European Journal of Agronomy 96 (2018) 77–86

Contents lists available at ScienceDirect

European Journal of Agronomy

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

Ligneous-cellulosic, nitrophilous and wetland plants for biomass production and watertable protection against nutrient leaching

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A R T I C L E I N F O

Keywords:
Biomass species
Arundo donax L
Nitrates directive
Nitrogen uptake
Phosphorus uptake
Percolation water

A B S T R A C T

Research has recently stressed the importance of combining renewable energy production with environmental protection. The aim of the present work was to find new perennial herbaceous plants adequate to figure out innovative energy cropping systems based on reduced input (no tillage, use of slurry and/or wastewater for nutrient supply) and with low environmental impact. Fourteen species were cultivated in growth boxes and fertilized with pellet manure (2010–2012) and digestate (2013). Research focused on comparison of biomass production, nitrogen (N) and phosphorus (P) accumulation in aboveground biomass and the quality of percolation water. Five species, *C. indica*, *C. pseudocyperus*, *G. maxima*, *P. arundinacea* and *S. sylvaticus*, did not survive more than one or two years of cultivation. *A. donax* had the highest biomass yield, increasing yearly (26.2, 62.8, 95.1 and 140.1 Mg ha^{-1}, from 2010 to 2013, respectively) and significantly higher than all the other studied species. *M. x giganteus* production increased from the first (13.1 Mg ha^{-1}) to the second year of cultivation and then remained stable (average 51.0 Mg ha^{-1}); the other species showed increased productivity in the first years and then a dramatic drop in the last year. Again, *A. donax* had the highest nutrient accumulation in aboveground biomass, with mean yearly values of 631 kg N ha^{-1} and 83.2 kg P ha^{-1}. The total N (TN) concentration in percolation water was higher in the first autumn-winter season, with a median close to 15 mg L^{-1} and great variability. Two years later, the median concentration fell to 2 mg L^{-1} and variability was considerably reduced. *A. donax* and *M. giganteus* turned out to be the best species in reducing nitrate N concentrations in percolation water. Concentrations of total P (TP) were two orders of magnitude lower than those of TN and showed higher and more variable values in 2012–2013 (from 0.060 to 0.145 mg L^{-1}) than in 2010–2011 (from 0.025 to 0.034 mg L^{-1}). The species did not significantly influence the TN and TP presence in the percolation water. Considering both biomass production and attitude to water table protection, *A. donax* gave the best results of all species studied.

1. Introduction

In Europe, specialization of agricultural systems between territories, with clear-cut separation between areas with very high livestock densities and others devoted to annual crop cultivation, has given rise to problems of waste management (Martinez et al., 2009). The former produces huge quantities of waste, which is difficult to handle and leads to excessive availability of nitrogen (N) and phosphorus (P) (Peyraud et al., 2014) respect to potential distribution area. The negative effects of excessive amounts of livestock effluent spreading over arable land are well-known (e.g., Borin et al., 1997; Smith et al., 2000) and indicate the need for new strategies and methods of management in order to comply with the Nitrates Directive (Henkens and Van Keulen, 2001; Harrington and Scholz, 2010) and also to protect water bodies from potential P leaching (Sims et al., 1998; Djodjic et al., 2004).

Partial (re)location of livestock production in territories specializing in crop production is an interesting strategy, but it is very difficult to apply, for organizational, social and economic reasons (Peyraud et al., 2014). The transfer of wastes between farms and/or territories is a more promising approach to improving nutrient management and reducing the need for inorganic fertilizers but, again, there are difficulties in terms of costs and CO_2 emissions related to transport.

Many specialized livestock farms, not having sufficient land to manage their liquid manure, have installed anaerobic digestion plants producing biogas as an integrative source of income. However, anaerobic digestion is a conservative process for N and P, the concentration of which in anaerobic digester effluent (digestate) remains high (Harrington and Scholz, 2010). The problem of nutrient excess is

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https://doi.org/10.1016/j.eja.2018.01.018
Received 29 January 2016; Received in revised form 26 January 2018; Accepted 31 January 2018

consequently not solved with biogas production from manure.

There is growing interest in permanent cropping systems which keep soil covered for several years in order to improve nutrient recovery. Of these, one possibility still to be explored is the cultivation of pluri-annual energy crops (López-Bellido et al., 2014). The increasingly important role of bioenergy is stressed in many studies (Van Vuuren et al., 2007; Dornburg et al., 2010; Nijsen et al., 2012) and many climate change mitigation policies stress the importance of replacing fossil fuels with renewable energy sources (RES) (Dandres et al., 2012). According to the Renewable Energy Directive (RED) (European Directive 2009/28/EC, 2009), by 2020 EU Member States (MS) must reach a 20% share of energy from renewable sources by 2020 and 10% of renewable energy, specifically in each MS transport sector. These targets rely on the widespread use of biomass in all energy sectors, and this is expected to account for 56% of RES supply by 2020 (Beurskens et al., 2011). In addition, the European Commission recently published a proposal (COM/2012/595) to limit to 5% the use of food-based biofuels to meet the 10% renewable energy target in the RED Directive. Bioenergy is therefore a crucial element in agriculture and energy policies in many countries (Oorschot et al., 2010; Nijsen et al., 2012).

Sustainable methods of cultivation of biomass crops can be achieved by growing vigorous and multi-year plants to minimize the yearly costs of sowing and soil tillage (Cosentino et al., 2008) and by using organic sludges and/or wastewater to apply nutrients (Lopez et al., 2006; Molari et al., 2014). These sources of nutrients can contribute directly toward reducing the disequilibrium in livestock effluent production among territories and, indirectly, by reducing greenhouse gas emissions caused by the production of chemical fertilizers (Maucieri et al., 2017).

