Carob-tree as CO_2 Sink in the Carbon Market

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Abstract: - Since the beginning of the XX century the median global temperature has raised more than 0.5 ºC, mostly due to the anthropogenic emission of carbon dioxide, methane and nitrous oxide. This rise will continue if emissions trend are not reversed and gases are allowed to remain in the atmosphere. Under Articles 3.3 and 3.4 of the Kyoto Protocol, developed countries are allowed the option to use net domestic changes in green house gases emissions through specific land use activities, including forest management to meet their reduction commitments. The present study contributes to this analysis by estimating the carbon assimilated by carob tree (Ceratonia siliqua) in the Algarve and the evaluation of its viability and generating potential in the carbon market. The method was based on mass balance and allometric relationships calculations for determining CO_2 fixation, and inquiries to farmers for complementing information. $CO_{2\ eq}$ fixation is 15.56 t $CO_{2\ eq}$/ha; with a total for the region 1 322 356 tCO_{2eq}. The values are low when compared to other tree forests, but still important in a region where autochthonous species have naturally low densities. Carob tree has, however ecological advantages over other species in the region.

Keywords: - Carbon storage, carob tree, carbon market, carbon fixation, allometric relationships

1 Introduction

Climatic predictions have led to proposals for conduct guidelines from various organizations who share a common goal in minimizing green house gases (GEE) emissions and reducing the possible harmful side effects on the atmosphere, particularly the effects on climate [1]. Specific GEE´s with a rapidly growing concentration level include: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Given the emission of such high quantities, CO_2 is becoming the main contributor to global warming. If this concentration level continues to rise, it can be predicted that the earth´s temperature will rise, which in turn will cause various problems in the atmosphere [2]. Since the beginning of the XX century the median global temperature has risen to 0,6 + 0,2º C [3]. In some regions it has risen even more, as is the case in Europe, where the numbers have reached 0,95º C [4].

Two different strategies for minimizing this problem arose: the reduction of GEE emissions and the discovery of alternatives for the absorption of O_2, through carbon fixation. The concept of carbon fixation (sequestration) was ratified in 1997 at the Kyoto Conference, setting a goal to contain and revert CO_2 in the atmosphere thus lowering the greenhouse effect [5]. Historically, emerging countries are not really held responsible for the intensification of global warming. This fact, in conjunction with the rise of GEE emissions (especially in China and India) have contributed in that these countries have gained significant power in negotiating in the international climate regime [6]. Therefore, it is important to understand how developing countries can act in an international regimen, committing to reduce GEE emissions to developing countries [7], alongside with measures taken in, and by, developed countries in the same direction. The GEE emissions in Portugal in 2000 reached 84,7 million tons of CO_{2eq}, which corresponds to a 30 % increase in relation to 1990. In 2003, this increase corresponded to 38,6 % [8]. Portugal is accompanied in this increase by Spain, Ireland and Italy [9]. National GEE projections for emissions point to an increase in 2010 comparing to the year 1990 between 46,5 % and 53,5 % [12]. In accordance with these estimates, Portugal will have to reduce its emissions between 12,6% and 17,5% in order to comply with the PK [9].

Under Article 3.3 of the Kyoto Protocol, Parties agreed in accounting certain activities for in meeting the Kyoto Protocol's emission targets, including afforestation and reforestation since 1990. Activities in land use, land-use change and forestry sector are among the measures for cost-effective offsetting of emissions. These include i) increasing the removal of greenhouse gases from the atmosphere (e.g. by planting trees or managing forests), or ii) reducing emissions (e.g. by curbing deforestation). Sustainable management of resources, plantations and the rehabilitation of forests can augment the carbon storage (it is estimated that forests worldwide hold 283 Gt C). Global rate of carbon assimilation by forest sinks provided in 1999 is 1.59 Gt C / year [11].

Portuguese state set its objectives for compliance with the PK is in the National Plan for Climate Change (PNAC). The PNAC promotes the increase in the capacity for carbon fixation through the bettering of management and the developing of new forest populations, in a total of 492 thousand ha. This measure permits the reduction of the national liquid balance of GEE emissions to 0,8 Mt CO_{2eq}, by the beginning of 2011, which in turn would value to about 60 million euros, according to Kyoto arithmetic [10].

The present study contributes to the evaluation of the potential of the Portuguese forest by quantifying of the carbon assimilated by the carob-tree in the Algarve and the evaluation of its viability and generating potential in the carbon market. Carob tree (*Ceratonia siliqua*) is found almost exclusively in the Mediterranean basin with dry climate.

