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# *Cynara Cardunculus* in Large Scale Cultivation. A Case Study in Portugal

Jorge Gominho*[a], Ana Lourenço[a], Maria Dolores Curt[b] , Jesus Fernández[b], Helena Pereira[a]

[a]Centro de Estudos Florestais, Instituto Superior de Agronomia, Universidade de Lisboa, Tapada da Ajuda, 1349-017 Lisboa, Portugal
[b]Departamento de Producción Vegetal: Botánica y Protección Vegetal, Universidad Politécnica de Madrid, Av. Complutense s/n, 28040 Madrid, Spain
jgominho@isa.ulisboa.pt

*Cynara cardunculus* L. was installed for biomass production in a total of 8.1 ha in Sesimbra (Portugal), using common agricultural practices and machinery. Installation by sowing was successful, in spite of the extreme drought during the first cycle (only 382 mm). In the second year, the rainfall was 683 mm and the plants developed well, with a mean density of 30 thousand plants per ha. The field presented a heterogeneous distribution of cardoon plants and the aerial photographs showed that 4.9 ha presented an occupation over than 50 %.
The yield of biomass was 9.7 $tha^{-1}$, with plants presenting on average, 2.2 m height, 2.3 cm stalk diameter, and 6.5 capitula per plant. The capitula contained on average 210 seeds, weighing 28 g per 1,000 seeds, and the mean seed yield was 1,065 kg $ha^{-1}$. The stalks represented 58.7 % of total dry biomass.
These results confirm that *Cynara* crops are suitable for biomass production in Mediterranean regions and that large scale operation can be applied including whole plant harvesting or plant fractionation for seed recovery. There was variation between plants, namely in oil seed production, which suggests potential improvements through breeding.

## 1. Introduction

The research on non-wood plants in Europe has been focused on species with high biomass productions, which can be grown in available areas as non-food industrial crops. Currently, cardoon (*Cynara cardunculus* L.) is considered one of the most promising plants for energy and industry uses in Southern Europe.
Cardoon is a Mediterranean herbaceous perennial crop with higher biomass productivity in dry and hot regions. The potential productivity (14 - 20 $t.ha^{-1}$ in the first years) and applications (biofuels, pulp and paper, pharmacology active compounds and green fodder) of this species started to be investigated in the decade of 1990 through projects supported by E.U. and by different national projects in Spain (Fernandez et al. 2005), Italy (Racuia and Melilli, 2004; Ciancolini et al. 2013), Portugal (Gominho et al. 2011) and Greece (Dalianis et al. 1996).
The aboveground biomass (stalks and capitula) is practically dry and without leaves, at harvest time. This is a great advantage compared to other crops, since high moisture contents affect the transport, storage and conservation of biomass.
Based on the promising results achieved in small scale scientific trials in the different Mediterranean sites where cardoon was investigated, the School of Agriculture in Lisbon (ISA), through the Forest Research Centre (CEF) coordinated a INTERREG IIIB project “ECAS - Energy crops in the Atlantic Space” (ECAS, 2008) where the main objective was to install the cardoon, in large scale, in central and southern of Portugal for energy purposes. A total area of approximately 150 ha was installed in different fields.
One of the installations was the Ferraria field with an area of 8.1 ha. In this paper we present the results of the cultivation of *Cynara* as a crop for biomass production in this field.

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## 2. Materials and methods

### 2.1 Site and climatic data

This study started in 2005 at the Ferraria estate (GPS: 38.466702,-9100084), near the city of Sesimbra, Portugal. Ferraria is characterized by a sandy type of soil, with light texture. The region is characterized by the following climate conditions: 630 mm annual rainfall, 17 ºC mean annual air temperature (data of 30 y average, obtained from the meteorological station of Sesimbra). The meteorological data during the period 2004 to 2006 is presented in Figure 1, on a monthly basis and is compared with the 30 y average.

### 2.2 Crop installation

The soil was prepared in February 2005, using a chisel ploughing at a 40 cm depth followed by two cross harrowings. The soil was fertilized between the two soil tillage practices with a solid NPK fertilizer with 50 kg ha$^{-1}$ N, 90 kg ha$^{-1}$ $P_2O_5$ and 40 kg ha$^{-1}$ $K_2O$. The field was sown in rows with a precision seeder; the distance between the rows was 75 cm, and in the row the distance between the seeds was 12 cm, corresponding to a density of approximately 111,000 seeds ha$^{-1}$ (± 3.1 kg ha$^{-1}$ of seeds). These seeds were obtained from fields installed by the Polytechnic University of Madrid (Spain). The plants were harvested in the second year of growing, since at this time the plant have completed its development, i.e, formation of stalks, flowers and seeds (Fernández et al., 2006). The mechanical harvesting was performed in August 2006, using a tractor with trailer.

