ENERGY AND COMPOSITIONAL CHARACTERISTICS OF GIANT REED GROWN UNDER DIFFERENT LEVELS OF WATER DEFICIT

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ABSTRACT: Concerns about land and water use have led to research on perennial grasses as energy crops for marginal lands, including abandoned lands, low fertility soils and water-deficit areas. The potential of this type of crops should be assessed not only in terms of yield but also in terms of quality of the crop produce. The aim of this work was to investigate if water-deficit conditions affect the energy and compositional characteristics of giant reed when grown under a continental-Mediterranean climate. A two-year field experiment was designed with two sources of variation: water-deficit level (three levels or treatments) and biomass fraction (leaves, stalks), and thirteen variables (biomass properties). It was found that the differences between the studied water-deficit treatments were small for most variables; on the contrary, the differences between the properties of the leaf fraction and the stalk biomass were much higher and often statistically significant. Therefore, the biomass partitioning into leaves and stalks was revealed as the main factor influencing the quality of giant reed biomass.

Keywords: Arundo donax, energy crops, biomass, chemical composition, water deficit.

1 INTRODUCTION

Giant reed (Arundo donax L), a rhizomatous grass originated from the circum-Mediterranean-Asian area, has been studied for biomass production [1-6] and bio-based materials [7-9] in the Mediterranean region. Literature data have shown that yields are site-dependent and that a major yield factor is the water availability [5]. Concerns about land use change and water use have led to research on perennial grasses as energy crops for marginal lands, including abandoned lands, low fertility soils and water-deficit areas [10-11]. So, the potential of this type of crops grown in marginal lands should be assessed in terms of yield and quality of the crop produce.

Properties of giant reed biomass as a solid biofuel have been assessed in relation to some crop management practices and other variables, like fertilization, soil water availability [5], harvesting date [12], poor-quality water [13], clone variety [14] and others. Field experiments have been usually carried out in fertile soils. Little is known about the quality of biomass when giant reed is grown in conditions of marginal soils and water deficit.

The hypothesis underlying this work was that limiting soil and water conditions may lead to variation in biomass properties. Hence, a field experiment was designed to study the effect of three water-deficit regimes on the energy and compositional characteristics of giant reed grown under a continental-Mediterranean climate. This study was part of the research conducted for the European project OPTIMA (www.optima.eu), which overall objective was to explore the potentialities of perennial grasses for biomass production in marginal lands.

2 MATERIAL AND METHODS

2.1 Location

The field experiment was carried out at the Experimental Farm of the College of Agricultural Engineering of the Technical University of Madrid, Spain ("Universidad Politécnica de Madrid") (UPM), at latitude 40°26’36" N, longitude 3°44’18" W, altitude 650 m a.s.l. (Figure 1). The climate is continental-Mediterranean, characterized by high temperatures and very low precipitation in summer (dry period) and modest winter lows. Historical means (1981-2010) at the meteorological station of Retiro-Madrid (40°24’43"N, 3°40’41"W, 667 m a.s.l.) are the following: annual rainfall, 421 mm; mean monthly temperature, 15.0°C; maximum value of the average daily maximum temperature, 32.1°C (July); minimum value of the average daily minimum temperature 2.7°C (January); duration of the dry period, four months (June to September) [15].

Figure 1: Location of the experimental crop.

2.2 Crop establishment

The crop was established on 5 October 2010 from pot-grown plants, using a frame of 1x1 m. The size of the field was 1188 m² (36 x 33 m) and included 1,054 plants in all. Plant material came from an only clone that was reproduced by stalk cuttings (1 stalk cutting per pot).
Prior to planting, a careful soil preparation was carried out by means of one pass of plough followed by another pass of rotary tiller. A drip irrigation system was established using one drip line per row, emitters every 30 cm and 4.4 L/h water flow per emitter. Just after planting, the crop was watered for 4 h in order to assure plant establishment. Treatments of water-deficit irrigation started in spring 2011 (see section 2.4).

2.3 Crop conditions

In order to describe the soil characteristics, the topsoil layer (0-35 cm depth) was randomly sampled in four spots of the field. Then, the soil samples were taken to laboratory to be air-dried in trays. They were sieved and the fine fraction (<2 mm) of each sample was kept into a zip-lock plastic bag, duly identified until analysis. Soil texture, pH, EC and the content in organic matter, phosphorus and potassium were determined according to official methods [16]. Total nitrogen and total carbon were determined by elemental analysis.