2 Material and Methods

2.1 Study area

The Algarve region occupies an area of 4 928 km^2, distributed throughout 16 councils which subdivide into 84 sub councils of very diverse geographic characteristics and distinct socio-economical activities [13]. The areas with the most amount of precipitation coincide with the mountainous areas, particularly Monchique, which has a barrier effect in relation to the Algarve [14]. Approximately 65 % of the Algarve territory registers a median daily temperature of 17,5º C, though there are variations between mountain, coastline and Barrocal [15]. The synoptic situations responsible for the occurrence of rain in the Algarve region are due, in the winter, to the passage of the polar front constituted by sea currents, which originate masses of cold air, of who´s influence is at times blocked by a warm anticyclone, located in the Biscaia Gulf and the British Islands. In the Autumn, the cyclonic "families" from the Atlantic are preponderant, reinforcing a tendency for unstable weather, characterized by cloudy skies and rain, while the summer is characterized by scarce precipitation, due to the action of two stable anti cyclones [16]. The distribution of carob trees in Portugal seems to restrict itself to regions of marked Euromediterranean characteristics (Algarve) [17]. Carob tree is a leguminous plant with evergreen, noted for longevity, and cultivated extensively through the Mediterranean basin [18]. By observing their cultural distribution, it is noted that the trees adapt to diverse edaphic conditions, but in the Algarve its preponderance is observed on limestone soils (karst topography) [19]. From a climatic point of view, once dealing with a sub-tropical tree, the most favorable conditions for growth are macro-thermal aridity of the euromediterreanean zone [20]. In the Algarve it can be found in either pure populations, disperse populations or, most often, in conjunction with other species [17].

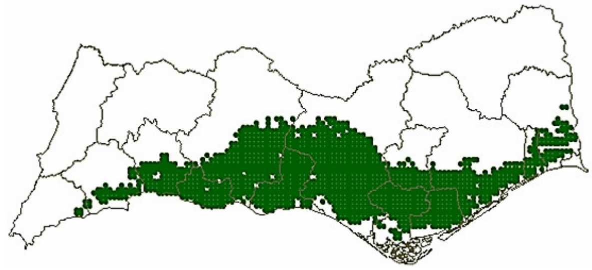

Fig. 1- Distribution of the carob tree in Algarve [17]

2.1.1 Biomass sampling

Five carob trees were cut down in three different locations: three in Faro, one in Loulé and another in São Brás de Alportel. Just before cutting, canopy diameter (CD), height (H) and trunk diameter ($Ø_t$) measurements were taken, to allow establishing allometric relationships between biomass carbon and the registered variables.

Table 1 – Characteristics of trees felled.

Proprieties	Tree 1	Tree 2	Tree 3	Tree 4	Tree 5
Location	São Brás de Alportel	Faro	Faro	Loulé	Faro
Annual Precipitation (mm)	653	600	600	653	600
Pruned	No	No	No	Yes	Yes
Age (years)	5	1	12	55	37
Trunk diameter (cm)	9.87	2.85	5.16	56.69	27.37
CD (m)	2.20	–	1.60	8.50	7.00
Trunk girth (cm)	31	0.91	16.2	178	86
Height (m)	4	0.48	1.90	8.5	7
Variety	Bravo	Bravo	Bravo	Mulata	Mulata
Cut date	Apr.	May.	Feb.	May.	Jul.

2.2 Data acquisition

2.2.1 Biomass carbon estimation

The trees were cut in various portions and the respective wet weight was determined (OHAUS I-10 model IS-15, 15±0,001 kg). After weighting samples were dried in a ventilated greenhouse at 65º, until constant weight (dry weight). The value of fixed biomass carbon (BC), kg, was determined by Brown et al. [21]:

$$BC = 0.5 \cdot B \qquad \text{Eq. 1}$$

with *B* the dry weight (kg).

2.2.2. Tree allometric variables for carbon fixation estimates

The following variables were determined: i) tree height (H); ii) trunk diameter ($Ø_t$); and iii) canopy diameter (CD). The first two variables were determined by direct measurement, while canopy diameter was obtained by fotointerpretation in Arcview 3.2 validated by field measurements for 93 trees, of which 51 in Tavira, and 32 in Castro Marim. Power law (quadratic) relationships between these variables and biomass carbon were tested, following conclusions from previous studies – see [22] and references therein. Annual carbon fixation in kg C/year per plant was estimated by averaging the derivative of the equation that relates carbon content per plant (kg) and plant age (year). The estimate of carbon fixation in the region was obtained by multiplying this estimate by the average tree density and by total planted area.

