GIS-BASED EVALUATION OF CARDOON (CYNARA CARDUNCULUS L. VAR. ALTILIS DC.) SUITABILITY IN APULIA REGION

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ABSTRACT: The potential of land for energy crops is determined by an evaluation of biophysical and economical variables. From this respect, climate, soil and geomorphologic environmental components are the most important agro-ecological variables to conduct this kind of evaluation. In this study, Geographic Information System (GIS) has been used to identify the most suitable areas for cardoon crop production in the Apulia region. Environmental components such as climate (precipitation, temperature), soil (chemical and physical characteristics including texture, gravel percentage, pH, electrical conductivity (EC), soil depth, etc.), topography (slope) were considered. Biophysical parameters (climate, geomorphology and soil) were used to draw a map of agronomic suitability of cardoon according to the "Agronomic Classification of the Territory II" (CAT II) classification system. The results for agronomic evaluation in the Apulia region showed that 5.14% (36,532 ha), 54.17% (384,796 ha), 31.57% (224,251 ha) and 9.10% (64,665 ha) of the arable land area respectively highly suitable, moderately suitable, marginally suitable and not suitable for cardoon cultivation.
Keywords: perennial energy crops, geographical information system (GIS), climate, biomass, lignocellulose.

1 INTRODUCTION

Nowadays, cultivation of energy crops plays a key role as a source of renewable energy, which has been confirmed by the recent Directive 2009/28/EC published in OJ 5.6.2009 and the Commission Decision of 30.6.2009 on National Renewable Energy Action Plans, aiming at reaching the EU environmental and energetic targets within 2020.

The low price of some agricultural products drives the research of new alternative use of the crops, in particular toward energy production direction. In the Apulia region (South Italy) a high percentage of arable land has been used for cereal crops, where durum wheat is the most widely grown crop.

Energy crops are object of great interest by farmers and industry in consideration of recent energetic and environmental targets of UE policy. Great importance has the suitability of different lands for the cultivation of energy crops, in order to improve the economic, environmental and energetic sustainability of agricultural systems [1].

Among energy crops, perennial species, seems to be more promising of annual plants in consideration of the their more favourable benefits in terms of emissions of Greenhouse Gas and of energy balance [2].

Among perennial plants the cardoon (*Cynara cardunculus* var. *altilis* DC.) represents a crop with low energy input. It is herbaceous perennial of the family *Asteraceae* [3] with a high growth and biomass production, fully adapted to Mediterranean climate conditions.

The typical characteristics of Mediterranean climates are the low annual rainfall regime as well as its irregular distribution and the hot dry summer. The way in which cardoon overcomes this unfavorable summertime is the so-called "drought-escape strategy": this species is a perennial herb with an annual development cycle in which its reproductive cycle is completed by the summer [4]. During summer, the aboveground part of the plant dries off and the underground part (a tuberous root system) remains in dormancy until a new cycle begins with the burst of leaves formed from root tissue with the autumn rainfall [5].

This succession of annual growth cycles may last several years; more than 15 years have been reported [4].

The traditional applications are the use of the blanched stalks as an edible vegetable and the use of the flowers as a rennet substitute to make cheese.

Alternatively, *C. cardunculus* can be cultivated as an energy crop using the whole aboveground biomass: lignocellulosic biomass directly for heating or for electric power generation and seeds, due to their high oil content, as raw materials for cogeneration (simultaneous production of electricity and heat) or biodiesel production [4]. The production of biodiesel from cynara oil has been the subject of experiments by several authors in Europe [6;7] and in Italy [8;9;10;11].

In the last few years, territorial studies have been developed thanks to the modern management system of geographical data called Geographic Information Systems (GIS). GIS is a powerful set of tools for collecting, storing, retrieving, transforming and displaying spatial data from the real world [12;13]. It has the ability to perform numerous tasks utilizing both spatial and attribute data. One of the most useful features of GIS is the ability to overlay different layers or maps.

For this reason, GIS can be considered a powerful tool to assess the suitability of a crop at a territorial level, as for energy crop [14;15;16;17].

The aim of this study was to assess the land suitability for cardoon cultivation in the Apulia region by integrating ecological information with spatial analysis technique and in the same time to estimate its yield potential at site-specific level. The results from this study could be an important tool to support planners in taking the right decisions about the energy and agricultural policy of the region.

