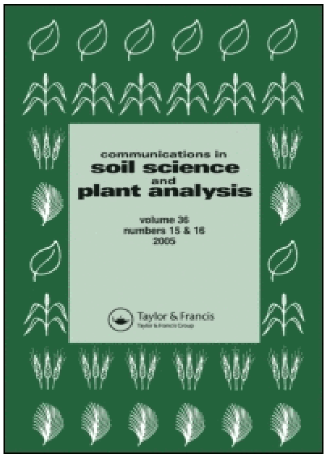

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Nutritional Evaluation of Nitrogen and Potassium Fertilization of Carob Tree under Dry-Farming Conditions

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Abstract: The aim of this work was to assess how potassium (K) and nitrogen (N) fertilization might affect the variation of leaf and fruit nutrient concentrations in carob tree (*Ceratonia siliqua* L.) under low precipitation. A field study was conducted in 1997, 1998, and 1999 in a calcareous soil. Four fertilization treatments were tested: no fertilizer (C), 0.8 kg N $tree^{-1}$ (N treatment), 0.83 kg K $tree^{-1}$ (K treatment), and 0.80 kg N $tree^{-1}$ plus 0.83 kg K $tree^{-1}$ (NK treatment). During the hydrological cycle 1998/1999, only 250 mm of rain were recorded. Because of this, from 1998 to 1999 a decrease in the concentrations of mobile nutrients N, phosphorus (P), and K and an increase in calcium (Ca), iron (Fe), and manganese (Mn) were observed in leaves. The application of N led to higher leaf N concentration compared with other treatments. This response allowed the establishment of a linear model that relates soil plant analysis development (SPAD) readings with leaf N concentrations ($r^2 = 0.55$; $P < 0.05$). Compared with leaves, fruits showed similar amounts of N and P; less Ca, Mg, Fe, and Mn; and high concentrations of K. Fertilization did not change considerably the mineral composition of fruits, and because of large variation among trees, yield was similar for all treatments.

Keywords: Fruits, nutrients, SPAD, yield

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INTRODUCTION

Intensive agriculture relies on a nonlimiting water supply.In these conditions, higher yields and improved quality of agricultural commodities are expected. In the Mediterranean basin, under water-shortage conditions, mixed dry-farming orchards of fig, almond, and carob trees are quite common. From these orchards, important economic revenues are taken without irrigation. The carobtree plays an important role in the economy of the south of Portugal. Portugal produces 45,000 tons of carob each year, making it the third-largest world producer (Freitas and Graça 2002). The endosperm of the seed is a polysaccharide (locust bean gum, LBG), which is used in the human food industry as a thickener and stabilizer. The mineral composition of the fruit in relation to soil nutrient availability is not known, and recently industrial manufacturers of LBG found a nutritional imbalance in the seeds that negatively affects the quality of the LBG (personal communication).

New plantations are now being planted in marginal, low-fertility soils to control desertification and prevent erosion. Most of the orchards are not irrigated, and farmers rely on annual precipitation to obtain reasonable yields. In regions where precipitation is less than potential evapotranspiration, the cations released by mineral weathering accumulate because there is not enough rain to leach them away from the soil profile. In these conditions, the pH is normally in the alkaline range (Brady and Weil 2002). The basic anions are carbonate and bicarbonate, and their presence leads to severe nutritional deficiencies at the plant level, namely iron (Fe) and zinc (Zn) chlorosis. It is estimated that from 20 to 50% of fruit trees in the Mediterranean basin suffer from this disorder (Jaegger, Goldbach, and Sommer 2000). Moreover, reduced tree water status may substantially enhance nutrient stress as a result of the disruption of the transpiration stream and a decreased phloem transport of ions (Pitman 1981). Under dry climates, root distribution depends mainly on the irrigated soil volume, meaning that under dry-farming conditions plants must explore deep-water sources to acquire nutrients.

Taking into account that the carob tree lacks symbiotic nitrogen (N) fixation, like most leguminous plants (Martins-Loução 1985), root N supply becomes extremely important for tree growth, and N application deserves special attention. The application of excessive amounts of N to increase yield is not uncommon in temperate climates (e.g., Tagliavini et al. 1996). To avoid nitrate contamination of water resources, N application should be optimized to meet plant demand. For evaluation of the N status in leaves, the leaf chlorophyll meter (SPAD-502) has been used to estimate total N concentration in peach (Tagliavini et al. 1996), *Citrus* (Intrigliolo et al. 2002), and forage grasses (Madakadze et al. 1999). Nitrogen assessment using SPAD readings needs proper calibration, and normally this is achieved by testing different amounts of N.

