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Research paper

Effect of water regime change in a mature *Arundo donax* crop under a Xeric Mediterranean climate

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ABSTRACT

In South Mediterranean conditions, during periods of severe drought mandatory watering restrictions can be established, such as the prohibition to irrigate crops. There is a need for growers of perennial crops such as *A. donax* to have data on crop response to dry conditions in order to decide on whether to keep or remove the crop. In this work, a four-year-old crop of nine *A. donax* ecotypes grown under optimal irrigation conditions was subjected to dry conditions for two years in a Xeric Mediterranean environment. Ecotypes performance in the two water conditions was assessed in order to provide data for growers to support their decision. Significant differences were found between ecotypes and water regimes for yield parameters. The interaction of water regime-ecotype was also significant, showing that the effect of the water regime change depended on the ecotype. The relative yield reduction of the mature crop ranged from 53% to 78%; this was as a result of the tough climate conditions in central Spain during the period of vegetative growth of *A. donax*. Over the whole experiment, an ecotype from South Greece outperformed and could be considered as a reference of the *A. donax* biomass potential in this environment. Further studies would be needed to assess the genetic distance among ecotypes, as well as to confirm the superiority of this ecotype in different environments.

1. Introduction

In the last years, perennial grasses have received much attention as a biomass source for bioenergy and bio-products, based on the grounds that they can give high yields with low production inputs in a broad range of environments [1,2]. Among the studied species, one of the most vigorous and productive is *Arundo donax* L. (commonly known as giant reed), a C3 species that shows high photosynthetic capacity and high water use [3–7]. Yields over 155 Mg ha^{-1} (dry biomass) have been reported for wild riparian giant reed stands (duration of the growth period and age of stands not specified) in the United States (US) [5,8]. Thus, giant reed can be very competitive in riparian habitats of temperate and warm areas, giving rise to closed stands that may displace native vegetation [9]. Due to that, *A. donax* has been included in inventories of invasive alien species of regions such as California (US), where it has become a riparian invader [10]. In non-riparian systems, the risk of invasion by cultivated giant reed has been considered to be generally low [11], based on the fact that it is a sterile plant and its propagation is strictly agamic [12,13]. Pros and cons of growing giant reed for biomass have been analyzed by several authors in Italy [14,15], the United States [16] and Australia [11]. Among these, there was consensus that growing nonnative plant species might imply threats to the natural environment and therefore, its potential damage would have to be assessed. In this regard, according to some authors, the risks of invasion of cultivated *A. donax* can be successfully managed by the adoption of simple precautionary measures, such as an adequate location of plantation (outside riparian areas, outside areas subject to flooding) [11] and other management practices [13].

In the Mediterranean Basin, *A. donax* has been grown for local uses since ancient times [17–21]. According to Tutin [22], this species originated from South and Central Asia and has been extensively planted in South Europe, becoming widely naturalized in ditches and nearby rivers. Studies by Hardion et al. [23] suggested that this species originated from the Middle East and was introduced in the Mediterranean Basin in the antiquity, before 1500 AD, meaning that, in botanical terms, this species is an archaeophyte.

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The cultivation of *A. donax* for biomass has been extensively studied in Europe since the 1990's [24]. Rather than a threat, giant reed appears as an opportunity for the supply of lignocellulosic biomass in South Europe [2,25]. Yields of cultivated *A. donax* vary widely according to crop age, management, environmental conditions and type of soils [26]. However, the most important factor for high biomass yield is meeting the full crop water demand, which can be very high in warm climates. Thus, the average crop evapotranspiration (*ETc*) of cultivated giant reed was estimated at 7.4 mm d^{-1} in Central Italy for the main growing period (from June to September). In addition, the cumulative crop evapotranspiration was 1082 mm y^{-1} [27], in agreement with [28], who reported that the crop water use was 1089 and 835 mm y^{-1} (3-y average) in Greece and Sicily, respectively, for the restitution of 100% maximum evapotranspiration (*ETm*). In riparian environments, stand-based transpiration of mature stands with high leaf area in Southern California was estimated as high as 40 mm d^{-1} [5]; on an annual basis, 1700 mm y^{-1} were estimated for those environments [6].

In most of the Mediterranean region, where low rainfall and high evaporation are recorded during the period of vegetative growth, the *A. donax* crop should be irrigated to ensure crop establishment [29] as well as for optimal yield [24,25]. Nevertheless, it should be noted that some authors reported rainfed field experiments in Italy and achieved good yields. For example, in the Campania region (40^0 60′ N, 14^0 21′ E, 21 m.a.s.l., 1264 mm y^{-1} rainfall, a volcanic soil suitable for intensive horticultural crop production), yields reached 35 Mg ha^{-1} (dry biomass) [30], and in Pisa (43^0 40′ N, 10^0 19′ E, 2 m.a.s.l., 857 mm y^{-1}, a Xerofluvent soil with a superficial water table), yields attained 37.7 Mg ha^{-1} [31]. Other studies mentioned rescue irrigations [32]. On the other end of the water supply scale, the cultivation of *A. donax* under high water input yielded 85–98 Mg ha^{-1} in North Italy [33].

