Carob residues as a substrate and a soil organic amendment

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Abstract: The objective of this study was to evaluate the agricultural use of carob (*Ceratonia siliqua*, L.) seed residues as a substrate and/or a soil organic amendment. The tomato (*Lycopersicum esculentum* L., cv. Realeza) was the studied crop. Plants were grown in pot filled with carob seed residues mixed with a sandy topsoil at the following rates (t/ha): 0; 10; 20; 30; 40; 50; 60; and 100 % of carob seeds. During the experiment, plant height, number of leaves, inflorescences, ripe fruits and the transversal and longitudinal diameters were measured weekly. Sandy soil, carob residues and soil and their mixtures were chemically analysed, in order to determine the following parameters: organic matter content, pH, electrical conductivity, N, P, K, Ca, Mg, Fe, Mn, Zn, Cu, Cd, Cr, Ni and Pb contents. Cu, Cd, Ni and Pb concentrations were determined in the carob residues only just before mixing with the sandy soil. Carob seed residues alone (used as an organic substrate) treatment promoted the highest root density, plant development, as number of leaves and fruits, and the highest crop yield. Plants of the 100% carob seed residues treatment also showed the highest density of roots. The obtained results suggest that carob seed residues may be used successfully as an organic amendment and/or as a horticultural substrate, mainly to root crops.

Key-Words: crop yield, *Lycopersicum esculentum* L. cv. Realeza, organic substrate, soil-substrate mixtures, tomato nutrient content

1 Introduction

The population increase and the industrial development produces an enormous amount of organic residues that nowadays generate great environmental problems. The appropriate agricultural use of these residues can become advantageous for the mankind because it allows nutrients recycling, improve crop production, less pollution problems, and as well the improvement of the physical, chemical and biotic conditions of the soils.

In certain areas, the soil is poor in organic content, and therefore needs organic amendment. In the last decades, the substratum growth crops are winning prominence in the world scenery.

World production of carob (*Ceratonia siliqua*, L.) is approximately 315,000 tons per year. The main producers are presented in Table 1 [1].

Table 1. CAROB (*Ceratonia siliqua*, L.) production (tons) presented by country producers

Country	**Yield (tons)**	**%**
Spain	132,300	42.0
Italy	50,400	16.0
Portugal	**31,500**	**10.0**
Morocco	25,200	8.0
Greece	22,700	6.5
Turkey	15,700	4.8
Total World Production	315,000	100.00

Portuguese carob production is located mainly in the Algarve region, distributed in an area of 85,000 ha [2], mainly on the districts of Albufeira, Loule, S. Bras de Alportel, Faro, Olhão e Tavira (Fig. 1).

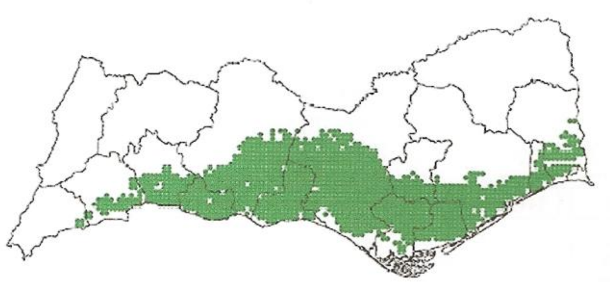

Figure 1. Carob tree distribution in the Algarve region.

The genus *Ceratonia* belongs to the family *Leguminosae* of the order *Rosales*; legumes are important members of tropical, subtropical and temperate vegetation throughout the world [3].

Contrary to other traditional crops, there is an increasing demand for carob products, which represents a potential benefit to farmers and a diversification of farm incomes [4]. However, current information about the ecology of this crop has not yet been integrated and so there are some doubts about the correct management of natural resources, like water and soil nutrients, in order to improve productivity; these items are particularly important in Mediterranean areas where growth and yield are mostly limited by both climatic and edaphic conditions [5].

During centuries carob had contributed to the Mediterranean economy. It was normally used for livestock food. Only in the last century, since the 40th, carob started to be exported as a fruit.

With the industry development carob constituents started to be exported separately, first as pulp and seed, and after, as flour of endosperm and germ.

The carob pod components are pulp (90%) and seed (10%), but pulp has a low commercial value.

Carob pulp has a high content of sugars (40-50%) and low content of proteins (2-5%). Seeds are composed by a tegument (30-35%), endosperm (40-45%) and germ (20-25%).

However, its main importance is related to the gum content of the seeds. Carob gum is extracted from the endosperm component, and has a high commercial value.

Carob bean gum, or locust bean gum, is codified as E410. The carob gum is applied as an additive and as a thickener (Table 2).

