BIOMASS AND BIOENERGY 63 (2014) 177–186

Available online at www.sciencedirect.com

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Potential of two cardoon varieties to produce biomass and oil under reduced irrigation and weed control inputs

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ARTICLE INFO

Article history:
Received 26 October 2012
Received in revised form
20 January 2014
Accepted 31 January 2014
Available online 25 February 2014

Keywords:
Artichoke thistle
Chlorophyll content index
Cynara cardunculus L. var. *altilis* DC
Quantum yield of photosystem II
Weed competition

ABSTRACT

Cardoon (*Cynara cardunculus* L.) is an important perennial energy plant, which may produce sufficient biomass under reduced inputs. A 4-years field study was conducted in northern Greece and was repeated for three years in central Greece to determine the productivity of two cardoon varieties ('Bianco Avorio' and 'C12') under different water (irrigated or non-irrigated) and weed control (weedy or weed-free) conditions. In northern Greece, the density of weeds grown with cardoon increased as years went by, but in central Greece decreased. The absence of irrigation and the presence of weeds significantly reduced cardoon dry biomass, seed and oil yields, especially in the first two years of cultivation. In both environments, irrigated with 90 mm cardoon achieved 22–42% and 35–42% greater dry biomass and seed yield, respectively, than achieved the non-irrigated crop. In weedy cardoon, the dry biomass or seed yields reductions were 33–66% or 41–64%, respectively, in central Greece and 21–95% or 8–99%, respectively, in northern Greece. In central Greece cardoon productivity increased as years went by, but in northern Greece decreased. Generally, the cv. C12 was more productive than the cv. Bianco Avorio. Conclusively, the cardoon cv. C12 could provide satisfactory dry biomass, seed and oil yields for energy use in semi-arid Mediterranean fields, without irrigation or weed control inputs, on condition that they have been successfully established the first year. However, cardoon should be irrigated and weeded in order to provide sufficient yields.

1. Introduction

Cardoon or artichoke thistle (*Cynara cardunculus* L.) is one of the most important energy crops expanding in semi-arid Mediterranean regions, as a consequence of the relatively low crop inputs, large dry biomass productivity, low moisture content and high calorific value [1–3]. The cultivated cardoon belongs to the botanical variety of *C. cardunculus* L. var. *altilis* DC [4]. Angelini et al., evaluated for 11 years the cardoon productivity, found that the mean dry biomass yield ranged from 13 to 14 t ha^{-1}, while the mean calorific value was 15 MJ kg^{-1} [1]. Cardoon can also be cultivated for seed oil yield and pharmacological or nutritional active compounds (vitamins, inulin, quercetin, rutin, myricetin, catechin, epicatechin, cynarin, silymarin, caffeic acid and gallic acid),

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0961-9534/$ – see front matter
http://dx.doi.org/10.1016/j.biombioe.2014.01.052

as well as for pulp and paper production [2,5–8]. Based on the oil characteristics, cardoon seed oil is suitable for biodiesel production and human consumption, due to its high content in unsaturated (linoleic and oleic) and secondarily in saturated (palmitic and steatic) acids [7,9,10]. Consequently, cardoon, in contrast to other energy crops like sunflower (*Helianthus annuus* L.), oilseed rape (*Brassica napus* L.) and miscanthus (Miscanthus × giganteus), can be used for different purposes, agreeing with the new aims of the EU strategies for biofuels [9,11]. According to Curt et al., the use of cardoon seeds for oil production would have the advantage of the simultaneous exploitation of the biomass for energy production [5]. In Greece, cardoon is mainly grown in Thessalia (central Greece) and Macedonia (northern Greece) regions, mainly on non-irrigated soils [12].

Cardoon is a perennial, richly branched herb which reaches up to 2.5 m in height and it produces a very deep perennial taproot [13]. Also, cardoon forms a rosette up to 2 m in diameter composed of very large leaves. Because of its morphological and physiological characteristics, cardoon has been mentioned as a very tolerant to draught and competitive to weeds crop [2,12,14–16]. In particular, Raccuia and Melilli reported that the storage of fructans in cardoon roots has been interpreted as an adaptive strategy to overcome unfavourable conditions, like the drought Mediterranean environments [16]. Fernández et al. have also characterised cardoon as drought-escape crop which has no need for weed control from the second year onwards [2]. This fact could be attributed to ground covering by the crop canopy, which interacts mainly with weed control. However, White and Holt found that cardoon seedling growth was reduced by root competition from grasses that emerged earlier, indicating the necessity of the early season weed control during cardoon establishment [15].

