Changing Roles: Cultivating Perennial Weeds vs. Conventional Crops for Bio-energy Production. The Case of *Cynara cardunculus*

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ABSTRACT

For many decades, humanity has spent enormous amounts of energy, money and time for combating the negative effects of weeds on cultivations. We thought to change this, by cultivating *Cynara cardunculus*, one of the toughest weeds for bio-fuel production. Thus, we changed an enemy into a friend and minimized the production cost to less than 15 €/t dry matter (practically soil preparation and sowing once in a 10 years plus annual harvest and transportation to the processing plant). With a heating value of the dry biomass measured at 18.5 GJ/t (seed excluded) to 21 GJ/t (seed included), the cost of the produced heat energy is <0.5-1 €/GJ on farm, 3 €/GJ including the farmers profit (dry biomass sold against 60 €/t in July 2008), and about 3.5-4.0 €/GJ including the cost of pellet production (note: current oil price in Greece 820 €/t). Unlike other biofuels such as bioethanol from maize and biodiesel from oilseed rape (energy balances respectively 1/1.3 and 1/2.5), heat energy produced from cardoon reaches 1:27 (average 1:25-30), thus leading to a revolutionary state of the art. Performing dry biomass yields of 12-16 t ha^{-1} without irrigation up to >25 t ha^{-1} upon 2-3 irrigation applications from mid-April to late May (when irrigation water is normally still available in many regions), the crop may produce 6-8 t oil equivalent (TOE) ha^{-1} (rainfed) to >12.5 TOE ha^{-1} (supplementary irrigated), so reaching pretty high output/input ratios on farm (3.5-4.5 € / €), comprising cardoon by far the most energy crop in Greece and elsewhere. Besides the obvious environmental benefits by producing green energy, cardoon cultivation keeps the topsoil covered throughout most of the year, so minimizing the risk of soil erosion and desertification threatening more than 35% of the Mediterranean areas. Moreover, cardoon cultivation ensures discontinuation of soil and groundwater pollution with agrochemicals, which is a major concern in many areas where intensified agriculture is being practiced. Even under supplemental irrigation, cardoon uses minimal amounts of water that is precious in semi-arid areas.
Finally, due to the minimization of soil tillage and rest cultivation practices and the enrichment of the top soil with organic matter, cardoon leaves to the subsequent crop well-structured topsoil with improved soil physical, chemical and biological properties.

***Keywords*:** Cynara, cardoon, biomass, biofuel, pellets.

1 INTRODUCTION

Biomass comprises the most important energy source, which due to the increasing energy needs, must replace the mineral energy sources for environmental sustainability, according to European and international protocols. Thus, until 2020 energy agriculture is due to contribute to the renewable energy sources by 31.1%, whereas transport energy in the EU-25 countries should be covered by renewable sources by at least 5,75% until 2010.

Energy crops are fast-growing agricultural crops that can be grown for the specific purpose of producing energy from all or part of the resulting plant. The most widely grown energy crops in America are sugar cane and corn producing some 25 Mt bio-etanol. The most commonly used energy crops in EU are rapeseed and sunflower producing some 5 Mt bio-diesel. Some trees are also important in the same respect, such as eucalypt grown on 1.2 Mha in Spain, Portugal and S. Italy for pulp and energy production, and willow that is cultivated mainly in Sweden for biofuel production, covering 14% of the country's total energy demand.
However, despite the improved technology in the agricultural sector, the economic feasibility of biomass crops is still uncertain in many European countries under the current market conditions. Any planning and analysis of alternative land use scenarios including the introduction of alternative, environmental friendly commodities is based on quantitative estimates of the production potential of these crops in specific soil-climatic environments and the inputs required for their realization, so that cost/benefit ratios can be determined. Distinct differences in soil and climatic conditions between areas in the temperate climatic zone and the Mediterranean zone should be considered, normally accompanied by differences in the socio-economic conditions. Certain crops are more important and economically feasible in northern (Germany, Austria, etc) than in southern European countries (i.e. Greece) For instance, despite its great popularity in northern Europe, rape seed cultivation failed in Greece due to the rather low yields under the xero-thermic conditions prevailing in this country. In general, a substantially greater profit is required for the farmers