According to [3] the fruit has numerous applications both in the food industry, thanks to its thickening and binding properties and it is a precious auxiliary in the manufacture of bread, ice cream, cheeses and pastries, or as an effective stabilizer and thickener in soups, sauces and canned fish and meat.

In the textile industry gum is used in the operations of printing and finishing of cotton textiles and paper industry is used to improve the hydration of the cellulose and the tensile strength.

Thanks to the gums adhesive, thickeners and emulsifiers properties it has been used in the pharmaceutical industry, namely in the manufacture of tablets, toothpaste, suspensions, lotions and beauty creams.

Gum extraction of the seeds is an industrial process, which results in a production of an organic waste, which may have a proper final destination (Figs. 2a and 2b).

Table 2. Carob applications as an additive and thickner

Carob Applications	
Pharmacy	
Food	Cakes Sweets Chocolates
Perfums	
Cosmetics	

Figure 2a. Carob industrial process machinery

Figure 2b. Carob industrial process – residues production

In the last years, especially in the last decade, improving efficiency of fertilizers use has been a trend in most agricultural studies related to soil organic fertilizer / amendment management. Total World consumption of N, P_2O_5 and K_2O fertilizers, in 1998, was 82, 32 and 22 million tons, respectively [6]. With the world population's growth, the demand of fertilizers was expected to rise, by the same amount, in the same period; however, since 1990/91, the total World consumption of N, P2O5 and K2O fertilizers, which was 78, 37 and 26 million tons per year [7], respectively, remained relatively constant. The population increase and the industrial development produced an enormous amount of organic residues which nowadays generate great environmental problems. Inorganic fertilizers production consumes energy and its resources are limited. Innovation in agrotechniques using controlled release fertilizers in crop production is one of the solutions related to the impacts on soil and water quality [8]. However, this type of fertilizers is expensive and their use is less than 1% of total World fertilizers consumption [9]. Another potential alternative for fertilizers consists in a better use of the organic residues.

The appropriate agricultural use of soil amendments / organic fertilizers can become advantageous, because it allows the waste recycling. Besides lessening the pollution problems it also improves the physical, chemical and biotic conditions of the soils. The correct use in crop production must be investigated, not only at nutrients and salinity levels but also concerning trace elements, when present [10, 11]. By using carob seeds residues, as soil substrate, less hazardous pollution was demonstrated when compared with the application of inorganic fertilizers. An excellent substratum depends on the techniques used on its production, on the type of the vegetable material, climatic conditions, water content and some economical aspects.

A high percentage of Portuguese soils, a highly percentage of soils shows a lack of organic matter and nutrients. So, there are several advantages of using certain properly treated organic materials in agricultural soils, such as: 1) better soil structure, through the formation of aggregates and the increase of its stability; 2) the enhance of the soil cationic exchange; 3) better conditions of the soil microbiology; 4) higher conditions of plant nutrition and, therefore, an enhance of the fertilization efficiency; 5) increase of soil fertility and productivity.

A brief classification of these treated residues reused in the agricultural soils is shown in Table 3.

Currently, new organic wastes appear at a significantly extent. Their deposition and final destination are an important environmental target. And, therefore, they should be achieved without environment risks to those types of organic residues.

Table 3. Brief classification of treated residues reused in the agricultural soils

Organic Wastes		References
Sludges	Urban sludges Industrial sludges	[12, 13, 14, 15, 16, 17, 18]
Agri-industries Residues	Mill residues	[19, 20]
Livestocks Residues	Manures	[21, 22, 23]
Agri-food Residues	**Carob seed residues** Sugar cane pulp res. Wine grape pulp res. Beer sludge residues Olive pulp residues	[24]

The "Danisco Portugal - Indústrias de Alfarroba, Lda." uses in its industrial processes the carob seeds, and the manufacturing process has the following key operations: cleaning and preparation of the carob seeds, physical-chemical peeling, selection and grinding. This process results in an acid wastewater effluent, which needs a specific treatment. Due to the environmental requirements currently imposed, this company opted for the neutralization of the effluent pH using sodium hydroxide along with a coagulant and a flocculant, and then, after filtration, the dehydrated sludge (carob seed wastes) is separated from liquid phase.

2 Materials and methods

The study was carried out in an investigation greenhouse, in the "Horto" of the Faculty of Natural Resources Engineering at the University of Algarve.

The experiment was accomplished in a 24 cm diameter pots (5 L volume),

Soil and carob seed residues were analyzed at the beginning and at the end of the experiment. Soil samples were dried at 40 °C and the residues at 60 °C for 48 h. The following parameters were determined: organic matter (OM) content, electrical conductivity, N, P, K, Ca, Mg, Fe, Mn; and Zn. Cu, Cd, Cr, Ni and Pb contents were only determined in the carob seed residues [25].