In a mature nonirrigated carob tree orchard, located on a calcareous soil in southern Portugal, Correia and Martins-Loução (2004) studied the effects of N and potassium (K) applications on the vegetative and reproductive growth during 3 years. It was observed that under extreme dry conditions (hydrological cycle 1998–1999), vegetative growth (measured by branch length increment) was totally suppressed and leaf area index decreased, though flowering was enhanced. It was hypothesized that under dry conditions the addition of fertilizers, particularly N, will significantly affect tree nutrient concentrations. To understand if fertilizer addition will prevent carob yield impairment under water-stress conditions, the objectives of this work were to evaluate (1) whether fertilizer addition will dilute seasonal leaf and fruit nutrient concentrations and (2) the leaf-to-fruit pathways based on the relationships between leaf and fruit nutrients.

MATERIALS AND METHODS

A nonirrigated mature carob tree orchard (approximately 15 years old), established at 7×6 m spacing and located in southern Portugal (37° 03′ N; 7° 35′ W), was used for this experiment. The experiment started in April 1997 and finished in October 1999. Four fertilizer treatments were tested, each with 12 trees distributed in a complete randomized design, because soil was homogenous throughout the plot. The treatments were no fertilizer (control treatment); 0.80 kg N tree^{-1} year^{-1} (N treatment); 0.83 kg K tree^{-1} year^{-1} (K treatment); and 0.80 kg N plus 0.83 kg K tree^{-1} year^{-1} (NK treatment). Nitrogen fertilizer contains 26% of N with equal amounts of nitrate and ammonium and was applied once in the beginning of April in 1997, 1998, and 1999. It was expected that the last rainfall events would dissolve the fertilizer. Fertilizer was spread over the area below the canopy and was mixed with soil to avoid ammonia volatilization. Potassium fertilizer had 50% of potassium sulphate and was applied in the same way as the N fertilizer.

The climate of this region is typically Mediterranean. Reference crop evapotranspiration (ETo) at the site was calculated for each month, using the modified Penman method and the computer program CROPWAT (FAO). However, no ETo records were available in 1999. Maximum ETo was 6.04 mm d^{-1} and 5.53 mm d^{-1} registered in June 1997 and July 1998, respectively. Precipitation was recorded every month from April 1997 to December 1999 in a nearby meteorological station.

At the start of the experiment, a composite soil sample was made from three different locations, at 30–40 cm deep, and considered as representative of the initial soil fertility conditions. The soil had 16.0 g kg^{-1} organic matter, 17.5% active lime, 10.9 mg phosphorus (P) kg^{-1}, and 269 mg K kg^{-1}. In the second year of the experiment (1998), three soil samples were collected at 40 cm deep, in each fertilization treatment, corresponding to each block. The samples were oven-dried for 48 h at 30°C and sieved through a 2 mm mesh. Potassium and P were extracted using a solution of ammonium lactate and acetic acid (Riehm 1958). The P content in the extract was quantified colorimetrically, and K was quantified by flame photometry (Isaac and Kerber 1971). Soil pH was determined in a soil–water (1:2.5) suspension and organic C by oxidation of dichromate (Walkley and Black 1934). A correction factor (1.724) was used to convert organic carbon C in soil organic-matter content (Walkley and Black 1934). Total carbonates were measured by quantifying the CO_2 produced from the reaction of soil with hydrochloric acid (HCl) (Allison and Moodie 1965) and active lime ($CaCO_3$) by the Drouineau (1942) method.

Mineral Composition of Leaves and Fruits, and Nitrogen Assessment

Three composite samples consisting of 30–40 mature leaves each were randomly collected in each treatment, irrespective of the type of branches, in all canopy orientations. Leaves were collected every month from May 1997 until October 1999. Fruits were sampled once per year, in June 1997, April 1998, and June 1999, before ripening stage. In fruits, the variation in sampling dates between years is related to the stage of fruit enlargement, which is not coincident every year. Plant material was washed and dried at 60°C for 48 h. Nitrogen was determined by the Kjeldhal method, K by flame photometry, and P colorimetrically. Calcium (Ca), magnesium (Mg), and micronutrients [iron (Fe), manganese (Mn), and zinc (Zn)] were measured by atomic absorption spectrometry. Standardized procedures for measuring the mineral nutrients concentration followed the guidelines of the AOAC (1990). Concentrations were expressed on a dry-matter basis.

