Agricultural Water Management 137 (2014) 15–22

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Actual evapotranspiration and crop coefficients for five species of three-year-old bamboo plants under a tropical climate

Julien Piouceau[a,b,*], Frédéric Panfili[a], Grégory Bois[a], Matthieu Anastase[a], Laurent Dufossé[b], Véronique Arfi[a]

[a] Phytorem S.A., site d'Areva, chemin de l'autodrome, F-13140 Miramas, France
[b] Université de La Réunion, Laboratoire de Chimie des Substances Naturelles et des Sciences des Aliments, site ESIROI Département Agroalimentaire, 2 rue Joseph Wetzell, F-97490 Sainte-Clotilde, France

ARTICLE INFO

Article history:
Received 29 August 2013
Received in revised form 28 January 2014
Accepted 4 February 2014
Available online 23 February 2014

Keywords:
Bamboo
Lysimeter
Evapotranspiration
Crop coefficient
Biomass
Tropical climate

ABSTRACT

Over the last decade, bamboo plantations have started to be used as vegetation filters for wastewater treatment. This treatment system can be useful in reducing wastewater discharge into the environment, thus contributing to the preservation of water resources by using the plantation's evapotranspiration to reduce the rate of water infiltration. The evapotranspiration rates of the bamboo species used is therefore an important factor. The actual evapotranspiration (ET) and the crop coefficients (k_c) for the five tropical and temperate species of three-year-old bamboo plants, *i.e. Bambusa oldhamii*, *Bambusa multiplex*, *Bambusa vulgaris*, *Phyllostachys aurea* and *Pseudosasa japonica*, were studied in lysimeters for a period of more than one year under a tropical climate. The average ET rates for the bamboo species studied ranged from 4 to 7 mm day^{-1} with maximum values of between 10.7 and 17.1 mm day^{-1} during the wet season, and an average k_c of 1.1 to 1.9. The ET was correlated to weather parameters, especially minimum temperatures. The differences in ET rates between the bamboo species can be explained by morphological parameters, in particular the total aboveground biomass. Among the five bamboo species studied, *B. oldhamii* had the highest ET rate and produced the most biomass. In comparison with other high-biomass-producing plants, the evaporation rates for young bamboo plants were similar to those for willow and poplar vegetation filters.

1. Introduction

Water resources conservation is an important issue today. The eutrophication process in water especially is a worldwide concern (Smith, 2009; Smith et al., 1999). Natural wastewater treatment systems using phytoremediation principles have been developed in order to provide a useful alternative to more conventional wastewater treatment systems, particularly in rural or isolated areas. Most of these systems involve constructed wetland using aquatic plants (Vymazal, 2011). Another type of system uses terrestrial plants such as poplar, willow and – more recently – bamboo, where the plants are used as vegetation filters (Arfi et al., 2009; Aronsson and Perttu, 2001; Perttu and Kowalik, 1997; Singh et al., 2008; Yadav et al., 2010).

Although bamboo is still rarely used for phytoremediation purposes (water or soil treatments), it nevertheless shares a number of interesting characteristics with other plants used in phytoremediation. Among these is bamboo's apparent tolerance to pollutants such as trace metals (Collin et al., 2013; Gui et al., 2011; Shukla et al., 2011), and to the excessive doses of nutrients that can be contained in wastewater (Piouceau et al., 2014). Bamboo also develops a dense root system with a profusion of fine roots and hair roots (Christanty et al., 1996) that favors the hosting of microorganisms and improves the rhizodegradation of organic matter contained in wastewater (Licht and Isebrands, 2005; McCutcheon and Schnoor, 2003). Lastly, giant bamboo species are among the most productive terrestrial plants in the world. The aboveground biomass yield of mature plantations can reach 25 and 47 t ha^{-1} yr^{-1} under temperate and tropical climates, respectively (Scurlock et al., 2000). These high-yield plants are interesting for wastewater treatment purposes because they can help preserve the quality of water resources by limiting the eutrophication phenomenon in two complementary ways. First, by storing large amounts of nitrogen and phosphorous (the main elements involved in eutrophication) in their biomass: a

