Industrial Crops and Products 95 (2017) 191–201

Contents lists available at ScienceDirect

Industrial Crops and Products

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

Biomass partition and productive aptitude of wild and cultivated cardoon genotypes (*Cynara cardunculus* L.) in a marginal land of Central Italy

Ulderico Neri, Bruno Pennelli, Giampiero Simonetti, Rosa Francaviglia*

Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria, Centro di Ricerca per lo Studio delle Relazioni tra Pianta e Suolo (CREA-RPS), Via della Navicella, 2-4, 00184 Roma, Italy

ARTICLE INFO

Article history:
Received 13 June 2016
Received in revised form
14 September 2016
Accepted 21 October 2016

Keywords:
Cardoon
Genotypes
Yield
Biomass partition
Mediterranean crops

ABSTRACT

A very limited number of field studies have addressed the suitability of *Cynara cardunculus* L. genotypes to local environmental conditions in terms of productive aptitude.

Four genotypes of Cardoon, under low input conditions (reduced nitrogen fertilization and rainfed conditions) were compared in a marginal land of Central Italy during the 2012–2014 period: two cultivated (CDL07 and Gigante) and two wild cardoon genotypes (RCT10 and Tolfa). At the ripening stage of capitula, all plant components were weighed separately, yields were calculated, and biometric traits were measured. Genotypes showed different productive aptitudes and suitability to the pedo-climatic conditions of growth. The total aboveground dry biomass per plant ranged between 114.4 and 353.6 g with variable values within genotypes and years, whereas the partition of the aboveground biomass was strongly affected by genotypes only. Analysis of variance (ANOVA) showed a general prevalent influence of the genotype factor on crop yields. Capitula components were of greatest importance in cultivated cardoons, but strongly affected by the annual climatic trends. The maximum achenes yield was in 2012 with 3.2 t ha^{-1} as a mean of the cultivated cardoons, whereas the wild genotype Tolfa reached a mean production of 2.1 t ha^{-1}.

In general the wild genotype RCT10 demonstrated a poor adaptability to the conditions of the experimental site. On the other hand, wild genotype Tolfa might be incorporated into the local cropping systems as an industrial or bioenergy crop, due the low management inputs required, its adaptability to the local conditions, and the fairy good aboveground biomass and achenes production.

1. Introduction

Growing energy crops such as cardoon is a nontraditional land use option able to convert solar energy into stored biomass relatively efficiently, and leading to positive input/output energy balances for the overall system. In addition, under specific soil and climatic site conditions, bioenergy crops can be optimized since low input systems requiring limited nutrients and chemical inputs are needed (Sims et al., 2006). When combining production and sustainability, cardoon helps to reduce soil degradation due to the protection of its dense canopy against the erosion caused by the intense precipitations that occur in Mediterranean areas (Grammelis et al., 2008; Lag-Brotons et al., 2014).

Over the last few years a renewed and growing interest in the cardoon (*Cynara cardunculus* L.), an old plant with new uses in bioenergy, bioindustry and functional foods, has been observed. Cardoon is a perennial plant native to the Mediterranean Basin belonging to the Asteraceae family, and includes two botanical varieties (Gatto et al., 2013): cultivated cardoon (var. *altilis* (DC)) and the ancestor wild cardoon or wild artichoke (var. *sylvestris* (Lamk) Fiori).

The cultivated cardoon has been cultivated as a vegetable since ancient times, but the land area devoted to this crop has never been large (about 2000–3000 ha), and mainly localized in Spain, Italy, France and Greece (Ierna and Mauromicale, 2010).

The wild cardoon is a robust thistle with a characteristic rosette of large spiny leaves and branched flowering stalks. It is distributed over the west and central part of the Mediterranean basin (Portugal to west Turkey), as well as Madeira and Canary Islands; in post-Columbian time it colonized some parts of the New World and has

* Corresponding author.
E-mail address: rosa.francaviglia@crea.gov.it (R. Francaviglia).

http://dx.doi.org/10.1016/j.indcrop.2016.10.029

spread as a weed in parts of Argentina and California (Marushia and Holt, 2006).

Both cultivated and wild cardoons produce lignocellulosic biomass and oil seeds for solid biofuel and biodiesel (Portis et al., 2012; Acquadro et al., 2013), and have been recognized as promising energy crops for rainfed farmlands in Mediterranean climates under low external management energy supplies (Ierna et al., 2012). This peculiarity is supported by the excellent adaptation of *Cynara* spp. to the Mediterranean climate, owing to the positive balance between the phases of the growth and development cycle under Mediterranean climatic trends, the capacity of photosynthesizing during winter time, as well as the capacity of nutrient uptake from deep soil layers (Fernández et al., 2006). The deep root system of cardoon annually produce high below-ground biomass, and its active root pools and soil microorganisms are important to stock soil carbon and as a nutrient cycling reservoir (Mauromicale et al., 2014).

The economic analysis of cardoon in comparison with other herbaceous annual crops, demonstrated the low cultivation costs, the higher total revenues, and its suitability for the inclusion in arable cropping systems in marginal lands (Papazoglou and Rozakis, 2011; Francaviglia et al., 2016; Mehmooda et al., 2016).