The carob seed residues were mixed with a Haplic Arenosol (ARha) [26] and pots were filled according to the following treatments:

A - 100% of soil; B - 10 ton ha^{-1} of carob seed residues (45 g pot^{-1}); C - 20 ton ha^{-1} of residues (90 g pot^{-1}) D - 30 ton ha^{-1} of residues (135 g pot^{-1}) E – 40 ton ha^{-1} of residues (180 g pot^{-1}); F - 50 ton ha^{-1} of residues (225 g pot^{-1}); G - 60 ton ha^{-1} of residues (270 g pot^{-1}) and H - 100% of carob seed residues (used as a horticultural substrate). Number of replications was 4. The pots contained tomato (*Lycopersicum esculentum* L., cv. Realeza) as an indicator crop with a cultural cycle was 190 days.

Plant development was registered weekly (plant height, number of leaves, number of floral clusters and number of set fruit) was registered weekly. Fruits were harvested and weighed individually and the fruit diameters of the transversal and longitudinal sections were measured. Fig. 3 shows the greenhouse tomatoes cultivated in pots.

Figure 3. Greenhouse - tomatoes cultivated in pots.

On the end of the experiment, the separation of the leaves and of the stem was done and their weights were registered and the biomass of the aerial part was determined.

Chemical analyses and plant biometric values had been submitted to a variance analysis, using SPSS ver. 14.0 (SPSS Incorporation, 1989-2005, Chicago, Illinois, U.S.A.) and the Microsoft Excel (Office 2003): differences were considered significant when p<0.05 [27]. Means were separated by the New Multiple-Range Test [28].

3 Results and discussion

Soil Properties

Chemical analysis of soil, carob seed residues and soil and carob seed residues mixtures at the end of the experiment, and chemical analysis of the soil on the beginning of the experiment are reported in Tables 4 and 5.

C/N ratio, Mn and Cu contents were not statistically affected by treatments.

The soil pH values increased comparatively with the initial soil pH value, and ranged 7.4 (neutral) and 8.0 (slightly alkaline), and it was lower in E treatment (40 ton ha^{-1}) compared to the others.

Table 4. Chemical analyses of the soil (initial and at the end), and soil and carob seed residues mixtures at the end of the experimental work

	A (100 % soil)	**B** (10 ton. ha^{-1})	**C** (20 ton. ha^{-1})	**D** (30 ton. ha^{-1})	**E** (40 ton. ha^{-1})	**F** (50 ton. ha^{-1})	**G** (60 ton. ha^{-1})	**Initial Soil**
pH	7,88 a	8,02 a	8,00 a	7,85 a	7,39 b	7,80 a	7,85 a	6,97
CE (dS.m^{-1})	0,17 bc	0,28 bc	0,09 c	0,28 bc	0,46 b	0,45 b	0,95 a	0,01
M.O (%)	0,52	0,55	0,76	0,57	0,80	1,04	1,30	0,38
N (%)	0,07 c	0,07 c	0,07 c	0,09 c	0,10 bc	0,12 ab	0,14 a	0,05
C/N ratio	5,35	4,79	6,50	4,02	5,11	5,35	5,91	4,66
P (%)	0,16 abc	0,16 abc	0,14 c	0,15 bc	0,17 abc	0,18 ab	0,18 a	0,15
K (%)	0,01 ab	0,01 ab	0,01 bc	0,01 bc	0,01 c	0,01 bc	0,02 a	0,01
Ca (%)	0,01 d	0,01 cd	0,01 d	0,01 cd	0,02 bc	0,03 ab	0,03 a	0,00
Mg (%)	0,01 d	0,01 bcd	0,01 d	0,01 cd	0,01 bc	0,01 b	0,02 a	0,00
Fe (mg. Kg^{-1})	1,83 bc	2,08 b	3,00 a	1,71 bc	1,62 bc	1,50 bc	1,29 c	0,25
Zn (mg. Kg^{-1})	1,13 b	3,04 a	2,08 ab	1,04 b	0,62 b	0,96 b	0,79 b	0,25
Mn (mg. Kg^{-1})	1,00	1,25	1,21	1,25	1,71	1,17	1,33	0,50
Cu (mg. Kg^{-1})	0,00	0,04	0,04	0,00	0,00	0,04	0,08	0,00

Note: Averages with different letters show significant differences (p <0.05)

Electrical conductivity (EC) ranged between 0.09 and 0.95 dS m^{-1}: compared to the untreated control it was higher in treatments E, F and G.