2 GIS-BASED METHODOLOGY

The first phase of the work was the collection and storage of regional data in the software ArcGIS Desktop version 9.2 (ESRI).

Climatic information was obtained from 188 meteorological stations located within the study area and the surrounding zones, provided by the Regional Association of Consortiums for the Protection of Apulia (Assocodipuglia), regarding daily minimum, medium and maximum temperature and precipitation. Data were collected at the meteorological stations in a period ranging from 20 to over 60 years. Daily average values for each variable were calculated.

Moreover, data about soil physical and chemical characteristics (texture, gravel percentage, pH, electrical conductivity (EC), soil depth, organic matter, total carbonate content, period of water logging) were picked up from a regional study about the agroecological characterization of the Apulia region [18], and average values of each soil parameters were calculated and assigned to the homogeneous soil areas (cartography units) used by Caliandro *et al.* [18] as polygons of the map constituted by soils with similar taxonomy.

Slope and land use (deriving from CORINE Project) were obtained from the Territorial Information Systems of the Apulia region (www.cartografico.puglia.it).

All the data were geo-referenced using a metric Universal Transverse Mercator (UTM) coordinate system, WGS84 (World Geodetic System 84), zone 33N.

Meteorological database allowed to define two climatic indicators: Crop-specific thermal index (CTI) and Seasonal Rainfall Deficit (SRD) [19].

The CTI indicator was calculated on the basis of thermal requirement of cardoon; base temperature (min for development) of 7.5°C and optimum temperature of 17°C, and heat stress temperature of 24°C were used [20; 21].

The first step was the calculation of Monthly Thermal Index (MTI) for each month of the crop cycle, according to the following procedure [19]:

$$MTI=(x-B)(x-L)*[(B+L-2T)(x-T)+(T-B)(T-L)]/(T-B)^2(T-L)^2$$

where

x=average monthly temperature of the site
B=base temperature
L=heat stress temperature
T=optimum temperature

The MTI ranged between 0 and 1. The MTI values of every month were added and the results were divided by the number of month, to obtain the CTI of cardoon for every meteorological site.

The second climatic indicator was the SRD, which has been defined as the difference between the precipitation of a specific site and the evapotranspiration of the crop during the critical period of plant life cycle (March-April-May in the case of cardoon).

In particular, the method proposed by Hargreaves [22;23] has been used to calculate the reference evapotranspiration according to the following formula:

$$ET_0 = 0,0023*Ra*(Tmed+17,8)(Tmax+Tmin)^{0,5}$$

where

ETo = reference evapotranspiration (mm/d)
Tmin= daily minimum temperature (°C)
Tmax= daily maximum temperature (°C)
Tmed= daily average temperature (°C)
Ra= extra atmospheric radiation expressed in equivalent evaporation (mm/d) [24; 25]

Crop coefficients (kc) of every growth stage were derived from FAO paper n. 56 [26].

The values of climatic indicators obtained from each meteorological site were elaborated through the process of geo-statistical interpolation *Inverse distance weighted*, in the Spatial Analyst tool of ArcMap. This process had to be interpreted to geo-referenced information (from punctual to spatial information) in order to obtain maps of the different indicators in the Apulia region.

Concerning the soil, each parameter value was assigned to homogeneous soil area to achieve the total covering of the region for examined physical and chemical characteristics. This gave the possibility to achieve the graph results of all the maps concerning biophysical components of the Apulia region.

In order to evaluate environmental suitability of cardoon, a classification system has been used as defined by the CAT II system [19].

The methodology is based on the assignment of restriction score given to biophysical components (Tab. II), which reduces the productivity.

It allowed to individuate 10 agronomical classes, in relation to the total restriction score of each area for the specific crop (cardoon in the specific case); whereas agronomical classes were grouped in 4 classes according to the suitability of the crop (Tab. I): i) highly suitable (S1), restriction scores were less than 30% while agronomical values were higher than 70%; ii) moderately suitable (S2), restriction score ranged from 30 to 60%, whereas agronomical values ranged from 40 to 70%; iii) marginally suitable (S3), restriction score ranges from 60 to 90%, and agronomical value ranged from 10 to 40%; iv) not suitable (N), in which restriction score was higher than 90%.

All the maps of the biophysical components were elaborated in GIS software for the reclassification process, with the aim to assign at every map point the restriction score deriving from the values of each parameter at that specific point.

