PERFORMANCE OF *Cynara cardunculus* GROWN ON A CALCIC HAPLOXERALF SOIL UNDER XERIC MEDITERRANEAN CLIMATE

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ABSTRACT: A three-year experiment on *Cynara cardunculus* under rainfed conditions was conducted in a 10-ha field of poor soil quality, as a contribution to the EU Project 'Bio-Energy Chains'. Crop conditions were marginal in that soil, a Calcic Haploxeralf, and climate, Xeric Mediterranean, were limiting factors for plant growth. Climate conditions were particularly severe during the third crop cycle, with frosts of up to -18.5ºC and 228 mm annual precipitation. The experiment showed that *C. cardunculus* endures harsh conditions and yields acceptable amount of biomass.
Keywords: cynara cardunculus, biomass production, energy crops.

1 INTRODUCTION

The species *Cynara cardunculus* is becoming a sound energy crop commonly known as 'cynara' whereas the name 'cardoon' is usually restricted to the horticultural use of the species. The potential of *Cynara cardunculus* for biomass production has been studied with the support of the EU since the decade of the 1980's [1][2][3]. One of the most relevant achievements of past R&D on cynara was the development of a new crop management system based on the natural growth cycle of the species. According to that system, cynara is grown as a perennial crop with annual harvests of the above biomass, once it naturally dries up.

The information collected so far regarding the biomass yield of cynara refers small experiments and controlled crop conditions. Large experiments of cynara grown in limiting soil conditions or in drought hydrological years have not been reported yet.

The typical moisture regime in regions of Mediterranean climates is the xeric moisture regime, characterized by moist and cool to mild winters and dry and warm to hot summers. Therefore, when potential evapotranspiration is at a maximum, precipitation is scarce or none. Annual precipitation is usually not high and plant species adapted to that regime have to endure long periods of water stress. An area with xeric moisture regime is the province of Madrid (Spain), where the annual precipitation amounts to 439 mm (30-year average, meteorological station of Madrid/Retiro), distributed as follows: 26.9%, 26.6%, 12.8% and 33.7% in the first, second, third and four trimester of the year, respectively. The dry period (precipitation<2*mean monthly temperature) extends from June to September (84 mm over that 4-month period) [4].

As regard as the soils, one of the most common soils in Mediterranean climates are those of the order Alfisols (USDA Soil Taxonomy, available at the web site http://soils.usda.gov/technical/classification/taxonomy/), which have an argillic horizon (rich in clay). The sub-order of the Xeralfs includes Alfisols with a xeric moisture regime. According to USDA Soil Taxonomy, Xeralfs are used mostly as cropland, forest, or grazing land and the most common crops are small grains, like winter wheat or barley. Calcic Haploxeralfs are a subgroup of Xeralfs with a calcic horizon that has its upper boundary within 100 cm of the soil surface. These soils have little organic matter and are regarded as low fertility soils; they are often limitant for the growth of crops.

The aim of this work was to study the performance of *Cynara cardunculus* grown for biomass purposes in a 10 ha field of low fertility located in Central Spain, where the soil is a Calcic Haploxeralf. Results of three development cycles: 2002/03, 2003/04 and 2004/05 are presented, being the 2004/05 one of the driest hydrological years of the last times in Spain.

This experiment was framed within the contribution of the Polytechnic University of Madrid (Spain) to the EU Project 'Bio-energy Chains' (Contract no ENK6-CT2001-00524) [5].

2 MATERIAL AND METHODS

2.1 Location, plant material and crop management

The experiment was carried out in a 10 ha field sited in the property 'El Encín' of the IMIDRA (*Instituto Madrileño de Investigación y Desarrollo Rural, Agrario y Alimentario*), at the North-East of the Madrid (Spain).

