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The ability of the *Arundo donax* crop to compete with weeds in central Spain over two growing cycles

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ABSTRACT

Nowadays there is extensive literature dealing with the cultivation of *Arundo donax* L. for biomass and bio-based compounds. Several agronomic aspects have been addressed while others, such as the need for weed control in the *A. donax* crop, have been barely investigated. In this work, the objective was to study the effect of weed competition on the *A. donax* crop in a Mediterranean environment over two growing cycles: the establishment year and the first maturity year of the crop. Weed diversity, weed abundance, plant traits and crop yield were determined in a field experiment with three treatments: no weed removal, weed removal in May and weed removal in June. The presence of alien species of genus *Conyza* Lessing was recorded throughout the field experiment. Weeds were detrimental to the *A. donax* crop in the two harvests under study despite the fact that *A. donax* competition increased from the first to the second growing cycle. In this study, the yield loss was estimated at 55% in the first harvest and decreased to 36% in the second one, showing higher *A. donax* competition. The results showed that weed removal should not be delayed until June for higher biomass yield.

1. Introduction

Arundo donax L., commonly known as giant reed, is a rhizomatous grass that has been grown for local uses in the Mediterranean region since ancient times; traditional uses of *A. donax* include basketwork, roofing, trellises and traditional medicine (Al-Snafi, 2015; Barreca, 2012; Morales et al., 2011). *A. donax* began to attract attention in Europe as a potential non-food crop in the nineties (El Bassam and Dalianis, 1998), probably linked to the development of a European collaborative project that aimed at the cultivation of giant reed for biomass production (Giant Reed Network, FAIR962028, European Commission, www.cordis.europa.eu). Several other European projects followed, giving rise to valuable insights into this challenge.

Nowadays there is extensive literature in relation to *A. donax* crop (Corno et al., 2014; Ge et al., 2016) and its physiology (Haworth M. et al., 2016; Webster et al., 2016), yield (Amaducci and Perego, 2015; Angelini et al., 2009), mechanization (Pari et al., 2016, 2015), crop costs (Soldatos, 2015; Testa et al., 2016), energy balance (Angelini et al., 2005; Mantineo et al., 2009) and environmental impacts (Bosco et al., 2016; Fagnano et al., 2015), among others. Studies of the potential applications of the crop products have increased considerably in the last years. As a result, *A. donax* applications have not been limited to bioenergy technologies −e.g. pellets (Aragón-Garita et al., 2016), biogas (Corno et al., 2016; Ragaglini et al., 2014), bioethanol (Scordia et al., 2013), pyrolysis (Saikia et al., 2015)-. Also they are extended to cellulose (Shatalov and Pereira, 2008; Ververis et al., 2004), bio-based compounds (Ferrandez-García et al., 2012; Fiore et al., 2014 Ferrandez-García et al., 2012) and other products (Muthanna, 2016; Sargin Karahancer et al., 2016).

As a recently-proposed crop, a research on the agronomy of *A. donax* has been conducted in the Mediterranean region. One of the first works about management techniques of the *A. donax* crop was the review by El Bassam and Dalianis (1998). These authors provided recommendations for growing *A. donax* and gave data on propagation, plant density, fertilization, yield and composition. Due to this, significant progress has been made on a number of agronomic aspects of the *A. donax* crop such as fertilization (Cosentino et al., 2014), irrigation (Zema et al., 2012), water use (Triana et al., 2015) and harvest time (Dragoni et al., 2015). However, other agronomic aspects, such as weed competition in *A. donax* crop, have been barely investigated (Curt et al., 2015).

It is important to mention that the need for weed control in *A. donax* crop has been seldom mentioned in the literature. Several authors have reported the weeding in the establishment year (Bosco et al., 2016). In a 6 year field experiment, Angelini et al. (2009; Angelini et al., 2009 reported that plots were kept weed-free by hoeing, but they did not

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clarify if weeding was made every year or only in the first year. Cosentino et al. (2006) reported manual weeding in a 2-year experiment but did not specify the frequency of that practice. Erickson et al. (2012) performed weeding as it was needed, during the experiment. In contrast, Nassi o Di Nasso et al. (2013b) stated that weeding was not necessary at any point of the field experiment. However, other authors did not mention if this practice was performed in the field experiments (Amaducci and Perego, 2015; Borin et al., 2013).

Several reports on the cultivation of *A. donax* showed that weeds could be a matter of concern in the establishment year. Zegada-Lizarazu et al. (2010) reported that during the establishment period of *A. donax* proper control of weeds was recommended, regardless of the plant propagation method. However, it has been stated that the huge canopy of giant reed suppresses any weed growth and that, even during the establishment year, no herbicide application was needed if rhizomes were used as planting material. Corno et al. (2014) reported that, if weeds were dominant in the period of crop establishment, herbicide treatment would be necessary; however, the strong development of *A. donax* during the second year suppressed weeds. Weed control in the establishment year was also recommended by Ge et al. (2016). The influence of the time of weeding on the yield of *A.donax* has not been studied so far.

