundary can occur in relation to the system chosen. As a result, roots are exposed, to oxygen restraint and anaerobic processes may occur (KLOCKE et al. 1993). Unsaturated conditions at the lysimeter bottom layer have been obtained by actively maintaining the tension at the bottom (DERBY et al. 2002) or passively, by designing lysimeters deeper than the estimated root growth (ERVET et al. 2009). A practical solution is given by wick lysimeters (BEN-GAL and SHANI 2002, BRAHY et al. 2002, ZHU et al. 2002), in which a constant suction at the bottom layer is exerted by a high conductive drainage extension (HCDE). Since the suction is a function of the dimension and hydraulic conductivity of the HCDE, it can be designed for a wide range of soil types. In our work we present a modified lysimeter for low-cost investigations. We carried out critical comparison of the drainage performance of the rockwool wick lysimeter (RWL) versus Pam lysimeter (PL), as a function of soil water content variation at the lysimeter top and bottom layer.

Material and Methods

RWL and PL with relative automatized drip irrigation system prototypes have been arranged at the Brandenburg University of Technology in Cottbus (*figure 1*). A 70x50 cm polyethylene drum has been chosen to contain a sandy soil column at bulk density 1.3. On the RWL, to avoid saturation at the bottom layer, a polyethylene extension pipe filled with rockwool (Sonoroll 035, ROCKWOOL®) has been installed at the lysimeter bottom. HCDE dimensions

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Figure 1: **Modified wick lysimeter and drip irrigation system**

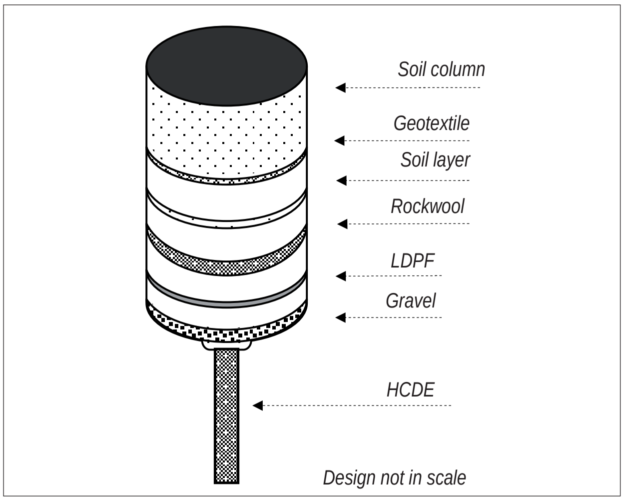

Figure 2: **Schematic diagram of the lysimeter**

(47 x 6.5 cm) and rockwool density (0.18 g cm^{-3}) have been calculated in relation to the soil column dimension and PSD (BEN-GAL and SHANI, 2002).

A funnel shaped bottom has been constructed, to avoid stagnancy by filling the lysimeter bottom with clean gravel, separated from the soil column by a low density polyethylene film (LDPF). Over the LDPF a 7 cm rockwool layer has been establish, in connection to the HCDE, to expose the soil column bottom layer to the suction. Root growing into the drainage extension is prevented by fitting a roots stop geotextile (Landschaftsvlies, DELTA® - Herdecke). Flax continuity at the interlayer rockwool-geotextile is guaranteed by an interposed 5 cm soil layer.

On the PL, instead of the HCDE, on the bottom layer 5 cm of clean gravel have been fitted separated from the soil column only with the roots stop geotextile. Water input amounts were controlled by an automatic drip irrigation system. To avoid uncontrolled water input by rainfall we installed the lysimeter under a light-transmissive roof. Water storage and soil matrix potential variations have been determined at two depths (40 and 20 cm deep) respectively by a TDR (Time Domain Reflectometry) device (SM 200, Soil Moisture Sensor, Delta-T Devices, Cambridge) and a gypsum tensiometer (SIS, UMS, München). Soil water content along all the profile (every 10 cm) has been recorded on a weekly basis by a TDR profile probe (PR2/4w-02, Delta-T). Soil temperature has been recorded at 20 cm deep by a thermistor (SKTS 200, Skye Instruments Ltd, Powys).