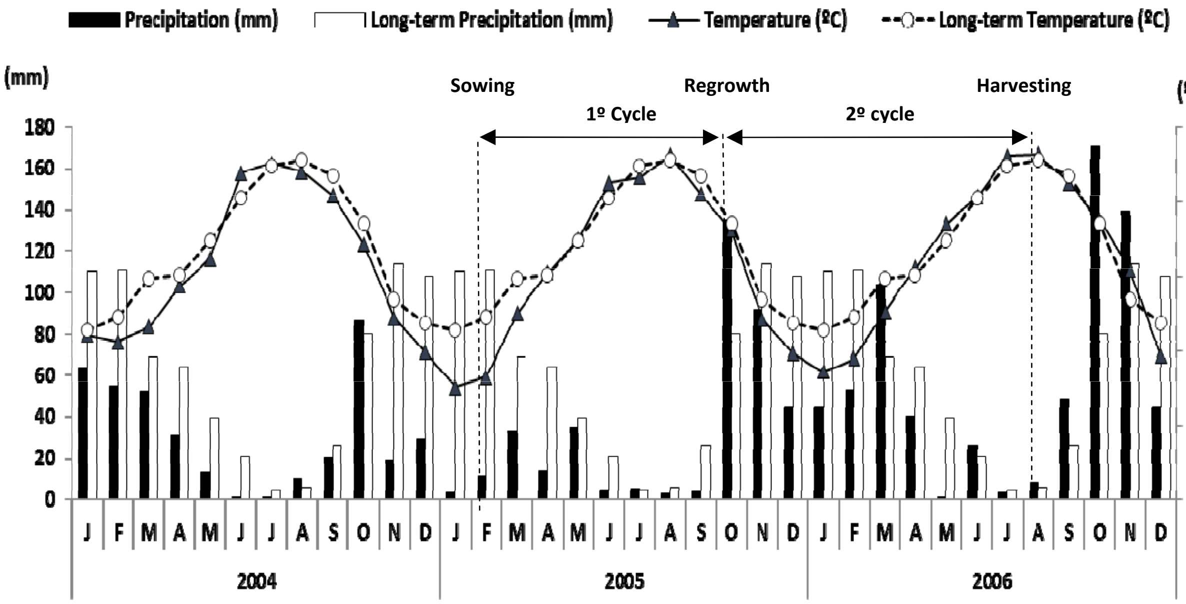


*Figure 1: Values of monthly rainfall and mean temperature for the 2004/06 period, and comparison with long-term average (30 years, 1961-1990, meteorological station of Sesimbra, Portugal)*

### 2.3 Evaluation of the field

The evaluation of the field ground cover was performed during the second cycle of the crop, by an aerial flight with 0.5 m spatial resolution (June 2006). The results were ortho-rectified from digital true colour aerial photographs. For their analysis, a Geographic Information System (GIS) projected onto the National Coordinate System (Gauss Projection, datum 73 Lisbon) was implemented based on three main overlays: i) delimitation of the study area; ii) delimitation of the *Cynara* area discriminated by ground cover percentage, in four classes: class 0 (without cardoon), class 1: < 30 %, class 2: 30 %-50 %, class 3: > 50 %. The mapping unit was 0.5 ha patch$^{-1}$.

### 2.4 The biomass evaluation

The biomass evaluation was done in 8 random transepts of 10 m x 75 cm, corresponding to 7.5 m$^2$ sampling area. In each transept, the following data were collected: i) number of plants; ii) number of capitula in each plant, iii) maximum and lowest height of capitula in each plant; iv) stalk cross diameters (measured at 10 % of plant maximum height); v) fresh weight of the above ground biomass separated in two fractions: stalks + leaves and capitula. Further fractionation was made afterwards to evaluate the seed yield.

