Industrial Crops and Products 75 (2015) 93–102

Contents lists available at ScienceDirect

Industrial Crops and Products

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

Saccharum spontaneum L. ssp. *aegyptiacum* (Willd.) Hack. a potential perennial grass for biomass production in marginal land in semi-arid Mediterranean environment

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ARTICLE INFO

Article history:
Received 12 January 2015
Received in revised form 16 April 2015
Accepted 20 April 2015
Available online 30 April 2015

Keywords:
Saccharum
Mediterranean environment
Marginal land
Perennial grass
Biomass yield
Water use efficiency
Crop physiology
Biomass quality

ABSTRACT

Research is needed to look for plants or lines that can thrive on soils affected by water deficit or other constraints. The present work investigated the potentiality of *Saccharum spontaneum* L. spp. *aegyptiacum* (Willd.) Hack., a lignocellulosic, perennial, rhizomatous, no-food crop in semi-arid Mediterranean area. A 3-year field trial was carried out with the aim to evaluate its physiology, biomass yield, water use efficiency, and biomass quality under different soil water availability. During 2011/2012, 2012/2013, and 2013/2014 growing seasons (hereinafter referred as 2011, 2012, and 2013, respectively), three levels of maximum evapotranspiration restitution (ETm) were compared: I_{100} (100% ETm restitution), I_{50} (50% ETm restitution), and I_0 (rainfed condition).

Net photosynthesis, stomatal conductance, and transpiration rate were strictly related to the available soil water content (ASWC), with maximum gas exchange at field capacity. However, gas exchange between plants and atmosphere was also measured when ASWC was close to wilting point.

Biomass dry matter (DM) yield and main morpho-biometric traits (e.g., stem height and basal stem diameter) were significantly affected by ASWC. A non-linear model showed that maximum DM yield, 37.86 Mg ha^{-1}, can be achieved when 1150 mm of water were used by the crop. Water use efficiency (WUE) was always highest in rainfed condition (I_0), however, only in 2013 I_0 was significantly higher than I_{50} and I_{100} (5.89 g L^{-1} vs 4.26 and 3.33 g L^{-1}). Within the variables employed, a linear model showed that WUE was negatively related to crop water use (CWU).

The fiber content was not affected by the irrigation treatments. In the average, hemicellulose, cellulose, and lignin accounted for 23.9 (% w/w), 35.0 (% w/w), and 19.9 (% w/w), respectively. On the other hand, moisture and ash content, bulk density, low heating value, and ash melting point resulted significantly affected by the treatment.

Present results suggested that *S. spontaneum* spp. *aegyptiacum* possesses a range of agronomically desirable traits of biomass crop: C4 plant, high biomass yield, active assimilation rates during drought–stress periods, able to use water efficiently, and satisfactory biomass quality.

1. Introduction

Serious concerns have been expressed over the cultivation of energy crops in arable lands. The main reason would be the competition for land with food crops, reducing the land area of cultivation and causing land use change (Cosentino et al., 2014a). It is repeatedly debating to cultivate energy crops in marginal lands, for example, in land that is not currently used with other crops. It is worth to note, however, that marginal land has not an unique definition and might change over region and time (Lewis and Kelly, 2014).

From an agronomic point of view marginal or unused lands in Mediterranean area are those mainly affected by severe drought, slope, and salinity conditions. It is expected that perennial rhizomatous grasses might have greater tolerance when grown on less productive soils, since they require limited soil management and lower demand for nutrient input than annual crops (Zegada-Lizarazu et al., 2010; Fernando et al., 2010; Rettenmaier et al., 2010). Amongst perennial grasses, C_4 photosynthetic pathway are able to use abiotic resources, mainly water, more efficiently than C_3 plants (Long, 1999).

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http://dx.doi.org/10.1016/j.indcrop.2015.04.043
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The Mediterranean area might foster growth of perennial C4 grasses, thanks to active temperatures (>10 °C), incoming solar radiation, and length of the growing season; however, low rainfall, drought, and lack of water for irrigation in spring–summer are main limiting factors for their fully exploitation. Indeed, species as the C_4 *Miscanthus* × *giganteus* or the C_3 *Arundo donax* might reduce considerably their biomass yield due to the high evaporative demand during the long dry and hot summer season in rainfed condition in this environment (Cosentino et al., 2007; 2014b).

Therefore, more research is needed to look for plants that still conserve those genetic traits associated with growth under drought stress and able to protect plants against severe water stress. Up to now, much emphasis has been placed to evaluate the potential yield of bioenergy crops, while biomass quality has not received as much attention (Osowski and Fahlenkamp, 2006; Monti et al., 2008). Biomass quality can drastically lower the net energy output, bioconversion efficiency, and lifetime of the equipment in both thermochemical and biochemical conversion of biomass to heat, energy, and biofuel due to inadequate moisture content, stem to leaf ratio, ash and mineral content, ash melting point, cellulose, hemicelluloses, lignin, and extractives, among others. Understanding the variation in chemical composition of a biomass crop and the interaction with the environment and crop management practices is of utmost importance for developing effective biomass energy chains (Monti et al., 2008).