to change their traditional cultivation with a new one for energy production, and this can be successful by introducing crops requiring particularly lower inputs. Obviously, the better chance would have perennial crops such as swich grass, with minimal establishment costs (e.g. once in a 7-12 years). However, even in those cases, the annual cost associated with fertilization, pest and weed control etcetera will remain. A perennial crop well adapted to the prevailing environmental conditions, well competitive to weeds and with minimal needs to nitrogen and other nutrients would be a very good choice in that respect.

For many decades, humanity has spent enormous amounts of energy, money and time for combating the negative effects of weeds on cultivations. We thought to change this, by cultivating cardoon (*Cynara carduncul*us) one among the toughest weeds for bio-fuel production, and studied its growth and productivity in a series of field experiments in the last decade. The results of changing an enemy into a friend have fully rewarded our efforts.

2 MATERIALS AND METHODS

A number of field experiments have been carried out in Thessaly plain (Experimental Farm of the University of Thessaly, Velestino), Central Greece during the last decade. Due to the encouraging results, field experiments have been expanded in to west and northern Greece (Agrinion plain and Kilkis area, respectively) in the last three years. The climate in Greece is typical Mediterranean with cool humid winter and very dry and hot summer. Small climatic variations exist: Thessaly, the largest Greek lowland and the centre of the country's agricultural production, is characterized by a more continental climatic character with colder winters and hot summers, whereas in Agrinion plain winter and summer are mild and precipitation is higher throughout the year. Funally, Kilkis' climate resembles that of Thessaly, with higher precipitation during spring. The study soils are all deep to very deep, moderately fertile to fertile and are classified as (Typic Xerohrept, Vertic Xerochrept, and Aquic Xerofluvent in Thessaly plain; Typic Xerofluvent in Agrinion; and Typic Xerochrept in Kilkis, according to [1]). Split-split plot experimental designs were applied in most experiments with studied factors: plant density, nitrogen dressing, levels of weed control, irrigation water depth, etc). In most experiments, the growth and aerial fresh and dry biomass (total and per plant component) were recorded in consecutive distracting samplings throughout the growing period. Seed yield was determined in the final harvest. Based on all data collected and the local socio-economic conditions, economic and energy budgets for cardoon cultivation have been produced at farm level.

Samples of cynara's biomass (including or not the seed) were analysed for their combustion and pyrolysis characteristics in various official laboratories. Elemental analyses and analyses of the ash were realized as well.

Fig. 1: Cardoon cultivation at mid-stage and ready to harvest (upper panel), and harvesting (cutting and balling) (lower panel).

Since November 2006, agri-pellets of cynara are produced on industrial scale (pelletizer 270 kW), and the production rate and operational cost of the produced bio-fuel both in the form of pellets for heating and biodiesel produced by the oil-seed have been calculated. The Laboratory of Agronomy of the University of Thessaly is already the first public building in Greece using "Greek oil" for heating.

Finally, a dynamic, crop growth simulation model is currently being developed in the Laboratory, is based on well-known approaches (Wageningen Modelling Approach) calibrated in the light of our field experiments. After calibration and validation of this biological model, we will be challenged to predict biomass production potentials of *Cynara cardunculus* and the associate inputs required for their realization in many other parts of the world characterized by climates other than Mediterranean.

3 RESULTS AND DISCUSSION

3.1 Cardoon origin and cultivation

Cardoon (*Cynara cardunculus*), also known as Spanish thistle artichoke, is a perennial very deep-rooted weed of Mediterranean origin, well adapted to the xerothermic conditions of southern Europe and Mediterranean climatic type areas. Cardoon has become important as a medicinal herb in recent years following the discovery of cynarin. This bitter-tasting compound, which is found in the leaves, improves liver and gall bladder function, stimulates the secretion of digestive juices, especially bile, and lowers blood cholesterol levels.