Besides the described evaluation, in each plot the highest plant was selected, denominated as reference plant, from where moisture content and seed yield were determined. The moisture content was determined by drying the biomass at 100 ± 3 ºC. For the seed yield determination, the capitula were oven dried at 65 ºC, during 72 h, after which the seeds were collected, counted and weighted. The potential seed yield of the field was estimated as the product of the seed yield (from the reference plant) by the number of counted plants.

## 3. Results and discussion

### 3.1 Soil occupation

The ground cover of cardoon in Ferraria field is presented in Figure 2, determined by aerial photography. The cardoon was well established in 60.5% of the field (> 50 % ground covered), although the area without cardoon was significantly high (29.6 % of the field). This high percentage of mortality can be explained by the drought that occurred during the crop establishment period (384 mm annual rainfall for 2005 vs. 753 mm for the long term period, Figure 1), but also, by severe attack of rodents, which destroyed the roots and a strong attack of snails and slugs who reducing the sprouted capability of the cardoon plants. Gominho et al. (2011) reported for a large installation field in Beja, a similar establishment of the crop, with 59.9 % (> 50 % ground covered) and 23 % where the crop was absent (class 0). In this field the absence of cardoon was explained also by the drought, but also by the soil heterogeneity and land topography (presence of rocks).

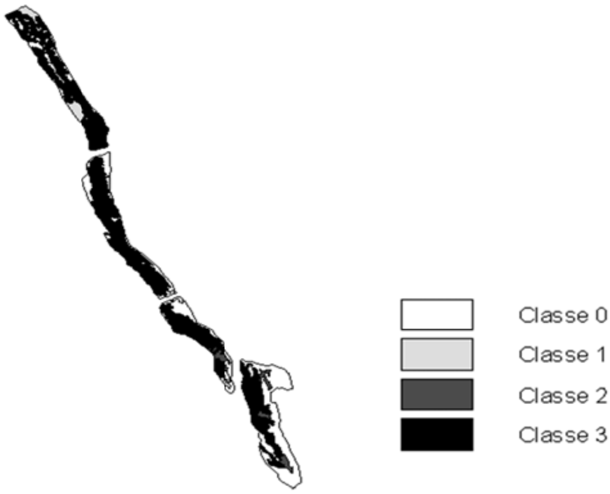


*Figure 2: Distribution of occupation of Cynara cardunculus in the Ferraria field (8.1 ha) by classes. Legend: Class 0: bare ground (2.4 ha); Class 1: less than 30 % (0.5 ha); Class 2: 30-50 % occupation (0.3 ha); Class 3: >50 % (4.9 ha)*

### 3.2 Biometric evaluation

*Table 1: Mean biometric data of cardoon and plant density (number of plants per ha) in the eight sampling transepts across the Ferraria field (mean ± standard dev)*

| Sampling transept | Nº of plants | Height (m) | | Basal stalk diameter | Capitula per plant | Plant density estimate |
|---|---|---|---|---|---|---|
| | | max | min | (cm) | | (n$^{o}$. ha$^{-1}$) |
| 1 | 21 | 2.5 ± 0.3 | 2.4 ± 0.2 | 2.5 ± 0.6 | 6.0 ± 3.5 | 28,000 |
| 2 | 21 | 2.5 ± 0.3 | 2.3 ±0.2 | 2.5 ± 0.7 | 5.6 ± 2.6 | 28,000 |
| 3 | 19 | 2.8 ± 0.3 | 2.4 ± 0.2 | 3.4 ± 1.3 | 13.3 ± 9.4 | 25,333 |
| 4 | 25 | 2.2 ± 0.5 | 2.1 ± 0.4 | 2.2 ± 0.9 | 5.8 ± 4.5 | 33,333 |
| 5 | 17 | 2,4 ± 0.6 | 2.3 ± 0.5 | 2.2 ± 0.8 | 6.8 ± 7.2 | 22,667 |
| 6 | 27 | 2.3 ± 0.5 | 2.2 ± 0.4 | 2.0 ± 0.7 | 5.0 ± 3.7 | 36,000 |
| 7 | 21 | 2.0 ± 0.2 | 1.9 ± 0.2 | 1.9 ± 0.5 | 3.4 ± 1.8 | 28,000 |
| 8 | 31 | 2.2 ± 0.3 | 2.1 ± 0.2 | 1.9 ± 0.6 | 4.0 ± 3.7 | 41,333 |
| **Field Mean** | **22.8** | **2.4 ± 0.4** | **2.2 ±0.3** | **2.3 ± 0.8** | **6.5 ± 4.5** | **30,333** |