Finally, after the sum of all restriction scores of each parameter, a final map of agronomical suitability of cardoon in the Apulia region, according to the CAT II classification system, was obtained.

Table I: Suitability and agronomic classes, agronomic values and restriction score according to CAT II classification.

Suitability classes	Agronomic classes	Agronomic values	Restriction score
S1	I	90.1 – 100	0 – 9.9
S1	II	80.1 – 90.0	10.0 - 19.9
S1	III	70.1 – 80.0	20.0 – 29.9
S2	IV	60.1 – 70.0	30.0 – 39.9
S2	V	50.1 – 60.0	40.0 – 49.9
S2	VI	40.1 – 50.0	50.0 – 59.9
S3	VII	30.1 – 40.0	60.0 – 69.9
S3	VIII	20.1 – 30.0	70.0 – 79.9
S3	IX	10.1 – 20.0	80.0 – 89.9
N	X	0.0 – 10.0	90.0 - 100

Table II: Restriction score (CATII classification method)

Environmental characteristics	Score
Pedology	
Depth (cm)	
60 – 100	10
25 – 60	30
< 25	42
Gravel (% of soil weight)	
5 – 20	19
20 – 40	39
40 – 70	55
70 – 90	65
<90	90
Texture	
Clay loam, sandy clay loam, clay silty, sandy clay	5
Clay	16
Clay (with clay percentage > 60)	30
Silt loam	10
Silt	25
Sandy loam	12
Sand	35
Organic matter (%)	
25 – 50	10
>50	20
Total carbonate (%)	
25 – 50	7
>50	16
pH	
7.4 – 8.2	5
5.8 – 6.5	8
5.0 – 5.7; 8.3 – 9.0	10
<5.0; >9.0	20
Salinity (ECe mS/cm) (1)	
2 – 4	5
4 – 8	16
8 – 12	25
12 – 16	60
>16	80
Hydrology	
Drainage	
Moderately well drained	7
Somewhat excessively drained	15
Somewhat poorly drained	20
Excessively and poorly drained	30
Very poorly drained	50
Geological characteristics	
Slope (S)(2)	
0.5 – 1.3	8
1.3 – 2.8	20
2.8 – 5.0	40
5.0 – 9.1	65
>9.1	90
Climate	
Crop-specific thermal index	
0.7 – 0.8	3
0.6 – 0.7	13
0.5 – 0.6	32
0.4 – 0.5	52
0.3 – 0.4	70
0.2 – 0.3	90
<0.2	95
Seasonal rainfall deficit (mm)	
100 – 200	7
200 – 300	10
>300	25

This final map, including all regional area, was compared to the map of Land Use in the GIS project.

This comparison was necessary to exclude areas where we can not grow rapeseed crop such as urban areas, forests, orchards including olive trees, vineyards, etc.

3 FIELD EXPERIMENTAL DATA

3.1 Location of trial

Field experimental was carried out at the experimental farm of CRA-SCA located in Rutigliano (Bari, Southern Italy), (41°01'N; 17°01'E; 147 m a.s.l.) on a clay soil classified as Rodoxeralph (USDA).

The local climate is semiarid-Mediterranean with mild winters and hot, rainless summers. During the growth cycle of cardoon, monthly temperature and rainfall were measured by a climatological station in the experimental farm (Tab. III).

Table III: Climatic data

Months	Mean Air Temperature (°C)		Total Monthly Rainfall (mm)	
	2009/10	long-term	2009/10	long-term
October	15.0	17.5	149.8	51.1
November	12.6	12.6	34.6	73.9
December	10.3	9.4	71.8	92.4
January	8.0	8.2	31.8	64.5
February	9.2	8.2	56.4	58.1
March	10.5	10.5	55.4	55.3
April	13.5	13.1	47.0	40.3
May	18.0	17.6	57.5	37.2
June	21.5	21.7	31.3	29.5
July	25.1	24.1	17.7	23.2
August	27.5	24.2	13.2	26.4
September	20.2	21.0	0.0	52.1

3.2 Crop management and data collection

A cultivar of *C. cardunculus* L. var. *altilis* DC. from Polytechnic University of Madrid (Spain) was compared in a randomised block experimental design with four replications.