Climate conditions throughout the experiment were followed up by compiling the daily temperatures, rainfall and evaporation (class A evaporation pan) recorded at the meteorological station of Madrid-Retiro (latitude 40° 24’ 43” N, longitude 3º40’4” W, altitude 667 m a.s.l.). Data were kindly supplied by the Meteorological Agency of Spain (AEMET).

2.4 Experimental design

The experimental design involved three treatments: T0 = rainfed (control), Tr-I= water-deficit level I, Tr-II = water-deficit level II, two harvests (February 2012 and February 2013) and thirteen biomass properties (quantitative variables) (see section 2.5). The target water-deficit levels were: rainfed, 450 and 600 mm per year in all (rainfall+ irrigation, if any).

In contrast to other studies, our water treatments aimed at the simulation of the rainfall distribution pattern in a continental-Mediterranean climate. One treatment (control) was maintained without irrigation (=rainfed); it represented the highest water stress for the crop since precipitation in Madrid is low during the growth cycle of giant reed. The other two treatments were irrigated to achieve two different levels of water deficit.

In order to schedule irrigations, a study of historical weather observations recorded at the same meteorological station (AEMET Station of Madrid-Retiro) was carried out. The aim was that the target hydric regimes should follow the distribution of the rainfall occurred in Madrid when the annual precipitation was in the range of 400-500 mm (level 1: 450 mm target) or in the range of 550-650 mm (level 2: 600 mm target). The historical weather series (1920-2012) showed that there were 28 years with precipitations within level 1 and 11 years within level 2.

The average rainfall distribution intended for the target water regimes of 450 and 600 mm are shown in Figure 2; the average rainfall distribution of the driest years in Madrid (rainfall in the range of 300-400 mm/year) is also shown. During the growth period of giant reed, the actual monthly precipitation was compared to the monthly precipitation of each target regime; if the former was lower, the amount of rainfall received by the crop was complemented up to the amount fixed for that month, by means of drip irrigation.

Figure 2: Target water regimes.

2.5. Biomass characterization

The aboveground biomass production in each treatment was collected and was sampled for this study in February 2012 and February 2013 (harvest time). Whole canes (stalks + leaves) were evaluated for their weight and biomass partitioning into leaves and stalks. Each biomass fraction was separately oven-dried at 105°C until constant weight. The dry samples were ground in a Retsch rotor mill; then, they were placed into zip-lock plastic bag and stored at room temperature until analysis. Further analytical milling (<1 mm) was performed as indicated by specific norms.

Biomass characterization comprised the following determinations:

- Ultimate analysis: Total Carbon (C), hydrogen (H) and nitrogen (N), by using a Thermo Scientific elemental analyser.
- Potassium content (K): by flame emission photometry. Biomass samples were dry-ashed in an electric muffle furnace at 450°C until a whitish ash was obtained (>4h). Then the ash was cooled, dissolved in HCl 1N, diluted and filtered prior to measurements.
- Chlorine content (Cl), by Volhard’s method (ASTM D-2361-66).
- Proximate analysis: Volatile Matter (Vol) (UNE-CEN 15148), Ash (UNE-CEN/TS-14775) and fixed carbon (Cfix) (=100- %Vol-%Ash).
- Calorific value: Higher Heating Value (HHV) and Lower Heating Value (LHV), by using a Leco AC 3500 calorimeter (UNE-EN 14918).
- Fibres: Neutral Detergent Fibre (NDF), Acid Detergent Fiber (ADF) and Acid Lignin (AL) according to Van Soest’s method [17]. A FiberTec apparatus was used in this study.

2.6 Statistical analysis

Mean values were subjected to two-way analysis of variance (ANOVA) where the first group variable was the biomass fraction (stalks or leaves) and the second one the water-deficit treatment. Values at p<0.05 were considered significant. Statgraphics Centurion XVI (ver. 16.1.15) software was used for that purpose.
3 RESULTS AND DISCUSSION

3.1 Crop conditions

Soil properties are shown in Table I. According to the results, the soil was basic, with low organic matter content, low content in total carbon and nitrogen, medium content in P and K, and sandy texture. Therefore, the soil was categorized as a very low fertility soil.