The field was ploughed and harrowed in April/2002 to be physically prepared. Basal fertilization was applied in the form of a slow release organic fertilizer (granulated dehydrated wastewater sludge 4.5% N, 1.6% P, 0.36% K) applied at a rate of 7,000 kg ha^{-1}. Sowing was performed in rows 0.80 m apart by means of a conventional grain driller, using a seed selection of the Agroenergy Group of the Polytechnic University of Madrid (GA-UPM). Herbicide (1.5 kg alachlor+0.4 kg linuron a.i. per ha) treatment was applied in pre-emergence. Mechanical thinning was carried out in June/02 by means of two crossed labours of cultivator (0.50 m between sweeps) to get a plant density of about 15,000 plants m^{-2}. To stimulate the rosette growth, the crop was fertilized with 60 kg N ha^{-1} (NH_4NO_3) in September/02. In spring, a pesticide treatment (dimethoate) against *Cassida deflorata* was applied. During the first 12 months (spring 2002 to spring 2003), the plants grew in size keeping the rosette stage (Figure 1). In May, stems elongated (floral scape) and the crop bloomed. The aboveground biomass was let to dry up and afterwards it was proceed to harvesting in September. So, the first growth cycle lasted 16 months (May/02 to September/03).

The harvesting method was the following: i) a combine harvester to pick up the heads and thresh the seeds, ii) a mower to cut into pieces the remained aboveground biomass, iii) a swather to place the cut biomass in swaths, iv) a rotobaler adapter to a tractor in order to make rotobales of cynara biomass. The end of the harvest marked the beginning of a new crop cycle.

Crop management techniques during the following years were similar. Top dressing fertilization (200 kg urea ha^{-1}) was performed in February to stimulate the growth of the crop. Growth cycle in these years lasted 12 months (September to August). Harvesting was always performed in August-September.

Figure 1: Cynara at the rosette stage. 100% ground covering.

2.2 Soil and climate conditions

The field was sampled for soil characteristics. Great differences were found in soil depth and in presence of gravel and stones. The land closer to the nearby river exhibited a soil depth of about 30-40 cm with abundant stones. In other spots the soil depth was >90 cm, with a thick argillic horizon. The field area with the poorest soil quality was approximately 70%. On average, the characteristics of the upper soil layer (up to 30 cm deep) were the following: pH 8.6 (basic), electrical conductivity 237 µS cm^{-1} (low), organic matter 0.77% (very low), total nitrogen (Kjeldahl) 0.08% (low), extractable phosphorus (Olsen) 23 ppm P (normal), extractable potassium (extracted in 1N ammonic acetate) 178 ppm (normal).

A description of the climate during the experiment is shown in Figure 2. As a rainfed crop grown under Mediterranean climate, the most important factor is the precipitation, in terms of quantity and distribution. In the 1st growth cycle (16 months) the crop received 471 mm (283.7 mm May-Dec/02 plus 183.3 mm Jan-Aug/03). In the 2nd growth cycle, the annual precipitation was 579.5 mm but not well distributed, because in Oct/03 fell 130.7 mm (53 mm is the average precipitation of that month), and in May/04 102.4 mm (44 mm is the normal precipitation in May). The 3rd growth cycle was extremely dry. The annual precipitation amounted to only 228.2 mm (54% in Oct/04) which is only 52% of the normal annual precipitation. The hydrological year 2003/04 in most Spain was recognized as one of the driest of the last times; in fact, the drought was so severe that public institutions were obliged to take measures in order to reduce the water consumption in Spain.

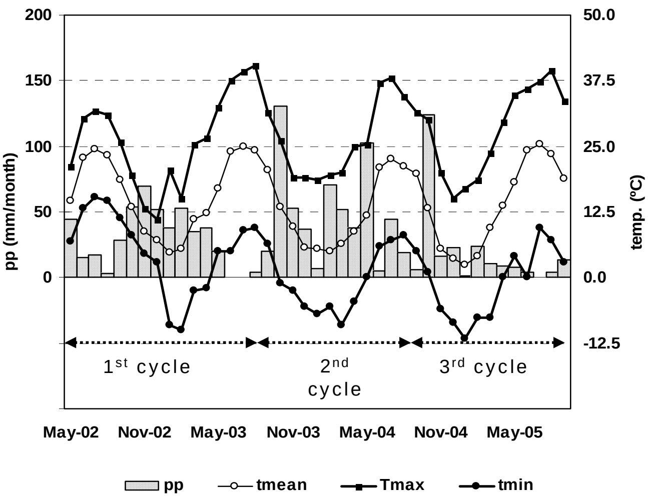

Figure 2: Precipitation (pp), mean temperature (tmean), maximum temperature (Tmax) and minimum temperature (tmin) during the experiment.

