Agricultural Water Management 196 (2018) 37–47

Contents lists available at ScienceDirect

Agricultural Water Management

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

Research Paper

Root system characterization and water requirements of ten perennial herbaceous species for biomass production managed with high nitrogen and water inputs

A. Barco, C. Maucieri*, M. Borin

Department of Agronomy, Food, Natural Resources, Animals and Environment – DAFNAE, University of Padua, Agripolis Campus, Viale dell'Università 16, 35020 Legnaro, PD, Italy

ARTICLE INFO

Article history:
Received 16 May 2017
Received in revised form 1 October 2017
Accepted 18 October 2017

Keywords:
Crop coefficient
Crop evapotranspiration
Rhizomes
Roots
Soil moisture

ABSTRACT

Although several studies have investigated the aboveground production of perennial herbaceous species for biomass production, only a few details are available on their root systems and water balance. This paper provides a root system characterization and a water balance calculation for ten perennial herbaceous species (*Arctium lappa* L., *Arundo donax* L., *Carex acutiformis* Ehrh., *Carex riparia* Curtis, *Glyceria maxima* (Hartm.) Holmb., *Helianthus tuberosus* L., *Iris pseudacorus* L., *Lythrum salicaria* L., *Miscanthus x giganteus* Greef et Deu., *Symphitum x uplandicum* Nyman) cultivated with high fertilizer and water inputs in a four-year study. Crop evapotranspiration (ETc) maintained the same seasonal trend for all studied species, with the highest cumulative seasonal average water losses for *A. donax* (1675.1 mm) and the lowest for *G. maxima* (1406.0 mm). During the growing season, crop coefficients followed a similar trend to that reported for ETc, with average seasonal values ranging from 1.9 for *A. lappa* and *G. maxima* to 2.6 for *M. x giganteus*. For all species soil moisture was higher in the deeper soil layers (20–50 and 50–90 cm) than in the upper (0–20 cm) where a high root system biomass was observed. At the end of the study, different root system biomass productions were found between species with the highest median value at 0–50 cm depth for *M. x giganteus* (62.6 Mg ha^{-1}) and the lowest for *S. x uplandicum* (0.5 Mg ha^{-1}). Since these topics have not been well investigated in other studies, our initial results need to be confirmed in different climatic conditions.

1. Introduction

Global energy demand is growing rapidly. Currently, more than 84% is satisfied by non-renewable energy fossil resources (Sawatdeenarunat et al., 2015), leading to obvious sustainability concerns. In this context renewable energy resources can largely substitute fossil fuels with important positive effects on the environment. New energy technologies have to contribute to reduce greenhouse gases emission in the atmosphere as required by European Union in its policy objectives (Popp et al., 2014). For this purpose, the agricultural sector contributes by producing several types of biomass that can be transformed into energy outputs by different processes (McKendry, 2002; Barbanti et al., 2014; Molari et al., 2014; Marchetti et al., 2016). In general, biomass as a renewable energy resource includes various substrates such as forest matrices, agricultural residues, post-processed biomass wastes and energy crops (Bentsen and Felby, 2012). These last are usually cultivated in intensive systems, adopting high plant density, mechanization and energy inputs, with short rotations (from 1 to 4 years) and plant cycles (less than 20 years) (Fiorese and Guariso, 2010). Currently, several food crops (e.g. corn, sorghum, sugar beet) are used for bioenergy purposes (Brauer-Siebrecht et al., 2016) leading to strong competition for arable land between energy and food production (Harvey and Pilgrim, 2011; Miyake et al., 2012). In this scenario, non-food biomasses derived from wetland perennial herbaceous species, harvested in marginal and set-aside lands, could offer an interesting integration to traditional energy crops (Pappalardo et al., 2015). Among these, particular attention is being paid to *Arundo donax* L. (Cosentino et al., 2006; Barbagallo et al., 2014; Corno et al., 2015) and *Miscanthus x giganteus* Greef et Deu. (Clifton-Brown et al., 2004; Dohleman and Long, 2009; Chung and Kim, 2012; McCalmont et al., 2015), due to their high potential productivity and stable yield over time (Angelini et al., 2005, 2009). These species can be sustainably cultivated minimizing the yearly