Cardoon's growth starts after the first rains in autumn and continues during winter and spring until the beginning of summer, when soil moisture drops at very low levels, and the aerial part of the plant dries out. Then the crop can be harvested almost dry (<15%

moisture content) in the period July-September, so avoiding drying costs (normally 7- >15 €/t) and soil compaction risks. Fast re-growth starts again after the first rains in the following autumn, and crop canopy is very soon fully closed, and so forth. Our field experiments demonstrated that cardoon, as a very competitive weed itself, wouldn't allow the mutual growth of other weeds, whereas its growth was not affected by pest and diseases, so that its cultivation can be realized without the use of agro-chemicals. Moreover, its deep and effective rooting system takes perfect advantage of the soil's inherent fertility so that the crop does not need but modest nitrogen dressings only in very poor soils.

Fig. 2: Cardoon's very deep rooting system takes up nitrogen leached below the root zone of earlier, intensively fertilized cultivations.

Growing during the rainy period, cardoon takes also good advantage of the winter and spring rains, and performs dry biomass yields of 12-16 t ha^{-1} without any irrigation. However, if the crop receives 2-3 irrigation applications from mid-April to late May (when irrigation water is normally still available in many regions), dry biomass yields in excess of 25 t ha^{-1} may be attainable.

2.2 Energy production and cost

With a heating value of the dry biomass measured at 18.5 GJ/t (seed excluded) to 22 GJ/t (seed included), such yields correspond to 6-8 t oil equivalent (TOE) ha^{-1} for the rainfed and >12.5 toe ha^{-1} for the supplementary irrigated crops, respectively.

Considering the modest inputs (practically soil preparation and sowing once in a 10 years plus annual harvest and transportation to the pelletizing plant estimated at 70-200 €/ha) cardoon may produce the cheapest biofuel comparing to all other bio-energy crops known.

Fig. 3: Cardoon pellet production on industrial basis and use in domestic ovens. About 2 tons of these pellets are 1 toe. The price of raw biomass is expected 70 €/t in July 2008. Thus cardoon pellets may be reach the user at prices lower than 150 €/t (300 €/toe).

Actually the energy production cost is determined at < 0.5-1 €/GJ on the farm, 3 €/GJ including the farmers profit (dry biomass sold against 60 €/t in July 2008), and about 3.5-4.0 €/GJ including the cost of pellet production (note: current oil price in Greece 820 €/t or 20 €/GJ). Unlike other biofuels such as bioethanol from maize and biodiesel from oilseed rape (energy balances 1/1.3 and 1/2.5 [2]), <u>heat energy produced from cardoon reaches 1:27</u> (average 1:25-30), thus leading to a revolutionary state of the art. Additionally, with on farm output/input ratios of 3.5-4.5 € / € cardoon appears to be by far the more interesting than many other crops in Greece and elsewhere and may secure a very good income to the farmers.

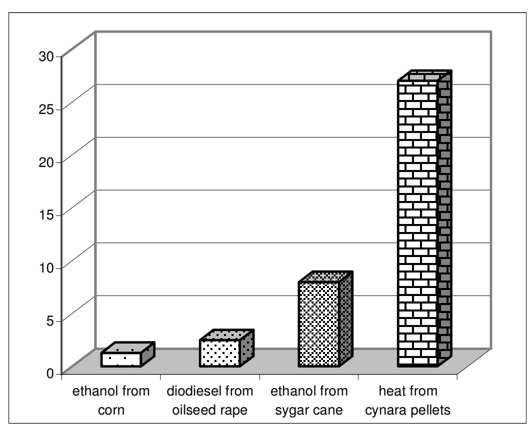

Fig. 4: Energy balance for the production of various biofuels [2].

Beside agro-pellet production, cardoon biomass contains 15-20% seed which is by 25% rich in oil that can be used for sustainable production of cheap bio-diesel. Finally, cardoon's rich in cellulose and hemi-cellulose biomass may produce considerable amounts of bio-ethanol in the future (second generation biofuels).