Table I: Soil properties

<table>
<thead>
<tr>
<th>Soil property</th>
<th>Mean (%)</th>
<th>cv (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>8.45</td>
<td>0.8</td>
</tr>
<tr>
<td>E.C. (dS/m)</td>
<td>0.43</td>
<td>1.3</td>
</tr>
<tr>
<td>Organic matter (%)</td>
<td>1.3</td>
<td>11.5</td>
</tr>
<tr>
<td>Ni (%)</td>
<td>0.1</td>
<td>9.8</td>
</tr>
<tr>
<td>Cl (%)</td>
<td>1.4</td>
<td>4.2</td>
</tr>
<tr>
<td>P (ppm)</td>
<td>28</td>
<td>1.1</td>
</tr>
<tr>
<td>K (ppm)</td>
<td>331</td>
<td>0.8</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>4.3</td>
<td>47.2</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>6.3</td>
<td>80.9</td>
</tr>
<tr>
<td>Sand (%)</td>
<td>89.2</td>
<td>3.4</td>
</tr>
</tbody>
</table>

Monthly temperatures and precipitation are depicted in Figure 3. The rainfall records showed that the annual crop cycles under study were drier than the average year. In the first season (Feb/2011-Jan/2012), the accumulated precipitation was 346 mm, the annual mean temperature, 16.1°C, the absolute maximum temperature, 38.3°C; and the absolute minimum temperature, -1.0°C; in the second season (Feb/2012-Jan/2013), 350 mm accumulated rainfall, 14.7 °C annual mean temperature, 40.6 °C absolute maximum temperature and -3.6 absolute minimum temperature. The dry period lasted five months in the first season (June-October) whereas it was one-month shorter in the second one (June-September).

![Figure 3: Monthly temperature and precipitation in the period under study. The arrows indicate the start of the annual crop cycle. In X-axis: 2=February; 12=December.](image_url)

3.2 Biomass characterization

Mean biomass partitioning into leaves and stalks (two-year experiment) in our experiment was 21.39 and 78.61%, respectively. From these values and the mean values of the studied properties for leaves and stalks, the properties of the aboveground biomass of giant reed, grown in water-deficit conditions were calculated; on average, they were the following: 1.7% N, 44.3% C, 6.5% H, 0.8% K, 0.22% Cl, 18.97 MJ/kg HHV, 17.63 MJ/kg LHV, 74.1% Vol, 17.8% Cfix, 8.1% ash, 69.5% NDF, 38.2% ADF, 6.4% ADL. Dahl & Obernberger [18] reported similar values for K (0.65%), Cl (0.22%) and ash (6.1%), but lower for N (0.71%). Chlorine, potassium and ash concentrations exceeded the guiding values for solid biofuels, set at 0.6% N and 0.1% Cl in the biofuel, and 7% K in the ash [19]. High levels of K can be attributed to mechanisms of drought tolerance. In the words of Zorb et al. ‘K plays a prominent role in crop resistance to drought, salinity, high light, or cold as well as resistance to pests and pathogens’ [20].

The multivariate analysis conducted for the results of a same biomass fraction (leaf or stalk biomass fraction) showed that the intra-fraction variability was low for most of the studied variables. Regarding the stalk biomass, the highest coefficient of variation (21.8%) was obtained for Cl content, followed by ash (cv=10.1%) and N (cv=10.1%). Concerning the leaves, higher variability was found; Cl was again the element with the highest variation (cv=42.1%), followed by N (cv=24.3%), ADL (cv=20.4%) and ash (cv=16.5%). Chlorine, nitrogen and ash content are commonly considered as key indicators of biomass quality; the lower their content, the better the biomass quality. In this regard, the mean values obtained for the leaf biomass: 0.18% Cl, 1.83% N and 8.9% were a clear indicator that the quality of giant reed leaves for solid biomass was much lower as compared to the stalks. This supports the choice of harvesting in late winter, because giant reed plants naturally lose part of its leaves during wintertime due to senescence and as an effect of harsh weather conditions.

3.3 Effect of the water-deficit regime

The effect of the water deficit regime was studied by means of two-way ANOVA (Tables II, III and IV). Results revealed that the differences between water-deficit treatments were significant for few properties; more specifically, for the contents in volatile matter (Vol), neutral detergent fibre (NDF) and acid detergent lignin (ADL).