Six trees per treatment were selected for leaf chlorosis evaluation. On each selected tree, eight branches were marked on the external side of the canopy and the terminal 100 cm was labelled. The degree of leaf chlorosis was evaluated using a portable SPAD-502 meter (Minolta Co., Osaka, Japan). SPAD readings were taken in mature leaves (middle third of the branch) in all the selected branches ($n = 48$), on five dates: April 1998, October 1998, February 1999, June 1999, and February 2000. These dates are representative of critical phenological stages of this crop: fruit enlargement and shoot growth (April), flowering (October), and vegetative rest (February).

Fruit Production

Carob pods were harvested in October 1997, 1998, and 1999 and expressed as kg per tree.

Statistical Analysis

Differences between treatments were compared by analysis of variance and means were compared using the Duncan multiple range test at 95%. For SPAD readings, each selected branch was considered as a replicate in data analysis (n = 48). In leaves, each sampling date (n = 21 months) was considered as a replicate, and one-way ANOVA was used to compare trends throughout the 3 years. Seasonal variations of leaf nutrients were also analyzed by choosing the best-fitted model, expressed by the higher correlation coefficient (r^2). In fruits, three replicates per treatment were used. Each replicate is a mixture of 30–40 pods randomly collected. Regressions were performed between leaf and fruit nutrients. All the statistical analyses were made using the software program SPSS.

RESULTS

Between October 1998 and June 1999 (Figure 1), 250 mm of rain were registered, half of the amount found in the previous year. This was mainly due to the very low values recorded between October and December 1998: only 14 mm.

In Table 1, the soil analysis made 1 year after the start of the experiment is shown. No effects of the fertilizers are visible, particularly on extractable K concentration, and the values obtained are similar to those registered before the application of fertilizer.

Nutrient concentrations in fruits were very similar between treatments in 1997 and 1998 (Table 2). In 1997, fruits of trees fertilized with K had more Fe than trees fertilized with N and K (NK treatment); but this was the first year of the experiment, and fruits were already growing at the time of fertilizer application. In 1999, greater concentrations of N were found in fruits of N and NK treatments (Table 2). Mobile nutrients (N and P) decreased in 1999, and

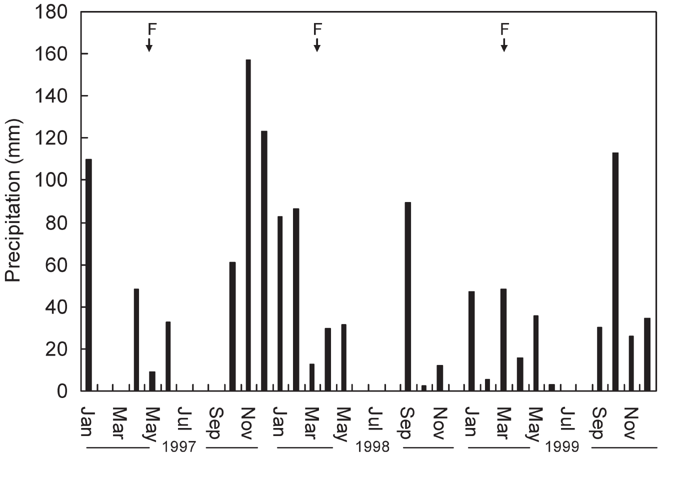

Figure 1. Seasonal variation of precipitation. “F” indicates the dates of fertilizer application.

Table 1. Soil chemical analysis in 1998 at 40 cm deep

Treatment	P (mg kg^{-1})	K (mg kg^{-1})	Organic matter (%)	pH (H_2O)	Total $CaCO_3$ (%)	Active lime (%)
C	14.0 a	229.1 a	1.5 b	7.9 a	67.9 a	17.2 a
N	20.9 a	242.4 a	1.6 ab	7.8 a	67.7 a	15.9 a
K	23.2 a	212.5 a	1.6 ab	8.0 a	69.1 a	17.2 a
NK	23.2 a	225.8 a	2.1 a	7.9 a	70.3 a	17.3 a

Notes: In each column, means followed by the same letter are not significantly different at $P < 0.05$ as estimated using DMRT, $n = 3$.

inversely, Ca concentration increased in the same year (Table 2). Similar trends were not so clear in micronutrients, but Mn concentrations also showed a significant year effect (Table 2).