Results and Discussion

Various tests were carried out to study the hydrological performance of the lysimeter. Differences between RWL and PL have been found in terms of water storage at the bottom layer, by subjecting the lysimeters to the same irrigation regime. *Figure 3a*, relative to the soil water content variation at 40cm deep, shows how RWL drainage system has kept the soil moisture content at the bottom layer (40

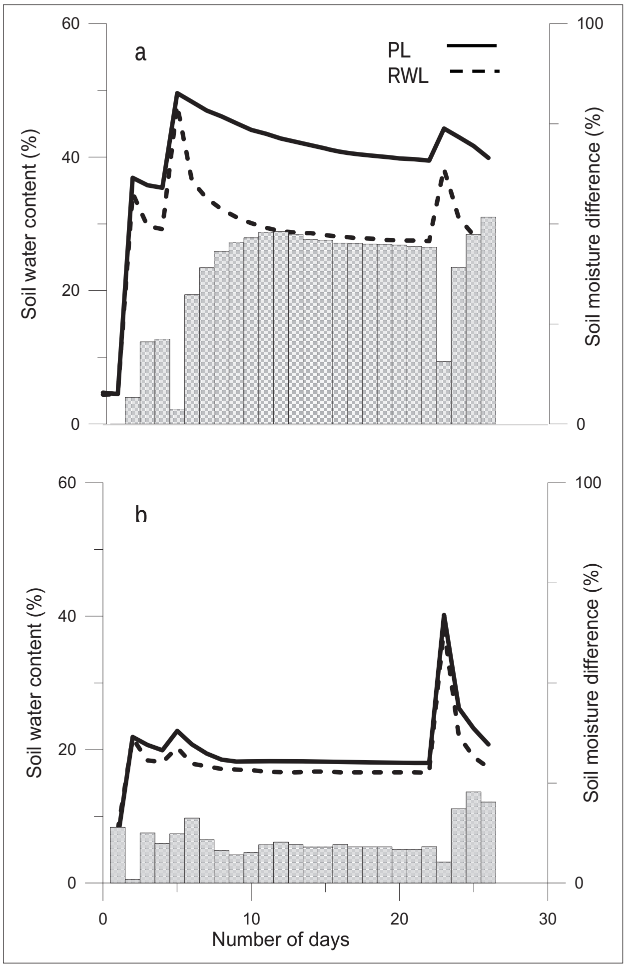

Figure 3: **Soil water content variation and difference (%) between RWL and PL a) 40 cm deep b) 20 cm deep**

cm) constantly under the PL soil moisture values. More in detail, the soil water content in RWL were 40% (arithmetic mean) lower than in PL, with a maximum value of 52% (*figure 3a*). Once the irrigation supply was stopped, the soil water content at the bottom layer decreased in RWL, at a rate evidently higher than in PL (*figure 3a*). On the upper layer (20 cm) instead, the difference in terms of water storage were less accentuated. After irrigation of RWL it was only 10% (arithmetic mean) less than in PL (*figure 3b*).

Our results show that the new developed wick lysimeter is a suitable tool for the determination of yield-transpiration relations of bioenergy crop. The data obtained in our experiments are in accord with those found in literature (ZHU et al. 2002). Wick lysimeters improve seepage, and thus promote unsaturated condition at the lysimeter bottom layer, due to the constant suction exert by the HCDE (BEN-GAL and SHANI 2002). The benefits on using WRL are the reduction of the soil profile deep that PL needed to have the same condition.

Besides after the set-up, WRL do not need the constant maintenance to the drainage apparatus that suction plate and suction cup lysimeter require. Furthermore, this lysimeter system will allow also investigating the impact of water quality (e.g. BEN-GAL et al. 2008) or the effects of fertilizers on plant growth and plant transpiration. Since RWL prototype together with the automatized drip irrigation system, during the tests demonstrate high drainage efficiency and low maintenance they will be adopted for our project. Water use efficiency and draught resistance of two fast growing trees specie will be investigated under different irrigation regimes. Furthermore fertilization rate optimization for an optimum yield is planned. Eco-physiological data obtained will be use for ecological model calibration and validation for yield modelling proposes.

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