Results obtained for Vol, NDF and ADL are shown in Figure 4. Despite the significance, no trend could be noticed; for this variable, the difference between Tr-I and Tr-II but not between rainfed and Tr-II for Vol or ADL. On the contrary, a trend towards less NDF content as water supply increased was noticed; for this variable, the difference between rainfed and Tr-II was significant.

Table II: Two-way ANOVA of the results of N, C, H, K and Cl contents for the factors: biomass fraction (leaves and stalks) and water-deficit regime (rainfed, Tr-I and Tr-II); ns= not significant (p>0.05); ***, p<0.001.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>N</th>
<th>C</th>
<th>H</th>
<th>K</th>
<th>Cl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fraction</td>
<td>***</td>
<td>ns</td>
<td>ns</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>Regime</td>
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<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>***</td>
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</tbody>
</table>
Table III: Two-way ANOVA of the results of calorific values and proximate analysis for the factors: biomass fraction (leaves and stalks) and water-deficit regime (rainfed, Tr-I and Tr-II). HHV, higher heating value (moisture free); LHV, lower heating value (moisture free); Vol, Volatile matter; Cfix, Fixed carbon; ns = not significant (p>0.05); ***, **, *, significant at p<0.001, p<0.01, p<0.05, respectively.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>HHV</th>
<th>LHV</th>
<th>Vol</th>
<th>Cfix</th>
<th>Ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fraction</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>Regime</td>
<td>ns</td>
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<tr>
<td>Interaction</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
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</tbody>
</table>

Table IV: Two-way ANOVA of the results of fibers for the factors: biomass fraction (leaves and stalks) and water-deficit regime (rainfed, Tr-I and Tr-II). NDF, neutral detergent fiber; ADF, acid detergent fiber; ADL, acid detergent lignin; ns = not significant (p>0.05); ***, **, *, significant at p<0.001, p<0.01, p<0.05, respectively.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>NDF</th>
<th>ADF</th>
<th>ADL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fraction</td>
<td>***</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>Regime</td>
<td>*</td>
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<tr>
<td>Interaction</td>
<td>ns</td>
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</tbody>
</table>

3.4 Effect of the biomass fraction

The factor: biomass fraction (leaves or stalks) resulted in significant differences for eight out of thirteen biomass properties. Thus, the leaf fraction significantly contained more N (1.86% vs 0.89%) and ash (8.95% vs 5.18%) than the stalks, in line with other authors. According to Monti et al. [21] the leaves of giant reed contain more N (1.57 vs 0.52%), ash (4-11.3% vs 2.9-3.9%) and Cl (0.70-0.56%) than the stalks. Amaducci & Perego [14] report from 5.3 to 8.1% ash content for the stalks of a collection of 24 clones. In our experiment the stalk fraction was significantly richer in Cl (0.35% vs 0.18%) than the leaf fraction, and the same happened with the K content (1.10% vs 0.72%).

On the other hand, the stalks also contained more Cfix, NDF, ADF and ADL than the leaves, showing that they have better properties for solid biofuel or fibre than the leaves. On average, we found 30.1% hemicellulose (NFD-ADF), 35.3% cellulose (ADF-ADL) and 7.5% acid lignin in the stalks and 31.6% hemicellulose, 30.8% cellulose and 3.6% lignin in the leaves. In the clonal experiment by Amaducci & Perego [14], values in the range of 25.1-29.2% hemicellulose, 43.4% cellulose and 6.9-10.6% lignin were reported for the stalks of a collection of 24 clones. Using different methodology, Pascoal Neto et al [22] found similar values of holocellulose (≈cellulose + hemicellulose) in the foliage and canes of giant reed (>60%) but they found differences between foliage and stalk for the lignin content. They reported 16.8% and 16.4-22.0% Klason lignin, respectively. Likewise, the range of values reported by Ververis et al [7] was similar, 30.8%-37.7% α-celulosa and 16.0-20.5% lignin for the stalks.

4 CONCLUSIONS

The effect of three water-deficit regimes on the energy and compositional properties of giant reed was studied in a two-year field experiment conducted in low-fertility soil conditions under a continental-Mediterranean climate. In our experimental conditions, statistical significance between water deficit treatments was found only for the properties volatile matter, neutral detergent fiber (NDF) and acid lignin (ADL), as a function of the water-deficit regime.
5 REFERENCES


6 ACKNOWLEDGEMENTS

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