In the frame of the European OPTIMA project (G.A. 289642), perennial grasses at their wild or near-wild state and well-adapted to Mediterranean semi-arid environment are collected from riparian areas and tested in field conditions in order to evaluate their suitability as energy crops. Out of several perennial grasses investigated, a plant from *Saccharum* genus looks the promising one.

Saccharum genus has approximately 40 species, mostly native to South-Eastern Asia (Clayton and Renvoize, 1986). *Saccharum* is considered as the closest relative of *Miscanthus*, and these two genera frequently hybridize (Sobral et al., 1994). The species of *Miscanthus* can be distinguished by those of *Saccharum* by their tough inflorescence rachis and both spikelets of a pair being pedicellate, although the pedicels are of different lengths (Hodkinson et al., 2002).

Amongst *Saccharum* genus, *Saccharum spontaneum* L. spp. *aegyptiacum* (Willd.) Hack. (common name African fodder cane) is a perennial, herbaceous, rhizomatous grass, native from North Africa and widespread in South Mediterranean regions; it is reported as a species with high polymorphism, robust, and resistant to the physiopaties (Pignatti, 1982).

The present work investigated the potentiality of *S. spontaneum* L. spp. *aegyptiacum* (Willd.) Hack. as lignocellulosic energy crop in semi-arid Mediterranean area. A 3-year field trial was carried out with the aim to evaluate its physiology, biomass yield, water use efficiency, and biomass quality under different soil water availability.

2. Methodology

2.1. Field trial set-up

Establishment was carried out in spring 2005 at the Experimental farm of the University of Catania, Italy (10 m a.s.l., 37°25′N lat., 15°03′E long.) in a typical xerofluvent soil keeping the following hydrologic constant: field capacity (FC) at −0.03 MPa (27% dry soil weight) and wilting point (WP) at −1.5 MPa (11% dry soil weight).

Rhizomes of *S. spontaneum* L. spp. *aegyptiacum* (Willd.) Hack. were collected in riparian area of South-Eastern Sicily (Italy). Fresh rhizomes were split in pieces of approximately 100 g with 2–3 main buds and directly transplanted at a density of 1 rhizome m^{-2} in a previously prepared soil bed, which was ploughed in autumn, and then disk harrowed in early spring.

A randomized block experimental design with three replications was applied, with a single plot measuring 15 m^2 (5 × 3 m).

Before transplanting 100 kg N ha^{-1} and 100 kg P_2O_5 ha^{-1} as ammonium sulphate and supersphosfate, respectively, were supplied. Weeds were controlled manually during the year of establishment.

Following stem sprouting, plantlets were kept in well-watered condition up to the end of summer; the irrigation was suspended from the beginning of autumn in view of uniform plant density. After the first harvest and up to the sixth growing season (2010/2011), neither fertilization nor weed control and other management practices were performed. Supplemental irrigation was applied only when leaf rolling was detected, while aboveground biomass was harvested each year on winter-time.

Soil water availability was differentiated from the spring–summer 2011, seventh growing season. During 2011/2012, 2012/2013, and 2013/2014 growing seasons (hereinafter referred as 2011, 2012, and 2013, respectively), three levels of maximum evapotranspiration restitution (ETm) have been compared: I_{100} (100% ETm restitution), I_{50} (50% ETm restitution), and I_0 (rainfed condition).

Irrigation was applied from the middle of May to the end of August/middle September (depending on rainfall), namely during the period of maximum crop ET.

A drip irrigation system with micro flow dispensing device was used for plot irrigations. Water to be supplied in each irrigation was determined on the basis of the maximum available soil water content in the first 60 cm of soil, where most of the root is expected to grow, according to:

$$V = 0.66 \times (\mathrm{FC} - \mathrm{WP}) \times \Phi \times D \times 10^3$$

where V = water amount (mm); 0.66 = readily available water not limiting for evapotranspiration; FC = soil water content at field capacity (27% of dry soil weight); WP = soil water content at wilting point (11% of dry soil weight); Φ = bulk density (1.1 g cm^{-3}); and D = rooting depth where the bulk of roots is expected to develop (60 cm).

Irrigation was applied when the sum of daily evapotranspiration (ETc) corresponded to V. The daily ETc was calculated according to:

$$\mathrm{ETc} = E_0 \times K_p \times K_c$$

where ETc is the maximum daily evapotranspiration (mm); E_0 is the evaporation of class-A pan (mm); K_p is the pan coefficient, equal to 0.80 in semi-arid environment (average relative humidity 40–70%, low wind speed, and fetch 1 m). Crop coefficients (K_c) were those applied for *Miscanthus* × *giganteus* and *Arundo donax* in the same environment (Cosentino et al., 2007; 2014b). Rainfall events were subtracted in the daily calculations.

The available soil water content (ASWC) was expressed as a percentage of maximum available water according to the following formula:

$$\mathrm{ASWC} = \left[\frac{(\mathrm{WC} - \mathrm{WP})}{(\mathrm{FC} - \mathrm{WP})}\right] \times 100$$

where WC = measured soil water content as % of dry soil weight; WP and FC as above.

For each water treatment, the crop water use (CWU) was determined by means of water balance calculation along the period between plant re-growth up to the last irrigation:

$$\mathrm{CWU} = I + P + \Delta C$$

where CWU = crop water use (mm); I = water supplied by means of irrigation (mm); P = precipitation (mm); and ΔC = difference