2.3 Environmental issues

As known, the environmental benefits associated with biofuels are important, including a reduction in greenhouse gases of at least 3.2kg of carbon dioxide-equivalent per kilogram of biodiesel, a 99% reduction of sulphur oxide emissions, a 39% reduction in particulate matter, a high biodegradability, and energy supply security.

Besides the obvious environmental benefits of using energy produced from cardoon, cultivation of this crop has direct positive effects on the environment

Nitrate pollution: Cardoon needs less nitrogen than many other crops. In many field experiments, high biomass yields were attainable under fertilization dressings from 0 up to 50 kg N/ha in shallow and poor soils. Thus, the modest fertilization dressings of cardoon help controlling the nitrate pollution of surface and ground waters in extensive areas where annual crops (cotton, maize, wheat, etc) are intensively cultivated.

Reduction of agro-chemicals: Due to its great adaptation, cardoon fast (re)growth controls the mutual growth of other weeds in many environments. On the other hand, in all field experiments, no evidence of cardoon suffering by any pest or disease was present. Therefore, cardoon can be cultivated without the use of any agrochemicals, so further reducing the production cost and the environmental risk from the use of these substances.

Water management: As mentioned, cardoon can take perfect advantage of the winter and spring rains and produces quite high biomass yields without any irrigation.

Soil erosion and land desertification: Cardoon starts growing at particularly high rates just after the first rains in October. Soon its canopy is closed and protects the soil from erosion, which is the most important environmental hazard on the sloping lands around the Mediterranean semi-arid zone.

Improvement of soil characteristics: After cardoon's establishment, the only field work is harvesting. Thus, cardoon fields do not suffer from soil compaction. The first leaves formed ("rozeta leaves") fall off creating a humus rich top soil with improved soil physical (soil structure, permeability and infiltration capacity, increased woter holding capacity, etc) and chemical characteristics (increasing organic matter content, cation exchange capacity, available nitrogen, phosphorus, ium, etc).

2.4 Agricultural and National Economy

Based on the above, cardoon is considered as the most important and promising crop for biomass and energy production in Greece in the near future.

Cardoon cultivation may partially replace traditional cultivations ensuring a good profit to the farmer (double compared to wheat and to cotton cultivation with present prices, e.g. 70 €/t dry biomass in the entrance of the factory) and producing biofuel of high energy content. Our research shows that is feasible to introduce 200 kha of cardoon cultivation in Greece in the immediate future (one fifth of the cultivated area with winter cereals, or 5% of the total agricultural land) for the production of 1 million toe. This would result in an increase of the farm income by 150-180 million €, whereas the operation of 40-50 processing plants and the creation of the new markets would create thousands of many new jobs. The solid biofuel (cardoon pellets, briquettes, etc) may reach the end user at prices by 30-40% lower than the oil price, whereas the dependence on the imported fossil fuels will be remarkably reduced.

Following the remarkable increase of oil price in the last two years, cardoon cultivation and biomass has attracted the interest of large companies towards the construction of medium-scale plants for electrical energy production. Given the heating value of the dry biomass of cardoon (20-22 GJ/t) and that 70 € per t dry biomass is an attractive stimulus of the farmer to cultivate cardoon bring the energy cost at about 55 €/MWh. In Greece, all produced electricity is bought by the National Electric Company against 78 €/MWh (still rather lower than in other EU-25 countries), and this means a gross margin of 2,8 million € of a 20 MW plant only by selling the electricity. The benefit will be much greater if one considers the heat production and distribution, the management of the ash for fertilizer use and the rights of CO_2 emission. But first of all let us thing of and protect our environment!

Concluding, we are not the first who strongly believe that cardoon is bio-fuel. This was already told by Homer (Iliad, *Φ*,364). We are first who believe strongly that by changing roles and cultivate perennial weeds versus conventional crops for bio-energy production might solve a great deal of environmental problems and in parallel improve local and regional economies. The case of *Cynara carduncululus* confirm this.

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