The lifetime of the *A. donax* crop has not been determined yet, but there is empiric evidence that the crop can produce significant amount of biomass in North Italy for at least 16 years [34]. Some authors have assumed that the production cycle of the crop could last 20 years [35]. Mid- and long-term studies have shown that the yields of the *A. donax* crop varied from year to year. These studies have also shown that the biomass production was low in the first year and thereafter increased rapidly from the young to the mature crop. Angelini et al. [31] identified three growth phases: an increasing phase from the first to the third year, a stationary phase from the fourth to the eighth year, and a decreasing phase from the ninth to the twelfth year; such yield pattern was confirmed by Impagliazzo et al. [30]. Due to low yields of the young crop and high establishment costs [35,36], profits should not be expected in the first year; i.e. the economic feasibility of the *A. donax* crop is determined by the performance of the mature crop, which in turn, depends on the water conditions -among other production factors-. Hence, a key factor for the adoption of the *A. donax* crop for a farmer in the Mediterranean region is the availability of water throughout the production cycle of the crop.

Mediterranean countries have the largest share of irrigable and irrigated areas in Europe. The share of irrigable agricultural area used in Greece, Malta, Cyprus, Italy and Spain was 44.9%, 38.6%, 34.9%, 33.9% and 31.1%, respectively. The largest irrigable areas, in absolute terms, and the highest volume of water used for irrigation were recorded for Spain (67 517 km^2, 16.7 $km^3\,y^{-1}$) and Italy (40 045 km^2, 11.6 $km^3\,y^{-1}$), in 2013 [37]. In accordance with the Water Framework Directive of the European Union [38], water regulation in agriculture should be made at the river basin level in each member state. In some river basin districts of Spain [39], water provisions are specifically allocated to existing crops while other districts set water provisions per type of irrigation system [40]. During periods of severe drought, mandatory watering restrictions can be established, such as the use of irrigation only allowed on certain days or reduction in irrigation provisions. Competent authorities can even prohibit irrigation to crops in order to ensure water supply for the population. Such a case would lead to uncertainties with regards to the performance of a mature *A. donax* crop and its continuity in dry conditions. An estimate of the biomass yield in such conditions would be needed in order to decide on whether to keep or remove the crop.

This article reports a four-year case study of water regime change in a mature plantation of *A. donax*, which involved nine ecotypes of different provenance grown in a Xeric Mediterranean environment. To the best of our knowledge, field experimental studies of the effect of the water regime change on mature clones of *A. donax* have not been undertaken so far by other authors. In order to provide decision support data for *A. donax* growers, the specific objectives of this work were: i) to compare the performance of the ecotypes in both irrigated and unirrigated conditions; and ii) to determine the relative yield reduction caused by the water regime change.

2. Material and methods

2.1. Crop culture

The field experiment was carried out at the experimental farm 'El Encín' of the Community of Madrid (Spain) (40^0 31′ 12″ N, 3^0 18′ 13″ W, 603 m a.s.l.) in a Calcic Haploxeralf soil with sandy clay loam texture, 10YR 5/4 Munsell color. The climate in that location was described as Xeric Mediterranean, with 430 mm y^{-1} mean rainfall and 13.4 °C annual mean temperature, and extreme temperatures of −17.2 °C (absolute minimum temperature, February) and 42.0 °C (absolute maximum temperature, August) (1957–2000 climate data) [41].

The field trial was designed as a demonstrative plantation *of A. donax*, in fulfillment of the objectives of the Singular Strategic Project of Spain PSE-On Cultivos [42]. Soil chemical characteristics were the following: pH (1:2.5 water), 8.0 ± 0.1; electrical conductivity (1:5 water), (0.195 ± 0.036) dS m^{-1}; organic matter, (0.97 ± 0.05) %; nitrogen, (0.08 ± 0.00) %; phosphorus (Olsen), (12 ± 3) ppm P; extractable potassium, (248 ± 22) ppm K; calcium carbonate, (6.4 ± 3.5) %. Soil bed preparation was undertaken by a pass with a subsoiler and a rotary tiller. Pre-plant fertilizer was applied at the rate of 75:75:75 N-P-K kg ha^{-1} before the rotary tiller pass. Immediately before planting, herbicide treatment (linuron) was applied for weed control.

Nine ecotypes of *A. donax* (i.e., nine geographical varieties or clones) were established from rhizomes in adjacent plots of equal size (500 m^2 per plot in this study). Planting was made by hand in May 2008, using a spacing of 1.6 m between rows and 1 m between planting points, which made a theoretical plant density of 6250 plants per hectare. All rhizomes came from a previous field experiment conducted at the College of Agricultural Engineering of Madrid (Spain), in the framework of the European Project 'Arundo Network' [43]. The origin of the ecotypes, the identification code used in this work and the institution that supplied each geographical variety (partner of the EU Arundo Network Project [43]) are given in Table 1.

The crop was managed according to a perennial cultivation system with annual harvest of the above-ground biomass in wintertime [24]. Mechanical weeding was performed in the establishment year (three passes with a row cultivator) and the following two years (one pass). Nitrogen fertilization (60 kg ha^{-1}) was applied only in the second and third year, in fertigation. No crop diseases were detected during the experiment.

During the first four years (2008–2012), non-limiting water conditions were maintained all throughout the growing season by frequent drip irrigation (May–September). Due to interruption of water supply, the water regime was changed to rainfed for two years. In order to assess the effect of the water regime change on the mature crop of *A. donax*, the two-year performance of the ecotypes under non-limiting water conditions (NLC, seasons 2010/11 and 2011/12) and rain-fed conditions (RF, 2012/13 and 2013/14) was studied.