TECHNICAL AND ECONOMIC ASPECTS OF *CYNARA CARDUNCULUS* L.: AN ENERGY CROP FOR THE MEDITERRANEAN REGION

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ABSTRACT

This paper carries out a general outlook on cardoon (*Cynara cardunculus* L.) as energy crop for Mediterranean areas. Also other possible uses are briefly described. Cultural techniques have been analysed in detail and all stages of the crop have been studied. Peculiar attention has been paid to the mechanisation of *Cynara* an evaluation of the feasibility on large scale of the crop is shown up. Energy and economic aspects of the chain have been investigated.

RÉSUMÉ

*Ce travail done un aperçu sur le cardoon (*Cynara cardunculus *L.) en tant que culture énergétique dans la région Méditerranéenne. D'autres utilisations possibles sont également décrites. On présente aussi une analyse détaillée des techniques culturaux et une étude des stades de la culture. On examine en particulier la mécanisation de la* Cynara *en fournissant aussi une évaluation de la faisabilité de cette culture sur grande échelle et une étude des aspects énergétiques et économiques de la chaîne.*

BOTANICAL DESCRIPTION

Cardoon is a species which belongs to the Asteraceae Family (Compositae), along with artichoke, sunflower, safflower and Jerusalem artichoke. It is a perennial crop which during its natural cycle sprouts in autumn. It passes throught the winter in a rosette form, developing a floral scape in spring. It dries in summer while the remanent roots remain alive. At the beginning of the autumn the buds, at the base of the stem, sprout and develop a new rosette in order to continue the cycle for several years.

Cardoon root system is very powerful and it can extract water and nutrients from very deep soils. The leaves of the basal rosette are petiolate, large (more than 50 × 35 cm), subcoriaceous, bright green and shortly tomentose in the upper part and white-tomentose in the lower one. They are usually deeply divided. Segments are ovate to linear-lanceolate, with rigid, yellow spines 15-35 mm at the apex and clustered at the base. The intensity of the spiny character changes on the basis of the variety. The leaves of the stem are alternate and sessile. The stem is the floral scape as a corymbose cyme. It can be higher than 2 m. The flowers are grouped in large globose capitula (up to 8 cm in diameter). Involucral bracts are ovate or elliptical, gradually or abruptly narrowed into an erect-patent spine (10-50 × 2-6 mm), which can be either glaucescent or purplish. Corolla can be blue, lilac or whitish. Achenes (6-8 × 3-4 mm) are shiny and brown-spotted. Pappus measures 25-40 mm. The chromosome number is 2n = 34. According to A. Wiklund, the species Cynara cardunculus may be divided into two subspecies (subsp. *flavescens* and subsp. *cardunculus*) based on geographical distribution. The subsp. *flavescens* is found in Macaronesia, Portugal and the NW Mediterranean region, whereas subsp. *cardunculus* is mainly present in central and NE Mediterranean areas. Naturalised cultivars in America and Australia are very similar to subsp. *flavescens.*

CLIMATE EFFECTS AND SOIL

The rainfall should reach a minimum of 400 mm (including autumn, winter and spring) to obtain a good development of the crop. The biomass production decreases substantially with lower precipitation. Cardoon is a species well adapted to Mediterranean climate. During seedling stage crop is quite sensitive to frost so it should be sown, in autumn, as soon as possible. When the first freezes will come the crop is in the rosette-stage, which is hardier and more resistant. Winter frost may cause a relevant damage on the rosettès leaves both in the first and successive years. The freeze can cause tears in the leaves that will be lost even if the plant will remain alive, recovering from the harm as soon as the freeze stop. As a general recommendation for the sowing schedule according to the weather, it is necessary to plan a period from 1 to 2 months (depending on the growth speed) without frost after the sowing. Note that the crop can tolerate temperatures below - 5 °C once the seedlings have 4 leaves. Cynara requires light, deep and limy soils, with capacity for retaining winter and spring water in the subsoil (1-3 metres)

CULTURAL TECHNIQUES

Soil tillage. The same operation as with cereal can be carried out. After removing the remains of the last crop by ploughing the land, a basal dressing should be accomplished. The fertiliser penetrates in the soil by means of a cultivator and after harrowing twice, the sowing can be executed. In order to avoid the cultivator labour, the fertilisation can be done before ploughing and as a result, the fertiliser will be incorporated more deeply, which is favourable for crops with very deep roots.