The biometric parameters of the plants harvested in the Ferraria field are presented in Table 1. The mean value of the stalks, in the harvested transepts were 22.8 plants with 2.4 m of maximum height, 2.3 cm of basal diameter and 6.5 capitula. Gominho et al. (2011) reported similar values: 2.1 m of maximum height and 2.2 cm basal diameter and 5.1 capitula per plant. Ierna and Mauromicale (2010) reported for cardoon genotypes a mean value of 1.12 m for plant height. Based on the number of plants in the 10 m transept, the estimated plant density was 30,333 plants per ha, ranging from 22,667 to 41,333 plants per ha. The transept with highest density (41,333 plants per ha), presented lower mean diameter (1.9 cm), this is consistent with Danilas et al. (1996), which referred that plant density affects negatively the stalk diameter.

### 3.3 Aboveground biomass yield and its partitioning

The biomass evaluation and its partitioning are summarised in Table 2. The aboveground biomass showed a mean of 336.1 g per plant, where 194.9 g are stalks and 141.2 g are capitula. The stalks represented 58.7 % of the total aboveground biomass. The mean yield of the total biomass was estimated as 9.7 t ha$^{-1}$, with the maximum value of 18.4 t ha$^{-1}$ and the minimum of 4.4 t ha$^{-1}$. These values are consistent with other results obtained in a large scale cardoon cultivation in Portugal (total biomass: 7.5 t ha$^{-1}$ (Gominho et al. 2011). In trial experiments higher values were reported by Fernandez et al. (2006) in Spain (18.7 t ha$^{-1}$) and by Angelini et al. (2009) in Italy (18 t ha$^{-1}$).

*Table 2: Aboveground cardoon biomass (mean dry weight per plant) and yield in the sampling transepts across the Ferraria field*

| | Partitioning | | | | Yield | | |
|---|---|---|---|---|---|---|---|
| Sampling transept | Stalks* (g plant$^{-1}$) | Capitulum (g capitulum$^{-1}$) | Total (g plant$^{-1}$) | Stalks* (%) | Stalks* (t ha$^{-1}$) | Capitula (t ha$^{-1}$) | Total (t ha$^{-1}$) |
| 1 | 204.3 | 107.8 | 312.1 | 65.5 | 5.7 | 3.0 | 8.7 |
| 2 | 230.9 | 102.1 | 333.0 | 69.3 | 6.5 | 2.9 | 9.4 |
| 3 | 393.6 | 331.8 | 725.4 | 54.3 | 10.0 | 8.4 | 18.4 |
| 4 | 191.7 | 148.9 | 340.6 | 56.3 | 6.4 | 5.0 | 11.4 |
| 5 | 200.6 | 182.5 | 383.1 | 52.4 | 4.5 | 4.1 | 8.6 |
| 6 | 126.4 | 114.5 | 240.9 | 52.5 | 4.5 | 4.1 | 8.6 |
| 7 | 94.1 | 64.1 | 158.2 | 59.5 | 2.6 | 1.8 | 4.4 |
| 8 | 117.6 | 78.1 | 195.7 | 60.1 | 4.9 | 3.2 | 8.1 |
| **Mean** | **194.9** | **141.2** | **336.1** | **58.7** | **5.6** | **4.1** | **9.7** |

* Includes cauline leaves.

### 3.4 Seed production

One of the potential uses of the aboveground biomass of the cardoon is the biodiesel production obtained from oil extracted from their seeds.

*Table 3: Seed production in the sampling 10 m transepts across the Ferraria field*

| Sampling transept | Nº capitula | Seeds Weight (g) | Seed weight (g per 1000) | Seed yield (kg ha$^{-1}$) |
|---|---|---|---|---|
| 1 | 126 | 420 | 20 | 559.9 |
| 2 | 117 | 471 | 26 | 627.9 |
| 3 | 282 | 1,089 | 22 | 1,452.4 |
| 4 | 154 | 1,163 | 35 | 1,550.0 |
| 5 | 124 | 1,076 | 39 | 1,434.4 |
| 6 | 136 | 1,018 | 31 | 1,357.7 |
| 7 | 71 | 319 | 15 | 425.3 |
| 8 | 124 | 836 | 39 | 1,114.1 |
| **Mean** | **124** | **798.9** | **28** | **1,065.2** |

In a previous study, Sengo et al. (2010) reported that the seed contained 24 % of oil (oven dry basis) and demonstrated that is possible to produce FAME (fatty acid methyl esters) with high quality according to the standard EN 14214. However, the seed oil yield content is lower when compared to 40 % for sunflower seeds or 32 % for rapeseed seeds (Bona et al. 1999). As a curiosity, during the ECAS project some quantity of biodiesel was produced and used in a small train during an agricultural fair.