An increasing interest on energy plants cultivation for biomass production is highly observed in the Mediterranean region. However, farmers warrant if cardoon could provide high biomass for energy purpose with low inputs to irrigation water and weed management, because the efficient growth strategies of perennial bio-energy crops rely on a continually shifting balance between sources and sinks. This balance is generally affected by biotic (e.g. weeds) and abiotic (e.g. drought) stresses [17]. Data concerning the cardoon productivity under reduced irrigation and weed management inputs, which could contribute farmers' decision, are limited in the literature. In this work it is expected that cardoon would provide sufficient biomass yield in semi-arid Mediterranean environments under reduced inputs. Therefore, the objectives of this research were to assess the photosynthesis parameters and the water use efficiency, as well as the productivity (biomass, seed and oil yields) of two cardoon varieties grown in two different environments (northern and central Greece) under i) semi-irrigated and non-irrigated and ii) weed-free and weedy conditions.

2. Materials and methods

2.1. Experimental sites

A cardoon field experiment was established in 2007 (Exp 1) at the Technological Educational Institute Farm of Thessaloniki in northern Greece (longitude 22°44′10″ E, latitude 40°37′06″ N, altitude 0–1 m) and was repeated in 2009 (Exp 2) at the Technological Educational Institute Farm of Thessaly (Larissa) in central Greece (longitude 22°22′48″ E, latitude 39°37′25″ N, altitude 81–82 m). Field experiment in northern Greece (Exp 1) was carried out during a 4-years period (2008–2011), while in central Greece (Exp 2) during a 3-years period (2010–2012). The Exp 1 was established on a sandy loam (Typic Xeropsamment) soil with the following physicochemical characteristics: sand 644 g kg^{-1}, silt 280 g kg^{-1}, clay 76 g kg^{-1}, organic C content 5 g kg^{-1} and pH (1:2H_2O) 7.6. The Exp 2 was established on a sandy clay loam (Vertic Chromoxerent) soil with the following physicochemical characteristics: sand 509 g kg^{-1}, silt 200 g kg^{-1}, clay 291 g kg^{-1}, organic C content 6 g kg^{-1}, and pH (1:2 H_2O) 7.5. Preplant soil analysis conducted in the middle of September showed that initial nitrate content (0–30 cm soil depth) ranged from 89 to 93 and 95–107 mg kg^{-1} of soil in Exp 1 and Exp 2, respectively. The experimental area in both locations was naturally infested by winter wild oat (*Avena sterilis* spp. *ludoviciana* L.), wild mustard (*Sinapis arvensis* L.) and common field poppy (*Papaver rhoeas* L.), as confirmed by visual assessments made during the previous of both establishments growing seasons. The area of the Exp 1 was also naturally infested by ivy-leaved speedwell (*Veronica hederifolia* L.). These four weed species are of the most important winter weeds in Greece [18]. The climate in Thessaloniki (northern Greece) is characterized as typical Mediterranean with cool humid winter and warm dry summer, while in Larissa (central Greece) is characterized by a more continental climate with colder winter, hotter summers and lower precipitation throughout spring. Mean monthly temperature and rainfall data recorded near the experimental locations (over a distance of approximately 900 m) are shown in Fig. 1.

2.2. Treatments and experimental design

Two cardoon varieties ('Bianco Avorio' and 'C12', Agricon Hellas, Larissa, Greece) were seeded by hand in 75-cm rows to achieve an approximate density of 60,600 seeds ha^{-1}, which reflects the common practice in Greek cardoon fields. These cardoon varieties have recently been introduced in Greece and they represent two of the most cultivated ones. The seeding dates were November 01, 2007 (Exp 1) and November 07, 2009 (Exp 2). Two days before cardoon seeding, 50 kg N and 25 kg P ha^{-1} as diammonium thiophosphate (20-10-0) were broadcast applied and incorporated into the soil of all experimental plots. No further fertilization was applied during the experiments. In both locations, the previous crop was barley harvested in mid-June. Barley straw was baled and removed after harvest. The land was ploughed after harvest of the barley and left undisturbed during summer. In mid October of both establishments' seasons, the experimental area was cultivated with a harrow disk to prepare the soil for cardoon seeding and to incorporate the fertilisers into the soil. Chlorpyriphos (O-O-Diethyl O-3,5,6-trichloro-2-pyridinyl phosphorothioate) was applied at 2 kg ha^{-1} at cardoon planting for general insect management.

A split-split-plot arrangement of treatments was employed in a randomized complete block design with four replicates. Main plots consisted of two irrigation levels (irrigated with