Sowing. It should be carried out with rows sited at 1 m apart, though it can vary in accordance with the required density. Optimal final density might be established in approximately 10000 plants/ha. This density can be raised to 15000 plants/ha if the ground is fresh and water does not lack or decreased to 7500 if the winter water reserve is too low. Seed consumption can vary from 3 to 4 kg/ha. Autumn sowing should take place as soon as the sowing conditions allow it, in order to let the plant develop the rosette of leaves before the wintry cold arrives. During the first year of growing, the production is low, but from the second year the production rises, reaching a steady level, depending mainly on weather conditions. Spring sowing is recommended for areas where frosts come soon in the autumnal season. In this case it is suitable to carry out the sowing as soon as frost risk has disappeared. During the first growing period, the crop will exploit the spring water to sprout and it will reach the stage of rosette in summer, although some of the leaves can be lost due to desiccation. The plants will continue to grow with the first autumnal rain. The size of the rosettès leaves will increase

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until the cycle is completed in the next summer when the aerial part dries. In the next autumn the plants re-sprout from the latent buds in the base of the stem and resume the normal growing cycle during the next years.

Fertilisation. Before implanting the crop an adequate basal fertilization is recommended, during the forthcoming years the soil fertility is restored according to the nutrients exported with the harvest. Cardoon is an important nutrients consumer due to the high amount of produced biomass. It is estimated that the harvest of 20 ton/ha of the aerial part of the plant extracts from the soil 277 kg/ha of N, 56 kg/ha of P and 352 kg/ha of K. On the basis of this consideration and taking into account the soil fertility, it is possible to calculate the fertilisation dose. After the first year, it is suitable to restore the fertilization in autumn, spreading nitrogenous in winter or spring. Peculiar cares must be paid to the fertility control of the deep layers of the soil (1-3 m); this is because of the accumulation of nutr ients proceeding from the lixiviation of previous tillagès fertilisation might permit to avoid the fertilisation for several years.

Weed control. Weed control can be carried out by use of herbicides (trifluraline, alachlor, linuron, etc.) or cultivator before the rosettès leaves have completely covered the soil. During the first year of the crop implantation a great part of the ground is still not covered by the crop. When the rosettès leaves grow, the crop will cover the soil, and weeds will not grow again. In the following years, weeds cannot compete with the crop's canopy that covers totally the soil. For example, a mixture of alachlor and linuron (4 l/ha of 48% alachlor and 1.4 kg/ha of 50% linuron) dissolved in 300-400 l water can be used.

OTHER USES

Paper pulp. Although many investigations are still being carried out to optimise the different processes, the outlooks for this use of cardoon biomass for paper pulp production look attractive.

Green forage utilisation. At the beginning of the winter the green leaves could be silaged or used as fresh fodder for livestock. They can also be grazed by goats and sheep (about 40-50 tons/ha fresh forage can be produced).

ENERGY ASPECTS

According to Fernandez (FIMA,1980), the total energy content of 1 ha biomass production (considering 20 t d.m./ha year) can be estimated in 334880 MJ (HCV = High Calorific Value) for the whole production period. The energy consumption for biomass production, including the proportional part corresponding to the implantation year is 9427 MJ/ha (**tables 1** and **2**).

ECONOMIC ASPECT

Cardoon cultural costs are divided into two different parts: implantation costs (first year) and production costs (following years). **Table 3** shows the implantation cost and **table 4** shows the annual production cost during the production period.

WEED AND DISEASE CONTROL

Pre-emergency treatments is carried out with conventional sprayers. When crop grows, tractors cannot go in the field without damaging the plants. For this reason a no cropped band (2,5 m width) should be set every 30-50 m; in this way the chemicals applications could be carried out using a pneumatic sprayer and taking advantage from favorable wind conditions.