The seed production is described in Table 3, where it is possible to verify that the sampling transepts contained an average of 124 capitula, with 798.9 g of seeds, and 28 g per 1000 seeds. Foti et al. (1999) obtained 26.0 - 32.5 g for 1000 seeds, according with the harvesting time. The seed yield was estimated at 1,065.2 kg ha$^{-1}$, corresponding to 255.6 kg ha$^{-1}$ oil yield. These values are slightly lower than the 1,360 kg ha$^{-1}$ yr$^{-1}$ for seed yield of Cynara crop in central of Spain (Fernandez and Curt, 2004).

### 3.5 Potential biomass production

The reference plants (Table 4) presented a mean value of 3 m of height and 3.1 cm of basal diameter. The proportion of stalks was the same (58.9 %) but the mean of total weight was 698.9 g, almost double compared to the plants harvested in the transepts (Table 2).

In a theoretic exercise we considered that all plants in the transepts were equal to the reference plants in order to estimate the maximum potential of the field. In this ideal field, the maximum biomass would be 20.5 t ha$^{-1}$, with a seed yield of 2,245 kg ha$^{-1}$, corresponding to an oil yield 539 kg ha$^{-1}$. These values are near those found in different scientific trials installed for the study of Cynara biomass evaluation.

*Table 4: Total yield from reference plants and values for maximum potential yield of biomass and seed yield and in the Ferraria field (dry weight basis)*

| Reference plants | Biometric data | | Biomass | | | Theoretic biomass | | |
|---|---|---|---|---|---|---|---|---|
| | Maximum height (m) | Basal stalk diameter (cm) | Stalks* (%) | Total* (g plant$^{-1}$) | Seeds weight (g) | Maximum potential biomass (t ha$^{-1}$) | Seed yield (kg ha$^{-1}$) | Oil yield ** (kg ha$^{-1}$) |
| 1 | 3.0 | 3.0 | 66.8 | 620.7 | 36 | 17.4 | 1,008 | 242 |
| 2 | 3.0 | 3.9 | 67.7 | 800.0 | 54 | 22.4 | 1,512 | 363 |
| 3 | 3.2 | 4.0 | 53.8 | 1,192.7 | 90 | 30.2 | 2,280 | 547 |
| 4 | 2.9 | 3.3 | 54.3 | 728.5 | 98 | 24.3 | 3,267 | 784 |
| 5 | 3.5 | 3.5 | 54.1 | 897.0 | 136 | 20.3 | 3,083 | 740 |
| 6 | 3.1 | 2.9 | 58.6 | 612.2 | 78 | 22.0 | 2,808 | 674 |
| 7 | 2.6 | 2.1 | 67.7 | 258.8 | 18 | 7.2 | 504 | 121 |
| 8 | 2.9 | 2.5 | 47.9 | 481.3 | 82 | 19.9 | 3,389 | 813 |
| **Mean** | **3.0** | **3.1** | **58.9** | **698.9** | **74** | **20.5** | **2,245** | **539** |

* Includes cauline leaves; ** assuming 24% of oil content

## 4. Conclusions

The general conclusions of this work are:

i) it was possible to install a Cynara crop in large scale (8.1 ha), although during the first year of growth, the plants sprout capability was diminished due to severe drought and the attack of rodents and snails, increasing mortality and reducing plant density;

ii) in spite of the heterogeneity of the plant coverage in the field, we can consider that the plants grew well, achieving 9.7 t ha$^{-1}$ (5.6 t ha$^{-1}$ of stalks and 4.1 t ha$^{-1}$ of capitulum) and a seed yield of 1,065.2 kg ha$^{-1}$ (corresponding to 539 kg ha$^{-1}$ of oil);

iii) based on the reference plants, the potential production of cardoon in this field would be 20.5 t ha$^{1}$, corresponding to 2,245 kg ha$^{-1}$ of seeds and 539 kg ha$^{-1}$ of oil production.

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