* Corresponding author at: Phytorem S.A., site d'Areva, chemin de l'autodrome, F-13140 Miramas, France. Tel.: +33486260805; fax: +33490581578.
E-mail addresses: julienpiouceau@phytorem.com, j.piouceau@hotmail.fr (J. Piouceau).

http://dx.doi.org/10.1016/j.agwat.2014.02.004
0378-3774/

mature bamboo plantation can store 131 to 619 kg ha^{-1} of nitrogen and 17 to 97 kg ha^{-1} of phosphorous in its aboveground biomass (Kleinhenz and Midmore, 2001). Second, by slowing the infiltration of water through their high evapotranspiration rates; Kleinhenz and Midmore (2002) estimated that the ET rate of a mature bamboo plantation can range between 9 and 13 mm day^{-1} under a tropical climate.

The development of vegetation filters using terrestrial plants has been boosted by regulatory pressure to reduce or stop the discharge of any treated water into the environment. Indeed, even if the treated water complies with environmental quality standards, it still contains small amounts of nitrogen and phosphorus that are potentially harmful for the water resources. This is particularly true for sensitive areas such as the lagoons and streams on Reunion Island (Chazottes et al., 2002; Naim, 1993; Semple, 1997; Tedetti et al., 2011), for which a target of zero discharge of any water into the environment needs to be implemented. In vegetation filters, the wastewater is directly spread over the plantation's soil surface. The treated wastewater is released through percolation, via the root zone to the water table and into the atmosphere through evapotranspiration. This kind of system can be designed and managed to avoid any discharge of any water into the water table. To do this, the evapotranspiration (ET) rates of the plant species used must be accurately known to set the appropriate wastewater volume to be spread on the plantation.

Some studies were carried out on the transpiration of various bamboo species using the sap-flow method (Dierick et al., 2010; Komatsu et al., 2010, 2012; Kume et al., 2010), but most of these did not take into account the evaporation via the soil. Furthermore, they were conducted in non-irrigated conditions so the experimental method did not allow the plants' full transpiration potential to be quantified. Another experimental method uses lysimeters (Aboukhaled et al., 1982). The lysimeter method is well-adapted to measuring the ET, that is to say both the plant transpiration and the soil evaporation are measured in field conditions. This method also allows the crop coefficient (k_c) to be calculated. The k_c of a plant species is the ratio between the ET rate of the plant studied and the reference evapotranspiration (ET_0) (Allen et al., 1998). The lysimeter method has been successfully used to study the ET and k_c of some high-biomass-producing plants such as poplar and willow (Guidi et al., 2008; Pauliukonis and Schneider, 2001; Pistocchi et al., 2009). To our knowledge, there is currently a lack of data on the evapotranspiration rates of bamboo and other giant grasses (*e.g.* switchgrass, *Miscanthus* sp. or *Arundo donax*). Consequently, the aim of our study was to determine the ET rates and k_c of several bamboo species and to compare them in order to select the most appropriate species for vegetation filters (*i.e.* the species with the highest ET rate). To this end, we put in place percolation-type lysimeters (Allen et al., 2011) to measure ET rates over a period of more than one year. Morphological parameters, such as leaf area and total aboveground biomass, were also measured to account for differences in ET rates between species.

2. Materials and methods

2.1. Experimental conditions

The experiment was conducted over one year, from August 20th, 2008 to October 30th, 2009 (436 days), on Reunion Island, an overseas French department in the south-west Indian Ocean. The experimental site was located at Le Guillaume, Saint Paul (21°03′ 48″S; 55°19′ 24″E) at an elevation of 1043 m.