Seeds were sowed on October 2009 with a plant density of 30,000 plants ha^{-1} with inter-row spacing of 1.2 m. Plot size was 2,250 m^2.

Tillage was conducted in the autumn of 2009 and consisted of medium-depth ploughing (0.3 m). Seed bed preparation was conducted immediately before sowing, by a pass with a disk harrow. Pre-plant fertiliser was distributed at a rate of 100 kg P_2O_5 ha^{-1} (triple superphosphate).

The aboveground biomass was harvested out on the 18 August 2010, when it was dry (about 70-80% of dry matter).

Harvested plants were separated (heads, leaves and stalks) and were immediately weighed in order to determine the fresh weight. Plant height, number of stalks per plant, stalks diameter, number of heads were also determined.

Each parts were placing in a thermoventilated oven at 65 °C until constant weight was reached weighed in order to determine the dry weight. Heads were threshed to separate grains (achenes), which were then weighed (grain yield).

Grain lipid substances were extracted and quantified by the Soxhlet method, using petroleum ether as solvent.

4 RESULTS AND DISCUSSIONS

4.1 Mapping cardoon suitability in Apulia region

The map for the SRD of cardoon (Fig. 1) showed a certain variability along the regional area, with values ranged from a min of -35.8 mm (no deficit) to a max of 235.1 mm, so water resources does not represent a restriction to the crop.

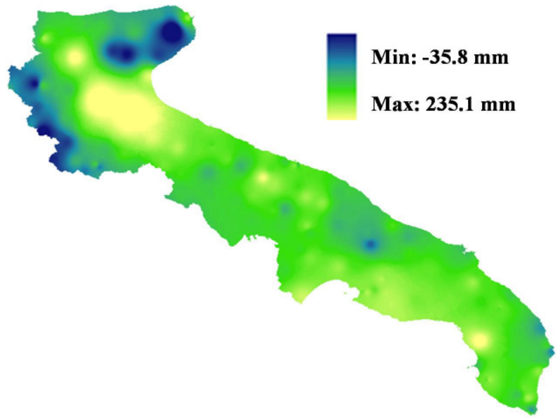

Figure 1: Map of SRD for cardoon

Considering the CTI (range from 0 to 1), the results (Fig. 2) in large areas of the region were not close to the value of thermic requirements of the species. In fact, the maximum value was CTI=0.74; values of the indicator were similar in most of areas in the south of the region and along the coastal zones, while in the inland zones values are close to 0.50 and in the coldest area of the North-East (Gargano's Promontory) the indicator reached the minimum of 0.29; in these areas minimum air temperature could be a limit for its cultivation.

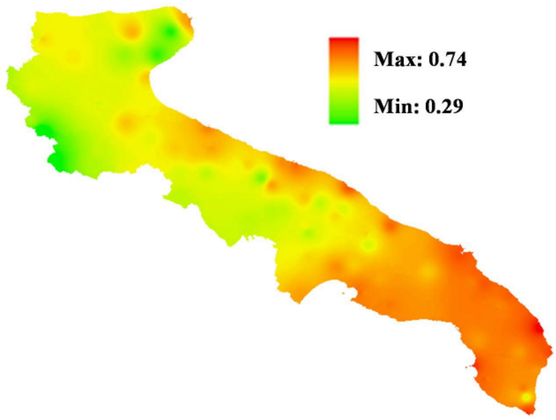

Figure 2: Map of CTI for cardoon

With regard to soil parameters, obtained map of soil depth showed the main restriction in the central inland area of the region (Murgia) and Gargano's Promontory; in the same areas another limitation resulted gravel content.

Data from the texture map indicated that in clay areas this component could represent a small restriction for the crop, whereas organic matter, total carbonate content and salinity did not show anomalous levels. Soil pH, on the other hand, showed a certain alkalinity in the some northern areas (province of Foggia) and Murgia, while restrictions derived from drainage were located in some small areas of province of Foggia and of extreme south of Apulia (Salento).

As regard topography Apulia is a region with large extent of flat land, restriction occurs only in the Gargano's Promontory and the hilly areas of Daunia, in the province of Foggia.

From the results of overlay maps for biophysical (climate, geomorphology and soil variables) suitability evaluation using CAT II classification method, we were able to classify 5.14% (365.32 km^2), 54.17% (3847.96 km^2), 31.57% (2242.51 km^2) and 9.10% (646.65 km^2) of the arable land area respectively highly suitable, moderately suitable, marginally suitable and not suitable for cardoon cultivation (Fig. 3).