* Corresponding author.
E-mail address: carmelo.maucieri@unipd.it (C. Maucieri).

https://doi.org/10.1016/j.agwat.2017.10.017
0378-3774/

costs of soil tillage (Lewandowski et al., 2003; Somerville et al., 2010) normally used for annual crops. In fact, the majority of agronomic operations (e.g. soil tillage, rhizomes transplant, fertilization, weed control) are concentrated in the first season during crop establishment (Angelini et al., 2009; Corno et al., 2014) even though the highest biomass productions are obtained by suppling water and nutrients over the years (Cosentino et al., 2007, 2014; Borin et al., 2013; Florio, 2014). Thanks to high pollutant load tolerance and nutrient uptake (Zhao et al., 2014), perennial herbaceous species could be used to exploit non-conventional waste and water resources, also in open field conditions. Wastes could include animal slurry or bioenergy byproducts (e.g. digestate) that are rich in organic matter and nutritive elements, thus reducing the dependency on inorganic fertilizers and their associated economic and environmental costs (Walsh et al., 2012; Maucieri et al., 2016a, 2017). Different types of wastewater can be used to irrigate perennial herbaceous species, such as urban wastewater (Zema et al., 2012), constructed wetland effluents (Barbagallo et al., 2014), or marginal waters (Molari et al., 2014).

In this context, wastewaters can only be rationally managed if perennial herbaceous species water requirements and water absorbing root systems are understood. Although a lot of information on water requirements is available in the scientific literature for open field herbaceous (Allen et al., 1998; Abdelhadi et al., 2000; Piccinni et al., 2009; Ko et al., 2009) and woody crops (Allen et al., 1998; Guidi et al., 2008) as well as shrubs (Rajaona et al., 2012), perennial herbaceous species have not been well-investigated from this point of view. A few papers have reported the water requirements of the most promising perennial herbaceous species for biomass production, such as *A. donax*, *M. x giganteus* (Triana et al., 2015) and *Phragmites australis* (Cav.) Trin. ex Steud. (Zhou and Zhou, 2009; Salvato and Borin, 2010; Borin et al., 2011; Headley et al., 2012). Other studies have characterized the root systems of *A. donax* (Monti and Zatta, 2009; Nassi o Di Nasso et al., 2013; Maucieri et al., 2014; Toscano et al., 2015) and *M. x giganteus* (Himken et al., 1997; Neukirchen et al., 1999; Kahle et al., 2001; Hansen et al.,. 2004; Monti and Zatta, 2009; Amougou et al., 2011; Toscano et al., 2015) cultivated in soil or substrates, while the root systems of *Carex* spp. (Aerts and De Caluwe, 1994; Pappalardo et al., 2017) and *Iris pseudacorus* L. (Pavan et al., 2015; Pappalardo et al., 2017) have been studied in hydroponic conditions. To our knowledge, no research has so far contemporarily characterized the water consumption and root systems of perennial herbaceous species. This paper presents the results of a four-year experiment on ten species, usually transplanted in constructed wetland systems and already investigated as a promising source of biomass for bioenergy production (Mantineo et al., 2009; Marchetti et al., 2016), but as yet little investigated when cultivated in agricultural soil with high water and organic fertilizers supply. The main objectives were to provide: 1) a characterization of their root systems in the top 50 cm soil depth; 2) their water requirements 3) individuation of the crop coefficients.