Fifteen percolation-type lysimeters were set up at the experimental site (Fig. 1). The lysimeters consisted of 1.2 m^3 plastic tanks (1.00 m deep, 1.00 × 1.20 m in area). The lysimeters were placed

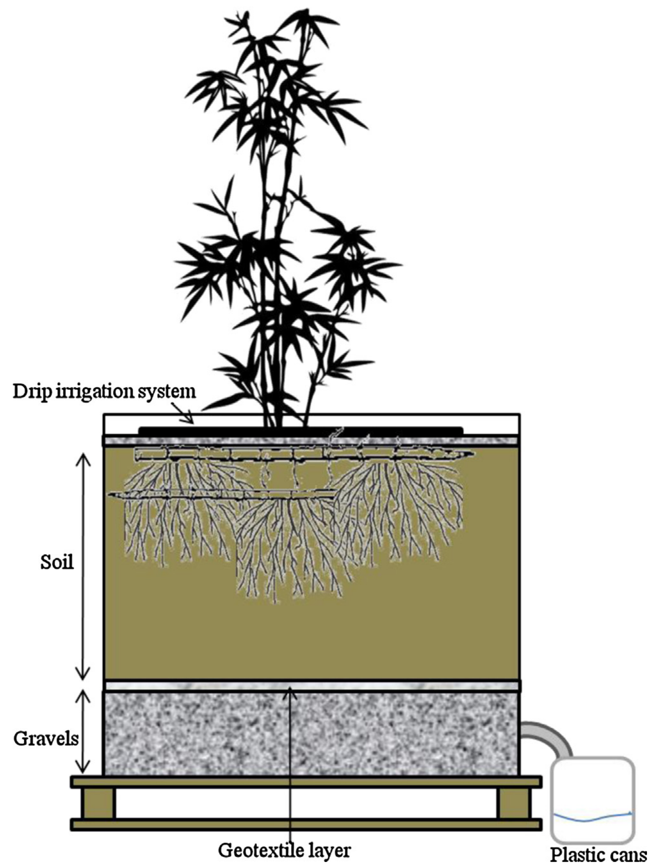

Fig. 1. Lysimeter set up at the experiment site.

70 cm apart to protect their sides from direct sunlight. The sides of the lysimeters were also insulated with a polypropylene membrane to prevent heating.

The lysimeters were filled with 20 cm of gravel at the bottom as a drainage layer. A geotextile (bidim green®, Ten Cate Geosynthetics, France) was laid on top of the gravel before the tanks were filled with a 3:1:1 (v:v:v) mixture of soil, scoria and sugar cane fibers, the characteristics of which are listed in Table 1.

The lysimeters were planted with five different species of three-year-old bamboo plants: three tropical species (pachymorph rhizome; Stapleton (1998): *Bambusa oldhamii* Munro (BO), *Bambusa multiplex* (Lour.) Raeusch (BGG) and *Bambusa vulgaris* Schrad. (BVV)) and two temperate species (leptomorph rhizome; Stapleton (1998): *Phyllostachys aurea* Rivière & C. Rivière (PA) and *Pseudosasa japonica* (Steud.) Makino (PJ)). The lysimeters were arranged in a completely randomized design based on the factor species (five levels) with three replicates per species. The bamboo species were planted in the lysimeters' reconstituted soil in May 2008, four months before the start of the experiment, to allow for the bamboo's proper rooting and a natural compaction of the soil.

Table 1
Average lysimeter soil properties after bamboo plantation.

Particle density (g cm^{-3})	2.8
Bulk density (g cm^{-3})	0.6
Soil water holding capacity (mm)	210
pH_{water}	6.3
EC (mS cm^{-1})	0.3
Total nitrogen (g kg^{-1})	2.7
Total organic carbon (g.100 g dry soil)	3.1
Phosphorus Olsen-Dabin (g kg^{-1})	0.3
CEC (m_{eq}.100 g)	14.1

Electrical conductivity (EC); Cation exchange capacity (CEC).