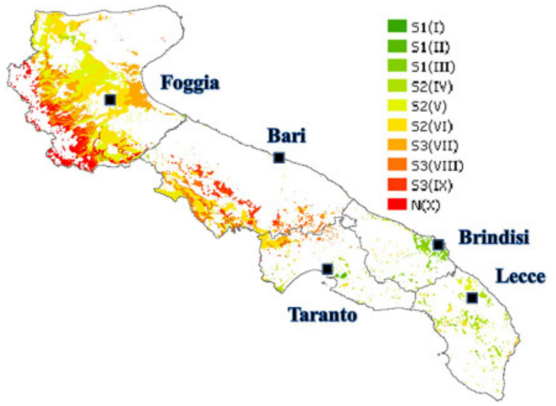

Figure 3: Map of agronomic suitability for cardoon

At provincial level, the map showed that most of areas classified as S1 belongs to the province of Brindisi (54.0% of provincial arable land, 241.89 km²), where the analysis showed large extension of land without restriction. In the province of Lecce, the extension of the land in the same class was 72.39 km², corresponding to 8.9% of provincial arable land. The potential suitable areas decreased passing to the province of Taranto (33.56 km²), Bari (9.49 km²) and Foggia (6.57 km²).

As regards to the zone classified in the class S2, in this case the province of Foggia showed the largest area with 2046.52 km² (54.6% of provincial arable land), followed by Lecce (697.32 km², 86.2% of provincial arable land), then Bari, Taranto and Brindisi with 543.72, 356.71 and 196.70 km², respectively.

4.2 Field results

The results concerning biometric parameters have been shown in Table IV. The mean plant height was 121.3 cm, the middle diameter of the stalk was 11.0 cm and the mean number of heads per plant was 4.2.

Table IV: Morphological characteristics

Part of plant	Mean	Dev.st.
Plant height (cm)	121.3	12.2
Stalk diameter at the middle (cm)	11.0	1.7
Heads (no./plant)	4.2	0.7

The total biomass yield (Tab. V) was 6.28 t ha^{-1} of dry weight subdivided in 41% of heads, 34% of leaves and 25% of stalks.

Table V: Productive characteristics

Part of plant	Fresh weight (t ha^{-1}) mean	dev.st.	Dry weight (t ha^{-1}) mean	dev.st.
Leaves	3.61	0.46	2.15	0.53
Stalks	2.69	0.69	1.61	0.52
Heads	2.75	0.52	2.52	0.53
Total biomass	9.06	1.50	6.28	1.42

Whereas, yield in achenes reached 0.75 t ha^{-1}, with an oil content of 23.4% and the oil yield was 174.9 kg ha^{-1} (Tab. VI).

Table VI: Grain production

Parameters	Mean	Dev.st.
Grain production (t ha^{-1})	0.75	0.09
1000-grain weight (g)	35.03	1.27
Oil content (%)	23.42	0.63
Oil yield (kg ha^{-1})	174.92	23.29
Grain moisture (%)	6.68	1.08
Ash (%)	4.19	0.13

5 CONCLUSIONS

This study confirmed that the methodology based on GIS was adequate to integrate database of climate, soil and topography factors with different spatial and temporal resolutions, which allowed us evaluating the agricultural systems. Besides, the application of CAT II classification method gave us detailed information about the suitability of the area studied for the cultivation of cardoon.

The results of this study showed that cardoon could enter in farming systems on the regional territory, even if there are wide areas with restrictive thermal conditions; nevertheless the crop could be introduced in non-irrigated areas of the provinces of Foggia and Lecce.

The results of the field experiment demonstrated that this crop can be grown as an energy crop in the Mediterranean area with minimum energy inputs.

This investigation provided data at a regional level, which could be useful to farmers to select their crop pattern.

However, the data presented here offer a useful background for more detailed territorial studies of the energy crops cultivation suitability to support the decision-makers for planning of agricultural and energy policy in the Apulia region.

6 NOTES

(1) ECe: electrical conductivity of a saturated soil paste extract;
(2) $S = 10.8\sin\theta + 0.3$ for slope <9%; $S = 16.8\sin\theta - 0.50$ for slope ≥9% [27].

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