2. Materials and methods

2.1. Site description and trial setup

The experiment was conducted at the University of Padua "L. Toniolo" Experimental Farm in Veneto Region, North-East Italy (Lat. 45°21′N, 11°58′E, 6 m a.s.l.) from 2010 to 2014, over four growing seasons. The climate of this area is sub-humid with a long-term (1995–2010) mean annual temperature of 13.3 °C and mean cumulative annual rainfall (1995–2010) of 867.4 mm, uniformly distributed throughout the year (Fig. 1). The experimental site was composed of 48 growth boxes (4 m^2 surface area), arranged in two symmetric lines of 24 boxes each, installed at 1.3 m above ground level to avoid water table interaction, especially during the winter, and with the bottom open, to allow water percolation. They were filled with fulvi-calcaric Cambisol (based on FAO classification) typical of the farm, the features of which, referring to the 0–140 cm layer, are reported in Table 1. Since disturbed soil was used to fill the boxes, a homogeneous profile has been obtained. Field capacity and wilting point were determined using Richards pressure plates.

Table 1
Chemical-physical characteristics of soil at the beginning of the experiment.

Parameters	Values
Sand (%)	33
Silt (%)	47
Clay (%)	20
pH	8.1
ECe (mS cm^{-1})	0.3
Total carbonate (%)	18.7
Soluble carbonate (%)	4.0
Organic matter (%)	1.2
Organic carbon (%)	0.7
C/N ratio	7.1
Total nitrogen (%)	1.1
Available P (mg kg^{-1})	33.0
Available K (mg kg^{-1})	131.5
Field capacity −10 kPa (%)	34.5
Wilting point (%) −1500 kPa (%)	16.5

Fourteen different species (*Arctium lappa* L., *Arundo donax* L., *Canna indica* L., *Carex acutiformis* Ehrh., *Carex pseudocyperus* L., *Carex riparia* Curtis, *Glyceria maxima* (Hartm.) Holmb., *Helianthus tuberosus* L., *Iris pseudacorus* L., *Lythrum salicaria* L., *Miscanthus x giganteus* Greef et Deu., *Phalaris arundinacea* L. var. picta L., *Scirpus sylvaticus* L. and *Symphytum x uplandicum* Nyman) were cultivated during the experiment in a completely randomized experimental design with four replicates, adopting 4 plants m^{-2} transplant density. The experiment was activated in June 2010 transplanting 9 species (Table 2). Of these, *C. indica* and *C. pseudocyperus* did not survive the first winter season so were substituted in March 2011 by *P. arundinacea* and *G. maxima*, respectively. After transplanting, *P. arundinacea* showed limited growth over the entire vegetative cycle and did not survive the following winter season. Instead *G. maxima* showed good establishment and growth during all years. *S. sylvaticus* did not survive the second winter season and for this reason it was substituted in March 2012 by *L. salicaria*. For this paper only ten of the fourteen species are taken into account – those that survived and have been cultivated until the last experimental year (Table 2): *A. lappa*, *A. donax*, *C. acutiformis*, *C. riparia*, *G. maxima*, *H. tuberosus*, *I. pseudacorus*, *L. salicaria*, *M. x giganteus* and *S. x uplandicum*.

The plants were fertilized in May of each year from 2010 to 2012 with a constant amount of pellet manure Biorex (Italpollina, Italy), supplying 400 kg N ha^{-1} and 186 kg P ha^{-1}, whereas in the last growing season (May 2013) by applying digestate liquid fraction at 250 kg N ha^{-1} and 120 kg P ha^{-1}. To maintain high water availability from May to September of the first three growing seasons, irrigations using tap water were applied supplying 47.6 mm (2010), 56.9 mm (2011) and 74.3 mm (2012) of water per week, divided in two weekly supplies of 23.8 mm (2010), 28.4 mm (2011) and 37.1 mm (2012) each, about every three days. In the fourth growing season (2013) the irrigation was reduced to two interventions (92 mm each) supplied in July and August. To maximize the irrigation efficiency, drip irrigation was used. During the four growing seasons (March–October), plants received (rainfall + irrigation) 1641.8 mm in 2010, 1571.8 mm in 2011, 1954.4 mm in 2012 and 974.4 mm in 2013.

Volumetric soil moisture was measured weekly every 10 cm down to 90 cm depth with a Diviner 2000 device (Sentek, Stepney, Australia). Data were collected from June to September in 2010,