In recent years, *Cynara cardunculus* L. has been considered for different industrial applications. Achenes can be utilized for oil production for human consumption, and after oil extraction, the cake could be used for animal feed. The evaluation of whole cardoon achenes for feeding ruminants has been conducted by Cajarville et al. (2000). Roots could be used for extraction of inulin (Raccuia and Melilli, 2004, 2010; Raccuia et al., 2005), a fructose polysaccharide of interest for food and not-food applications (Ritsema and Smeekens, 2003). The use of fresh biomass as forage for livestock feeding is another possible application of the crop (Fernández et al., 2006). *C. cardunculus* L. has also been used for medicinal purposes (Kraft, 1997). Leaves, rich in polyphenols, are used because of the pharmacological properties of their constituents and extracts (Clifford, 1992; Grancai et al., 1994; Valentao et al., 2002; Curt et al., 2005; Fernández et al., 2006; Pinelli et al., 2007; Ciancolini et al., 2013). Recently, there has been an increase in the use of these polyphenolic compounds also in cosmetics (Lupo, 2001; Peschel et al., 2006).

In terms of dry biomass, yields are very variable in relation to the pedo-climatic conditions, the cropping techniques and the genotypes compared. Studies from Italy, Portugal and Spain report dry biomass yield ranging from 10 to 15 to 30 t ha^{-1} due to differences in irrigation inputs and fertilizer applications (Gonzáles et al., 2004; Raccuia and Melilli, 2007; Gominho et al., 2014). With reference to biomass partition, Raccuia and Melilli (2007) reported that 38% were heads and 62% were stalks + leaves.

The aims of the research were to evaluate the biomass yield and partition in two cultivated and two wild cardoon genotypes under a low input rainfed cultivation system, to evaluate their response and adaptability to the local environment, and to assess their potential use for food or bioenergy purposes. An advanced statistically based interpretation of the data was adopted to assess the suitability of the different genotypes to the local conditions and possible uses.

2. Materials and methods

2.1. Study area

The field experiment was carried out in a marginal area of the hills of Latium Region (Central Italy) at the CREA-RPS research farm of Tor Mancina near Rome (lat. 42°06′ N, long. 12°40′ E, alt. 43 m a.s.l.) during a 3-year period (2012–2014) and under rainfed conditions. The study is the follow-up of an experiment started in 2011 (Francaviglia et al., 2016), but yields were not economically significant in the first year, that can be considered as a stabilization stage (Angelini et al., 2009), thus only the last three years are included in this study. Soils were Eutric Cambisols (WRB, 2014), and more details about the site characteristics are given in Francaviglia et al. (2016). Marginal area in the context of the paper refers firstly to a low soil fertility level as evidenced by the low organic C (0.81%) and total N (0.105%) values, and the consequent unfavourable C/N ratio (7.7) indicating an accelerated decomposition of soil organic matter. In addition, soil erosion rates measured in the same farm during other field experiments were higher than 12 t ha^{-1} in the period September–November (Bazzoffi et al., 2015).

The long term mean climate (Fig. 1) has a mean annual temperature of 15.2 °C (24 °C in July–August, 7 °C in January), and 800 mm total rainfall (28 mm minimum in July). According to the updated Köppen-Geiger climate classification (Kottek et al., 2006), the climate is warm temperate with hot summers (Cfa). In 2012, total rainfall was 713 mm of which 421 mm from September to December, with a long dry period in June and July; temperature was higher in comparison with the long-term values in the period June–August. In 2013, total rainfall was considerably higher than the mean value (1130 mm), particularly in the spring, summer and winter months, and temperature was lower (14.6 °C). During 2014 total rainfall was 908 mm, and temperature was higher than the long-term value (16.0 °C).

2.2. Experiment set-up and crop management

The characteristics of cultivated (*Cynara cardunculus* L. var. *altilis* DC) and wild (*Cynara cardunculus* L. var. *sylvestris* Lam) cardoon genotypes were studied, both in terms of biomass yield and its partition. Four genotypes were compared: two cultivated genotypes (CDL07 and Gigante) and two wild cardoons, one from Sicily (RCT10) and the other from Latium (Tolfa Mountains). The research is part of a field experiment set up in autumn 2010 (Francaviglia et al., 2016) following a split-split plot scheme with 3 replicates (12 plots, plot size 28 m^2, planting density 8 plants m^{-2}), where the crop genotype was the main factor. A basal dressing fertilisation with 300 kg ha^{-1} of triple superphosphate (P_2O_5 46%) was applied in October 2010.

The experiment included two transplanting periods at the beginning of 2011 (second factor) due to the low seeds germination, with a total of 24 sub plots. Nitrogen fertilization was added as third factor (0–50 kg N ha^{-1} from urea) in the second and third year (November 2011 and 2012), with a final total of 48 sub-sub plots (Francaviglia et al., 2016).

Yearly samplings on each sub-sub plot (4 plants randomly selected but avoiding the borders) were taken in late August at stage 8N9 of the BBCH scale proposed for C. cardunculus (Archontoulis et al., 2010), to determine the yield (fresh and dry biomass of stalks, leaves, capitula, achenes, receptacles, bracts and pappi), the biomass partition, and the biometric parameters (plant height, basal diameter of stalks, no and weight of capitula per plant, weight of receptacles, bracts and pappi, weight of achenes per capitulum, 1000 seeds weight). Fresh samples of the biomass components (200 g of plant material) were oven dried at 105 °C until constant weight was reached.

2.3. Statistical analyses

Chi-Square test was used to check normality of data distribution, and Levene's test to check homogeneity of variances; Box and Cox and logarithmic transformations of data, before ANOVA, were used when necessary (untransformed data are reported and discussed). Differences among treatments were determined by analysis of variance (ANOVA), related to the experimental design adopted in the