3 RESULTS AND DISCUSSION

3.1 First growth cycle: 2002/03

Seed germination and subsequent plant growth was apparently normal and homogeneous all throughout the field. By March/03 the plant leaves had formed large rosettes and the crop canopy covered nearly 100% of the ground. The effect of the irregular soil characteristics was noticed once the stems started elongating. In the poorest part of field -where the plant growth was low- some spots with well-developed plants stood out (Figure 3). Trial pits performed in those spots showed that it was an effect of soil quality, because the soil was much deeper there. Probably those spots were old wells, eventually filled with soil of the arable layer. It was made clear that the soil was, therefore, a more important limiting factor than the climate in that year of the experiment.

Figure 3. Well-developed cynara plants standing out in the poorest part of the field.

Results of biomass production at the end of the first growth cycle (16 months) are shown in Table I. The coefficients of variation obtained for the parameters of productivity were generally high (>30%), showing the effect of the irregular soil characteristics. In spite of that, the final yield was not bad, 8.7 t dm/ha, taking into account that most of the field exhibited low fertility. As regards the biomass dry matter content, it was shown that it did not depend on the soil quality since the value of coefficient of variation was very low.

Results of biomass partitioning on dry weight basis are given in Table II. The basal leaves represented a large proportion (38.6%) of the whole biomass, because in this first crop cycle (16 months duration), the crop had been at the rosette stage for about 12 months.

Table I. Plant height, biomass production and dry matter content of cynara biomass at the end of the 1st crop cycle. Scape: plant stems + branches + cauline leaves + heads; c.v., coefficient of variation in %; fm, fresh matter; dm, dry matter.

2002/03	Max	Mean	Min	c.v.
Plant height (cm)	260	113	95	35.3
Production (t fm/ha):				
- Scape	10.4	4.8	1.8	43.6
- Basal Leaves	9.9	4.7	1.0	43.5
Sum (t fm/ha)	17.9	9.5	3.2	30.6
Production (t dm/ha):				
- Scape	9.7	4.4	1.6	43.9
- Basal Leaves	9.2	4.2	0.9	45.3
Sum (t dm/ha)	16.6	8.7	2.9	31.2
Dry matter (%):				
- Scape	96.9	92.3	89.4	1.3
- Basal Leaves	94.4	89.8	74.6	4.8

Table II. Biomass partitioning (percentage) on dry weight basis, at the end of the 1st crop cycle. c.v., coefficient of variation.

2002/03	Stems+ Branches	Cauline leaves	Basal leaves	Heads
Maximum	50.0	29.7	77.5	42.3
Mean	27.2	14.5	38.6	19.7
Minimum	8.8	0.9	11.3	8.1
c.v. (%)	35.8	46.7	38.4	36.9

3.2 Second growth cycle: 2003/04

The crop performed rather well in this cycle (12 months) in spite of the poor soil characteristics because the precipitation was really high for that site, 579.5 mm. The October peak (130.7 mm) stimulated the growth of the rosette and the May peak (102.4 mm) the stem elongation. As a result, the final yield was higher (8.9 t dm/ha on average) and the coefficients of variation lower (see Table III) than in the 1st growth cycle. Furthermore, the yield of some of the samplings was over 13 t dm/ha.

Results of biomass partitioning are shown in Table IV. In this cycle, the proportion of basal leaves was lower than in the 1st one, which is a good index for harvesting mechanization; if the basal leaves were not harvested the mechanization would be easier and the risk of soil contamination in the harvested biomass would decrease.

Table III. Plant height, biomass production and dry matter content of cynara biomass at the end of the 2nd crop cycle. Scape: plant stems + branches + cauline leaves + heads; c.v., coefficient of variation in %; fm, fresh matter; dm, dry matter.

2003/04	Max	Mean	Min	c.v. (%)
Height (cm)	250	158	45	15.6
Biomass production (t fm/ha):				
- Scape	11.0	6.2	3.9	34.9
- Basal Leaves	5.8	3.5	2.1	25.9
Total	14.4	9.7	5.9	28.2
Biomass production (t dm/ha):				
- Scape	10.1	5.7	3.5	34.9
- Basal leaves	5.3	3.2	1.9	25.9
Total	13.2	8.9	5.5	28.2
Dry matter (%):				
- Scape	92.5	91.7	90.5	0.7
- Basal leaves	94.4	92.9	91.7	0.9

Table IV. Biomass partitioning (percentage) on dry weight basis at the end of the 2nd crop cycle. c.v., coefficient of variation.