As it is well known, the presence of weeds and competition with the crop may lead to a significant reduction in the crop yield. Thus, the importance of weed management in Europe is demonstrated by the amount of herbicides used in the European Union (EU). According to Muthmann and Nadin (2007), the use of herbicides in EU-25 amounted to 83,934 tons of active ingredient (a.i.) in 2003 representing 38.2% of all plant protection products (PPP). In terms of European countries, four accounted for 63% of the total consumption of herbicides in the European Union in 2003: France (26%), Germany (15%), Spain (11%) and the United Kingdom. In Spain, the share of herbicides increased from 28.7% in 1995–39.3% in 2010. In monetary terms, the consumption of herbicides amounted to 259.6 10^6 € in Spain in 2010 and increased up to 343.8 10^6 € in 2014, which made 36% of all PPP expenses (MAGRAMA, 2016).

Concerning the *A. donax* crop, it should be mentioned that some economic studies authors considered the weeding costs of this crop. Panoutsou (2007) assumed 130 € ha^{-1} for herbiciding in the first year, which represented 4.6% of the establishment costs. Soldatos (2015) indicated that the cost for herbiciding *A. donax* was 16.5–22.0 € ha^{-1} and that the annual crop cost was 786–1247 € ha^{-1}, which means that herbiciding builds up to 2.1–1.8% from the total annual cost of the crop. In contrast, Bosco et al. (2016) assumed that weeding was never necessary, supported by Nassi o Di Nasso et al. (2013a). Given the lack of agreement in the above mentioned data and from the literature review on the *A. donax* crop, it seems that the weeding of this crop should be studied further.

Therefore, the aim of this work was to assess the effect of weed competition on biomass yield of the *A. donax* crop. In order to achieve this, a field experiment involving three different treatments was conducted in irrigated conditions in central Spain: no weed removal, weeding in May and weeding in June. The objectives of the field experiment were: to evaluate weed diversity in the *A. donax* crop; to determine the effect of weeds on *A. donax* plant traits; to assess the yield reduction in the establishment year and in the first maturity year; and to provide recommendations about the time of weeding.

2. Material and methods

2.1. Study area

The experiment was carried out at 'El Encin', an experimental farm of the Madrid Institute for Rural, Agrarian and Food Research and Development (603 m a.s.l., 40°31′26" N, 3°17′27" W) located in Spain Central Plateau.

The region climate is Xeric Mediterranean, with cold winters and hot and dry summers. Annual mean temperature (tm) and mean precipitation (pp) are 13.4 °C and 429.7 mm, respectively. Temperatures may vary from 0 °C (January mean minimum temperature) to 32.3 °C (July mean maximum temperature); however, extreme values of −17.2 °C (absolute minimum temperature recorded for February) and 42 °C (absolute maximum temperature, August) are reported for the historical series of 1997–2000.

2.2. Field experiment

The field experiment was performed from October 2013 to February 2016, including the establishment of the *A. donax* crop and two annual harvests (February 2015 and February 2016) of the above ground biomass. The field size for this work was 1005 m^2 of flat arable land (40°31′12" N, 3°18′13" W), which was left fallow in the 2012/13 season.

Soil preparation was made in September 2013 and consisted of subsoiling at approximately 40 cm depth followed by tilling using a rototiller. Afterwards, it was randomly sampled at 30–40 cm depth for: pH and electrical conductivity (EC) in 1:2.5 soil to water extract, nitrogen (Kjeldahl N, %), assimilable phosphorus (Olsen, ppm), calcium, magnesium, sodium and potassium extractable in NH_4OAc 1N (pH = 7) and texture (% sand, silt and clay, Bouyoucos hydrometer method), following official methods of Spain (MAPA, 1994). Soil tests showed that soil properties were homogenous (< 25% coefficient of variation) across the experimental field. The soil was basic but not saline; it contained low N, medium P, medium to high K content and high Ca and Mg; soil texture was categorized as loam-clay (Table 1).

Planting was manually carried out on 11th October 2013 using micro-propagated plantlets from a single clone. Plants were spaced in a density of 1.3 plants m^{-2} (1 × 0.75 m). Also, a drip irrigation system was installed which involved one drip line per row, emitters every 33 cm drip line and 2.2 L/h water flow per emitter. Immediately after planting, plants were watered to ensure crop establishment. Following Cosentino et al. (2014), the dressing fertilization was 60 kg N ha^{-1} $year^{-1}$.

The weeding experiment started in spring 2014. The treatments studied were: T0 = control (no weed removal), T1 = weeding in May and T2 = weeding in June. In the crop, treatments were assigned at random to 15 × 15 m (225 m^2) plots; then, four elementary plots of 9.75 m^2 (border plants not included) were signposted to identify 4 replications per treatment (same elementary plots every year). Weeding was manually performed throughout T1 and T2 plots by weed pulling in order to prevent herbicide damages to the crop. Non-limiting water conditions were equally maintained in all treatments during the growing cycle by drip irrigation.

2.3. Weed assessment

An in-field weed survey was conducted at the end of each growing

Table 1
Soil characteristics.

	Mean	cv (%)
pH	8.39	0.8
E.C. (dS m^{-1})	0.31	21.4
N (%)	0.06	24.0
P (mg kg^{-1})	18	12.0
Ca (mg kg^{-1})	3129	1.6
Mg (mg kg^{-1})	373	17.3
Na (mg kg^{-1})	52	6.4
K (mg kg^{-1})	247	12.1
Clay (%)	23.5	18.7
Silt (%)	28.1	18.3
Sand (%)	48.4	6.5