Table 1 ***Energy consumption for the implantation of*** **Cynara** ***crop (first year).***

Concept	Work capacity	Energy coefficient	Energy consumption	Manpower *
Tasks	(h/ha)	(MJ/ha)	(MJ/ha)	(MJ/ha)
– Fertilisation	0,5	138	69	12.5
– Earthing up	3	419	1257	75.3
– Harrowng	1	280	280	24
– Sowing	0,8	280	224	20.1
– Herbicide application	0,5	138	69	12.5
– 2 Cultivator passes	1,5	280	420	37.5
– 1 Insecticide treatment	0,5	138	69	12.5
Total	–	–	2388	194.4
Materials	(kg)	(MJ/kg)	(MJ/ha)	
– Basal dressing 700 kg de 9:18:27				
N	63	75	4725	
P_2O_5	126	14	1764	
K_2O	189	10	1890	
– Seeds	4	33	132	
– Herbicide	3	110	330	
– Insecticide	1	110	110	
Total	–	–	8951	
Total consumption			11339	194.4

* 25 MJ/h as manpower consumption
Total energy consumption 11534 MJ/ha
Proportional annual consumption 1153 MJ/ha
(Considering 10 years of standard production)

Table 2 ***Energy consumption in*** **Cynara** ***biomass production after the implantation year. Figures are referred to a self-propelled baler (30 l fuel/h). The energy rate is obtained multiplying the fuel consumption by 1.4. Transport of bales is not considered.***

Concepts	Work capacity	Energy coefficient	Energy consumption	Manpower *
Tasks and manpower	(h/ha)	(MJ/h)	(MJ/ha)	(MJ/ha)
– Fertilisation	0.5	138	69	12.5
– 2Cultivator passes	1.5	280	420	37.5
– 3 Insecticide treatments	1.5	138	207	37.5
– Harvesting	1.3	1800	2340	32.5
Total	–	–	3036	120.0
Materials	(kg)	(MJ/kg)	(MJ/ha)	
– Basal dressing 400 kg de 9:18:27				
N	36	75	2700	
P_2O_5	72	14	1008	
K_2O	108	10	1080	
– Insecticide	3 kg	110	330	
Total	–	–	5118	
Total consumption			8154	120.0

* 25 MJ/h as manpower consumption
Annual energy consumtpion during production: 8274 MJ/ha
Assigned annual consumption for implantation task: 1153 MJ/ha
Total annual forecast production: 9427 MJ/ha
Energy balance: 334880 - 9247 = 325453 MJ/ha = 7.8 tep/ha Energy yield: 334880: 9427 = 35.5

HARVESTING

Harvest apart seeds and residual biomass

Seeds can be harvested with a conventional cereals-harvester. Tests have been carried out employing conventional cereal header and special adapted header for sunflower. Both tests

Table 3 ***Implantation costs of cardoon (first year). Values in ECU. 1 ECU = 157 PTA (6th March 1996).***

Task	Labour	Material	Total
Fertilisation 700 kg/ha	5.0	133.8	138.8
9:18:27	44.6	–	44.6
Earthing up	25.5	–	25.5
Harrowing twice	17.8	31.9	49.7
Sowing 5 kg/ha	5.1	35.0	40.1
Herbicide application	25.5	–	25.5
2 cultivator passes	12.3	11.1	23.4
Herbicide application			
Total	135.8	211.8	347.6
Depreciation annuity in 10 years at 8%			51.8

Table 4 ***Production cost of* Cynara *biomass during the production periodo (after the implantation year). Figures in ECU/ha. 1 ECU = 157 PTA (6th March 1996).***

Task	Labour	Material	Total
Fertilisation 400 kg/ha	5.1	76.4	81.5
15:15:15	25.5	–	22.5
2 Cultivator passes	36.9	33.2	70.1
3 Insecticide treatments	161.9	–	161.9
Harvesting y baling	91.7	–	91.7
Transport to thermoelectric plant (0,72 pt/kg en radio de 10 km)			
Total	321.1	109.6	430.7
Crop establishment depreciation			51.8
Total production cost			482.5

gave good results. Difficulties are causedby the large size of some plants and by the unhomogeneous height of capitula. It will be necessary also to develop special reel for this crop. Using a cereal header, sometime it was necessary to pass over two times for collecting all the seeds and leaving the residual biomass available for the pick up of the baler. In the second pass, the cutter bar will be set closer to the soil so all the biomass will pass throught the threshing drum. It is important to take care of the refrigeration system of the harvester engine. This is because the lightest part of capitula, the pappus, will fly away and it can cover radiator and grids. Before collecting the residual biomass is necessary to windrow the product with a side-rake. To bale the product doesn't show any problem working with conventional balers even if high capacity and large section balers avoid possible problems determined by large stem plants. The conventional small balers, producing bales of 40*45*80 cm, carried out some difficulties to absorb the twine. The forward speed is low also to avoid to overload the pick up and to fill up the knotter of product. The bales density is 140-150 kg/m^3.