2003/04	Stems + Branches	Cauline leaves	Basal leaves	Heads
Maximum	46.3	15.3	38.6	45.7
Mean	37.6	8.9	27.5	25.9
Minimum	29.8	4.1	13.0	11.9
c.v. (%)	14.8	35.7	27.4	29.1

3.3 Third growth cycle: 2004/05

In this cycle 2004/05, the crop had to endure severe climate conditions of temperature (frosts) and precipitation. In February/05 the absolute minimum temperature recorded at ground level was -18.5ºC, this causing damage to the crop. However, the plants managed to overcome that. Moreover, the hydrological year (September/04-August/05) was characterized by the deficiency of precipitation that gave rise to one of the worst droughts of the last times. Therefore, the crop suffered an extended period of water stress and the yield resented. Tables V and VI show the results of biomass production and biomass partitioning, respectively. The final yield was rather low, 6.0 t dm/ha. However, if that yield is compared to the yield of wheat estimated by the Ministry of Agriculture for the same year -2.3 t/ha in Castilla-León- (data available at the web site http://www.mapya.es), it can be deduced that cynara performed quite well, taking into account that the precipitation was only 228.2 mm.

Table V. Plant height, biomass production and dry matter content of cynara biomass at the end of the 3rd crop cycle. Scape: plant stems + branches + cauline leaves + heads; c.v., coefficient of variation in %; fm, fresh matter; dm, dry matter.

2004/05	Max	Mean	Min	c.v. (%)
Height (cm)	190	132	50	19.8
Biomass production (t fm/ha):				
- Scape	8.6	3.0	0.7	57.9
- Basal Leaves	7.2	3.5	0.5	38.9
Total	12.7	6.6	1.5	33.5
Production (t dm/ha)				
- Scape	7.8	2.8	0.6	57.9
- Basal Leaves	6.6	3.2	0.5	38.9
Total	11.5	6.0	1.3	33.5
Dry matter (%)				
- Scape	94.3	90.9	74.6	5.4
- Basal Leaves	94.6	91.2	79.5	4.0

Table VI. Biomass partitioning (percentage) on dry weight basis, at the end of the 3rd crop cycle. c.v., coefficient of variation.

2004/05	Stems + Branches	Cauline leaves	Basal leaves	Heads
Maximum	39.2	13.1	38.7	48.0
Mean	26.5	6.8	28.6	38.3
Minimum	19.5	3.6	10.1	29.9
c.v. (%)	18.0	39.8	26.2	15.1

3.4. Summary of yields in the three-year experiment

Figure 4 shows the yields obtained (fresh and dry matter) in the three years of experiment.

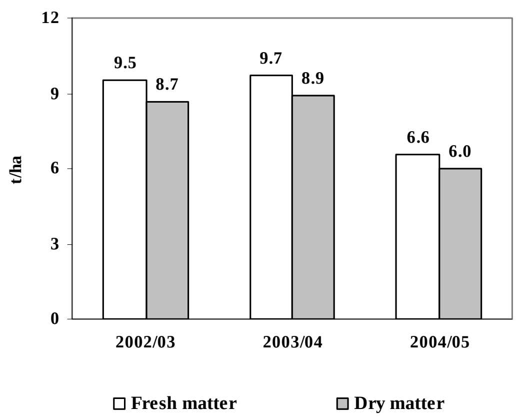

Figure 4: Biomass production of cynara under rainfed conditions grown on a Calcic Haploxeralf soil of Central Spain. Precipitation: 471, 580 and 228 mm in 2002/03 (16 months), 2003/04 (12 months) and 2004/05 (12 months).

4 CONCLUSIONS

This experiment represented a good opportunity to study the performance of *Cynara cardunculus* under xeric conditions in a low-fertility soil (Calcic Haploxeralf), when grown on a large scale. Biomass production was nearly 9 t dry matter per hectare in the 1st and 2nd development cycle, with 471 and 580 mm total precipitation, respectively. In the 3rd development cycle the crop had to endure an extended drought; only 228 mm total precipitation was recorded. In spite of that, the yield in aboveground biomass was acceptable, 6 t dm per hectare.

5 ACKNOWLEDGMENTS

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