Using multi-year herbaceous plants suitable for wetland treatment systems may offer an interesting solution to achieve the double target of huge biomass availability for renewable energy production (Marchetti et al., 2016) and allocation of organic wastes and poor-quality waters. Wetland plants are able to tolerate high N and P loads and can improve water quality, while providing 50–60 Mg ha^{-1} per year of biomass at the same time (Kadlec and Knight, 1996; Maucieri et al., 2014a) with an energy potential close to 70 GJ ha^{-1} (Pappalardo et al., 2015) and harvests of up to 1000 kg ha^{-1} $year^{-1}$ of N in aboveground biomass (Borin and Salvato, 2012). The allocation of wetland plants in marginal lands and the use of poor-quality water, animal wastes or digestate as fertilizers may represent a low-cost itinerary of biomass production considering that they need a reduced number of operations during their growing cycles. In this way, it would be possible to combine relatively high biomass yields with high N recovery (Dragoni et al., 2015) and energy efficiency, as envisaged by Muylle et al. (2015) for ligneous-cellulosic crops which have similar features to wetland plants.

In order to combine all the above-mentioned positive aspects, suitable species for biomass productivity and water protection must be identified. Reported values of biomass production and nutrient uptake of ligneo-cellulosic and wetland species are mainly obtained in natural conditions (e.g., Kadlec and Wallace, 2009), with few exceptions (e.g., *A. donax* and *M. x giganteus)*. However, the behavior of the same species in nature and under cultivation may be very different, and data regarding agronomic management are required. The aim of the present work was to find new pluri-annual herbaceous plants adequate to figure out innovative energy cropping systems based on reduced input (no tillage, use of slurry and/or wastewater for nutrient supply) and able to reduce water pollution risk in areas with large nutrient loads. At this purpose 14 ligneous-cellulosic and wetland species have been studied in terms of: 1) their biomass productivity; 2) how productivity is affected by single or double harvests during the growing season; 3) their N and P uptakes; and 4) N and P concentrations in water percolating under the species.

2. Materials and methods

2.1. Description of site

The experiment was conducted from June 2010 to October 2013 on the 'Lucio Toniolo' Experimental Farm of the University of Padova at Legnaro, near Padova (45° 21′ N; 11° 58′ E; 6 m a.s.l.), north-east Italy. In this part of the Veneto Region, the climate is sub-humid, and the long-term (1995–2010) average cumulative annual rainfall is about 867 mm, with moderately uniform distribution throughout the year and higher variability from September to November. The mean annual average temperature (1995–2010) is 13.3 °C. The reference evapotranspiration value (ET_0), according to Penman-Monteith, is 945 mm in an average year, reaching peak values in July, when it is about 160 mm (Bonaiti and Borin, 2010).

In this work, meteorological data for the period June 2010 – October 2013 were examined. In 2010 and 2013, annual precipitation exceeded the long-term average (1141 and 1084 mm), but was lower than average in 2011 and 2012 (601 and 603 mm, respectively). 2010 was the rainiest year during the vegetative period (April–September) and 2011 the driest. During the four-year experiment, the monthly temperature trends were generally higher than the long-term average, especially from May to September. Data were only lower than the long-term average in the winters of 2010 and 2011 and spring 2013 (Fig. 1).

2.1.1. Experimental set-up and management

The experimental site was composed of 48 concrete growth boxes (sides of 2 × 2 m), laid out in two parallel lines of 24 boxes each. They were installed with their tops at 1.3 m above ground level, to avoid influencing the water table, and their bases were completely open, to allow water percolation. They were filled with fulvi-calcaric Cambisol (CMcf) soil, according to the FAO-UNESCO (1990) classification (Table 1). A semi-automatic tension-controlled ceramic suction plate system was installed not in all boxes at a depth of 0.90 m, to allow collection of percolated water (Morari, 2006). The system was controlled by an electric vacuum pump, activated by hand to maintain the ceramic plate suction at 0.02 Mbar.

Fourteen herbaceous species were cultivated during the research period (*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). They were chosen according to their characteristically high productivity, tolerance to high N inputs and low water quality,

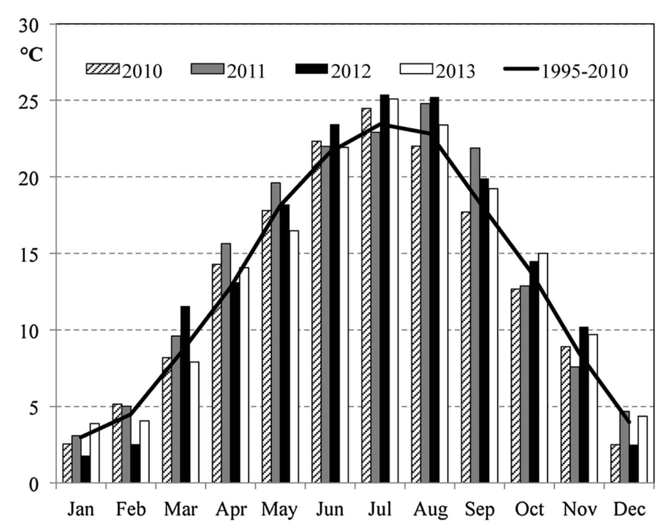

Fig. 1. Monthly average temperature data during the trial in Legnaro (PD) (ARPAV data).