Soil organic matter content ranged between 0.5 % and 1.3 %. According to [29] these values are classified as low values. Comparing to the organic content of the soil at the beginning of the experiment, it was observed an increase of this parameter with additional increased amounts of carob seed residues.

The soil chemical analyses showed that K content decreased, comparatively with soil K content at the beginning of the experiment.

Fe, Zn, Cu and Mn contents were very low and were higher when compared with the initial soil contents.

The heavy metals contents of the carob seed residues (Cd, Cr, Ni and Pb) were low and below of the Portuguese law-decrete n. 118/06, which regulates the application of organic residues to soil, according to residue types and soil heavy metals contents.

Table 5. Chemical analyses of the carob seed residues at the beginning and at the end of the experimental work and their comparison with the optimum values

Parameters	Carob seed residues – initial	Carob seed residues – final	Optimum values (*)
pH	6,82	7,25	
EC (dS.m^{-1})	2,02	1,44	2 – 10
M.O (%)	63,17	50,45	> 35
N (%)	1,16	0,98	> 1
C/N	31,85	29,83	< 18
P (%)	0,01	0,01	> 0,43
K (%)	0,01	0,01	> 0,41
Ca (%)	0,33	0,40	> 1,40
Mg (%)	0,05	0,06	> 0,20
Fe (mg.Kg^{-1})	9,99	12,69	
Zn (mg.Kg^{-1})	2,08	2,50	
Mn (mg.Kg^{-1})	2,50	2,28	
Cu (mg.Kg^{-1})	3,70	5,00	
Pb (mg.Kg^{-1})	0,40	-	
Cr (mg.Kg^{-1})	0,40	-	
Ni (mg.Kg^{-1})	1,63	-	
Cd (mg.Kg^{-1})	0,00	-	

(*) - Optimum values proposed by [30]

Plant development

Plant height increased along the experimental period and did not statistically differ between treatments (Fig. 4).

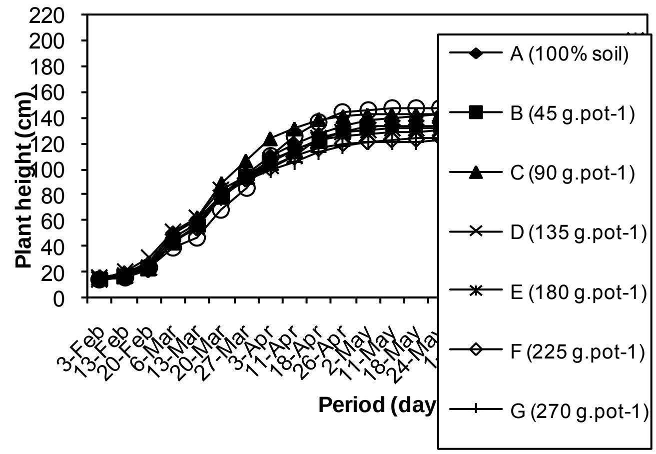

Figure 4. Evolution of plant height (cm) throughout the experimental period

Five weeks after transplantation, the highest plants were those from the A (100% soil), C (20 ton ha^{-1}) and D (30 ton ha^{-1}) treatments.

The number of set fruits per plant was affected by treatments (Fig. 5). In the plants of B (10 ton ha^{-1}) and H (100% carob seed residues) treatments, the first set fruits appeared one week later compared to the other experiments. The highest number of set fruit per plant was observed in the H (100% carob seed residues) and C (20 t.ha^{-1}) treatments. The H treatment had also the largest number of flower clusters.

The first flower clusters, located at the lower part of the plant, showed a greater number of flowers comparatively with those at the highest part of the tomato plant. This fact is according to [31], which refers that the increase of temperature decreases the number of flowers per cluster.