2.2.3. Selected orchards and field extrapolation

Fotointerpretation of 106 orchards (17 in Tavira, 12 in Castro Marim, 64 in Loulé, 11 in Albufeira, 1 in Faro and 1 in Olhão) was done in order to estimate trunk diameter. Validation of interpretation was made using data from field measurements for 93 trees. The 106 orchards corresponded to 240,8 ha and 5 543 trees, which corresponds to an average density of 23.02 trees per ha. Canopy area covered an area of 5.23% of the total orchards plots (12.6 ha). Sampled area corresponds to 3.2% of the total carob tree single species orchards area and to 0.28% of the total area of orchard, including mix orchards.

2.2.4 Carbon conversion into CO_{2eq} and CCE

Carbon content conversion into CO_{2eq} is obtained by a simple mass balance conversion, both in units of mass:

$$CO_{2eq} = 3.67 \cdot BC \qquad \text{Eq. 2}$$

3 Results and Discussion

3.1 Allometric models with biomass carbon

Allometric models with biomass carbon are presented in Table 3, following data presented in Table 2. With the exception of the relation between trunk diameter and biomass carbon (Figure 2), all the remaining models are only valid for plants older than 15 years, which was considered as an important limitation. Hence, consequent estimates of biomass carbon estimates were based only on the allometric relation with trunk diameter.

Table 2 – Tree measurements

Tree	$Ø_t$ (cm)	WW (kg)	DW (kg)	% PH	BC (kg)	H (m)	CD (m)
1	9,87	17,97	10,06	44	8,55	4,0	2,2
2	0,91	0,054	0,027	50,5	0,022	0,5	–
3	5,16	12,70	6,64	48,7	3,15	1,9	1,6
4	56,69	915,5	613,4	33	521,4	8,5	8,5
5	27,37	350,3	209,6	40,2	178,7	7,0	7

WW: wet weight; DW: dry weight

Table 3- Allometric relationships with biomass carbon

Relations	Equations	R^2
BC *vs* H	$BC = 12.218\ H^2 - 48.496\ H$	0.944^{*}
BC *vs* CD	$BC = 10.885\ CD^2 - 37.902\ CD$	0.929^{*}
BC *vs* CD.H	$BC = 0.1388\ (CD.H)^2 - 2.8895\ CD.H$	0.995^{**}
BC *vs* $CD.H^2$	$BC = 0.0012\ (CD.H^2)^2 + 0.1086\ (CD.H^2)$	0.999^{**}
BC *vs* $Ø_t$	$BC = 0.1196\ Ø_t^{\ 2} - 2.482\ Ø_t$	0.994^{**}

* ($\rho < 0.050$); ** ($\rho < 0.010$)

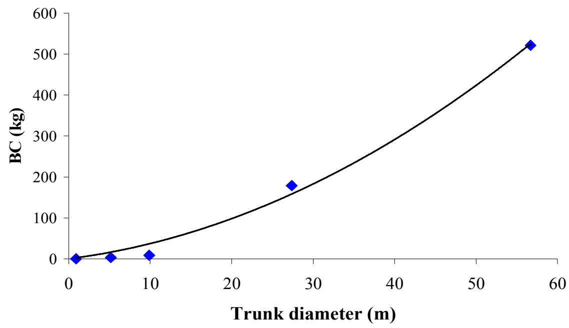

Fig. 2 – Relationship between trunk diameter and biomass carbon

3.2. Relationship between allometric variables

Biomass carbon estimates for the region required the determination of equations relating trunk diameter and other easily measured spatial variables such as densities of trees and canopy diameter. Relationships between allometric variables are shown in Table 4.

Table 4 – Equations for allometric relationships

Relations	Equations	R^2
$Ø_t$ *vs* CD	$Ø_t = 4x10^{-5} CD^2 + 0.0323\ CD$	0.783
$Ø_t$ *vs* H	$Ø_t = 4.792\ H$	0.634
H *vs* CD	$H = 0.0096\ CD$	0.599

The equation relating trunk diameter and canopy diameter (CD) showed a good correlation coefficient, having been therefore used for estimating total biomass carbon fixation in the region.

3.3. Estimation of total biomass carbon in the Algarve

Total biomass carbon in was estimated by substituting the total area of canopy in the first equation of Table 4, and the result on the last equation of Table 3. Results per orchard plot are presented in Table 5.