Whole biomass harvest

A mowing-chopping machine can carry out the harvest of all biomass without parting the seeds. Plants of 3 m height can be harvested without any problems during the operation, using a "Kemper" header set on a self-propelled forage harvester. The disadvantages of this system are: the high energy consumption and the transport and logistic of the low density chopped product. So it would be necessary to find alternative systems to press the product before transport and storage. Probably the best solution would be to harvest using a self-

propelled big baler with a "Kemper" header so it would be possible to clean the field in one time and to transport and storage high density bales. It is foreseeable that tradicional systems can be used to transport the product to the plant.

POSSIBLE ENERGY USES

Solid fuel. Dry aerial biomass of cardoon can be used as a raw material for fuel usage in large scale combustion plants, either for electricity production or for heating applications.
Oil from seeds. Seeds seem to be an interesting source of oil production, since they represent a high percentage in the total harvested dry biomass (13.2%) with a oil content of 25%. Referring to its possible utilisation as a fuel, its main characteristics are the following:
Density (g/ml): 0.916 - – Cetane number: 51
Flash point (°C): 350 – Viscosity (mm^2/s) for 20 °C: 95
Iodine value: 125 – Pour point (°C): -21
Saponification value: 194 – Heat power(MJ/kg): 32.99
The most significant characteristics are the high cetane number and the low pour point that are favorably evaluated for its straight usage mixed with diesel oil in indirect injection diesel or normal diesel motors.
Crop pests and diseases. Main pests are aphids, stem-borer (Gortyna xantenes Germ.), leaf-borer (Apion carduorum kirby), leaf-miner (*Sphaeroderma rubidum* Graells), as well as cutworms (*Agrostis segetum* and *Spodoptera littoralis*) and several flies (*Agromyza* ssp., Terellia spp.) and moths (*Pyrameis cardui* L.). They can be treated either with specific or many-sided insecticides. Phosphored insecticides usually work well in most of the cases.
Among the main possible diseases caused by fungi it is suitable to mention downey mildew, powdery mildew and the botrytis blight rot. Against downey mildews, treatments in the basis of copper or Zineb, Maneb or Captan are recommended; for powdery mildew an d botrytis blight rot, it is usually profitable to apply sulphur or Benomyl-based treatments.
Harvesting. The harvesting of aerial biomass is carried out in summer (from July to September), as soon as it is dry, and always before the seed dissemination. At first, two situations are worth to be considered, depending on whether we want to harvest the seed separated from the rest of the biomass or the whole matter.
Estimated yield. Aerial biomass production depends mostly on the available water present in the soil during the active growing period, i.e. spring.A rainfall of 450 mm, distributed in accordance with the Mediterranean rainfall pattern, will determine an average biomass yield estimated at approximately 20 ton odm/ha.
The harvest is carried out when the aerial biomass moisture is 10-15%.

The average distribution of the biomass in the different parts of the crop is the following:

Basal leaves	21.0%
Stem leaves	12.1%
Stems and branches	21.9%
Capitula	45.0%
TOTAL	100.0%

The main components of the capitula represent the following percentage of the total biomass:

Receptacle	9.5%
Bracts	13.2%
Pappi	9.1%
Seeds	13.2%
TOTAL	45.0%

MECHANISATION OF THE CROP

Soil tillage and sowing. Presowing operations for cardoon are similar to the soil preparation systems adopted on other crops with autumnal or spring sowing season. In this way it is possible to use a precision seed drill with a disk adapted to the seed charcacteristics.
Two different sowing systems can be carried on employing a pneumatic seed drill with the target to set 1 plant/m^2 density: the plants are sowed at row distance of 1 m and 5-10 cm on the row. When the plants are grown a crossed harrowing can be carried on to reduce the density.
Groups of 2-3 seeds could be sowed at 1 m apart on the row. The disk should have a high number of cells so, closing some of them, it would be possible to plant "grouped seeds". Also in this case the row distance is 1 m.
The first option seems to be the best one because the crop is more homogeneous and easier to collect. ●

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