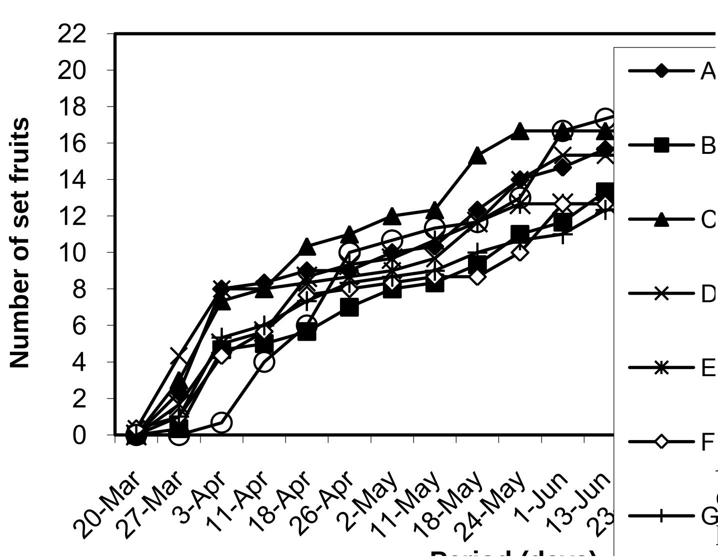

Figure 5. Number of set fruits per plant throughout the experimental period

Plant production

Plant production and fruit longitudinal and transversal diameters were not statistically different between treatments (Figs. 6 and 7). The highest plant yield and the lowest fruit average weight were obtained in treatment H.

Comparing root system development, it was observed long roots and higher root density (Fig. 8) in plants of the treatment H (plants cultivated only with carob seed residues.

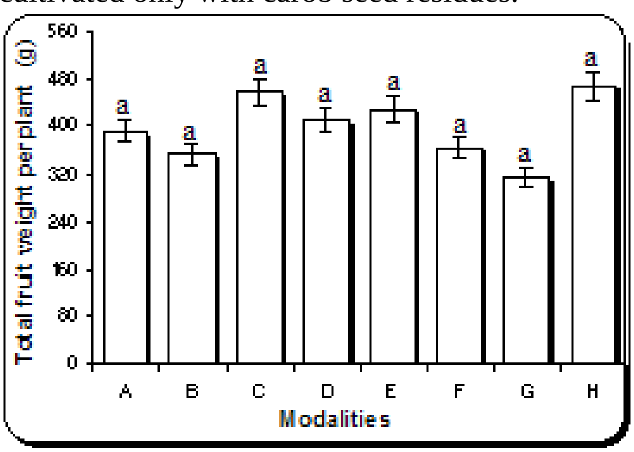

Figure 6. Total plant production (g) per treatments. Treatments with the same letter do not present significant differences (p<0.05)

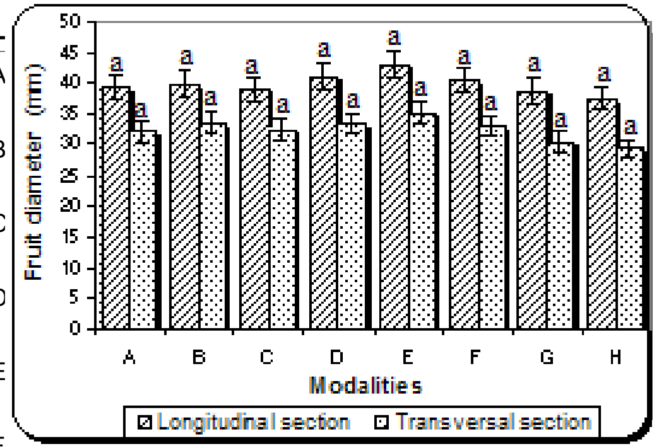

Figure 7. Fruit longitudinal and transversal diameters. Treatments with the same letter do not present significant differences (p<0.05)

A treatment (100 soil %) H treatment (100% carob seed residues)

Figure 8. Root systems of the A and H treatments

4 Conclusions

Portuguese soils, especially thus on the south, are usually poor in organic matter content, once that the local weather increases mineralization. Hence, this work shows that the use of the sugarcane residues has potential to be a reasonable soil organic amendment, increasing soil fertility and improving crop production.

The increasing application of carob seed residues increased the soil organic matter content, which demonstrates the importance of this material as an alternative soil organic amendment in soils with low content of OM content

According to carob seeds residues, initial C and N contents, and consequently to its C/N ratio, it seems that submitting residues to a composting process treatment before its agricultural use it will allow the achievement of an organic product (compost) with a lower C/N ratio, improving its mineralization and nutrients availability, especially on N uptake by plants [32].

The H treatment (100% of carob seed residues) improved the highest plant growth, especially when compared the root system density and appearance. The highest plant yield results were also achieved with the 100% carob seed residues substrate.

Results showed a great interest for the use of these kind of experiments. And, therefore, other experiments should be done for other species under various other types of substrates, increasing yields and improving the energy, environment, ecosystems and the sustainable development.

As final remarks, it may be concluded that carob seed residues present interest as an organic soil amendment or as a horticultural substrate, not only as an economical aspect, but also for the environmental perspective. These results suggest the possibility of the single use these residues or mixed with the soil. Additionally, due to the very high development of the tomato roots, this study showed that is probably the root crops, those which are adequate to the use of these residues. However, additional studies are needed, especially with other crops.

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