Table 5 – Assimilated carbon for plots and in the Algarve area

Location	Nº of plots	Area (ha)	BC (kg)	kg C/ha
Tavira	17	49.72	125363.56	2521.4
Castro Marim	12	109.18	277350.53	2540.3
Loulé	64	66.15	515508.39	7793.0
Albufeira	11	9.15	73280.19	8008.8
Faro	1	6.22	25367.74	4078.4
Olhão	1	0.47	4305.94	9161.6
Total	–	**240.89**	**1 021 176.34**	**4239.2**

Biomass carbon in the studied area amounted to 1021,2 tons (3.2% of the total), though BC changed significantly between plots, by almost five times, due to different tree densities. The average BC per ha is 4239.2 kg/ha (15 557.8 kg $CO_{2\ eq}$/ha). For the entire region BC estimate is of 31 912 tons (117 117 t $CO_{2\ eq}$) for single species orchards and of 360 315 t C (1 322 356 t $CO_{2\ eq}$) for total orchard area. These values indicate a low carbon fixation when compared to other forests – see Table 6 for some examples. It should be noted, however, that edaphic and climatic conditions in Algarve are very limitative for the development of dense forests.

Table 6 – Above ground carbon dioxide fixation

Reference	Place	$CO_{2\ eq}$/ha (t/ha)
Present study	Carob tree - Algarve	15.56
NESFA [23]	Northeast USA forest	~23.0 - ~36.0
Taki et al. [24]	Japan – coastal black pine	171.4 – 320.0
Hsuan-Te et al [25]	Camphor tree forest	120.5-256.4
Del Rio et al [26]	Pine forest - Spain	182.3-529.3

3.4 Estimate of annual carbon assimilation

Data for carbon fixation per age considered only plants taken from natural orchards, which excludes plants 2 and 3. Though the resulting sample set is very limited, an exponential relationship between biomass carbon and age is well defined (Figure 3) (r^2 = 0.979).

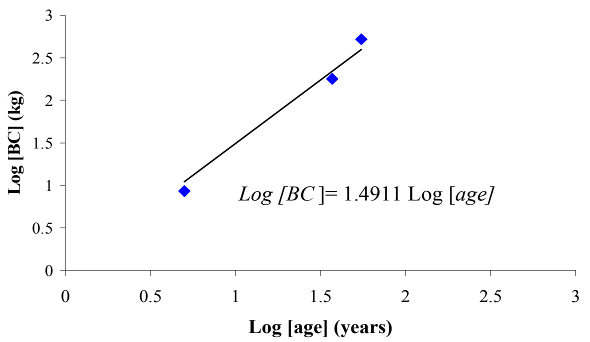

Fig. 3 – Relationship between biomass carbon and plant age

The assimilation of carbon per year per plant may be estimated by the derivative $\delta BC/\delta age$. The model then becomes:

$$\partial BC / \partial age = 1.4911 \cdot age^{0.4911} \qquad \text{Eq. 3}$$

Considering an average plant age of 30 years, according to the results of the inquiries to the farmers, the rate of assimilation is equal to 7.92 kg/year per plant, and the assimilation per ha equal to 182.2 kg/ha/year. This value corresponds to 668.8 kg $CO_{2\ eq}$/ha/year, which is one order of magnitude lower than that referenced for above ground pine forest in a similar climate 17.4 kg/tree/year [26]. These results still need further verification with a larger set, but seem consistent as the relationship holds for an interval range between 5 and 55 years, which includes the age range of most orchards.

4 Conclusions

Results presented in this article show that carob tree has a low carbon fixation potential when compared to other species, both due to a slow growth rate and small densities. This crop has, however potential to grow if with better cultural practices are implemented. Moreover, the edaphic conditions in Algarve limit the development of dense forests, with the exception of pine in some the interior mountainous areas. Carob tree orchards have at least three competitive advantages over other forests in Algarve: i) carob ranks first as agriculture product, with very high annual revenues; ii) carob tree is very resistant to water scarcity, frequent in Mediterranean climates; iii) the plant is very resistant to forest fires, in particular when compared to pine forests. This latter issue may impose itself one of the most relevant reasons in support of carob tree as CO_2 sink under the Kyoto Protocol's Article 3.3, due to the lower risk of lost revenues in the future, which has been keeping investors away from the market (more on this may be found in Hamilton et al [27] and Chenost et al [28].

Future works will include the collection of more field data, both about allometric variables and silvicultural practices, allowing the proposal of alternative management practices.

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