Seasonal trends of leaf nutrients are shown in Figures 2 and 3. For most macronutrients, seasonal variations were more visible than differences because of the application of fertilizer. Based on the line fitted to all data points, it is possible to observe a decrease in N, P, and K leaf concentrations in 1999, which was independent of treatments. Slight interannual changes can be seen in 1997 and 1998. Leaf N was higher in winter 1997 and in the beginning of spring, but the same trend was not registered 1 year later. However, trees fertilized with only N (N treatment) showed higher leaf N throughout the years (Table 3), particularly in 1997 and 1998 (Figure 2). Phosphorus was more concentrated in leaves sampled in spring 1998 than in other sampling dates, but in 1999 this response was not observed. The variation of K in leaves also showed a marked decrease in April 1999. Unlike the other nutrients, leaf Ca concentrations increased in 1999, showing a different seasonal pattern. Magnesium did not show a clear seasonal variation and was constant throughout the experimental period.

Leaf Fe (Figure 3) concentration is similar between treatments and also constant in 1997 and 1998. In 1999 a slight increase was registered, but it was not as clear as Ca. Leaf Mn increased in 1999, and trees fertilized with N had greater Mn concentration than with the other treatments (Table 3). The variation of Zn is poorly consistent, showing an unclear pattern. Apparently the application of N and K (NK treatment) to the trees lowered Zn concentration in the leaves (Table 3).

Positive relations were found between leaf and fruit nutrients (Table 4), but only for P, Ca, Mn, and Zn are those relations significant. For Zn, an inverse trend is obtained, meaning that higher fruit nutrient concentrations are coupled with low concentrations in the leaves.

Fruit production was similar in all treatments, showing large standard deviations among treatments, but a significant increase was observed from 1997 to 1999 (Table 5). In 1999 and 1998, leaf nutrient concentrations

Table 2. Fruit mineral composition in June 1997, April 1998, and June 1999

Element	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})	Ca (g kg^{-1})	Mg (g kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})
June 1997								
C	15.5 a	1.6 a	12.3 a	4.7 a	0.8 a	18.3 ab	20.0 a	13.0 a
N	16.3 a	1.5 a	12.5 a	5.0 a	0.8 a	21.7 ab	19.7 a	14.7 a
K	15.4 a	1.5 a	13.1 a	6.2 a	0.9 a	33.3 a	19.7 a	14.0 a
NK	15.8 a	1.5 a	12.0 a	4.9 a	0.8 a	10.0 b	14.3 b	14.0 a
April 1998								
C	14.5 a	1.5 a	14.0 a	3.6 a	0.8 a	17.7 a	11.3 a	12.0 a
N	17.2 a	1.6 a	13.7 a	3.5 a	0.8 a	18.0 a	17.3 a	12.7 a
K	16.9 a	1.6 a	13.9 a	3.2 a	0.8 a	15.0 a	12.3 a	14.0 a
NK	15.5 a	1.6 a	12.7 a	3.6 a	0.7 a	14.7 a	13.3 a	12.7 a
June 1999								
C	13.0 b	1.2 a	13.6 ab	7.0 a	0.8 a	35.7 a	20.7 a	13.7 a
N	15.7 a	1.2 a	12.3 b	9.6 a	0.8 a	25.0 b	20.7 a	13.3 a
K	12.7 b	1.2 a	14.0 a	7.2 a	0.7 a	26.7 ab	20.3 a	11.7 a
NK	14.9 a	1.2 a	13.5 ab	6.7 a	0.8 a	28.0 a	20.3 a	13.3 a
Year effect	ns	**	ns	**	ns	ns	**	ns

Notes: For each year, column means followed by the same letter are not significantly different at $p < 0.05$ as estimated using DMRT, $n = 3$. Year effect was analyzed by one-way ANOVA, combining all treatments.

**Significant at $P < 0.01$; ns: nonsignificant.

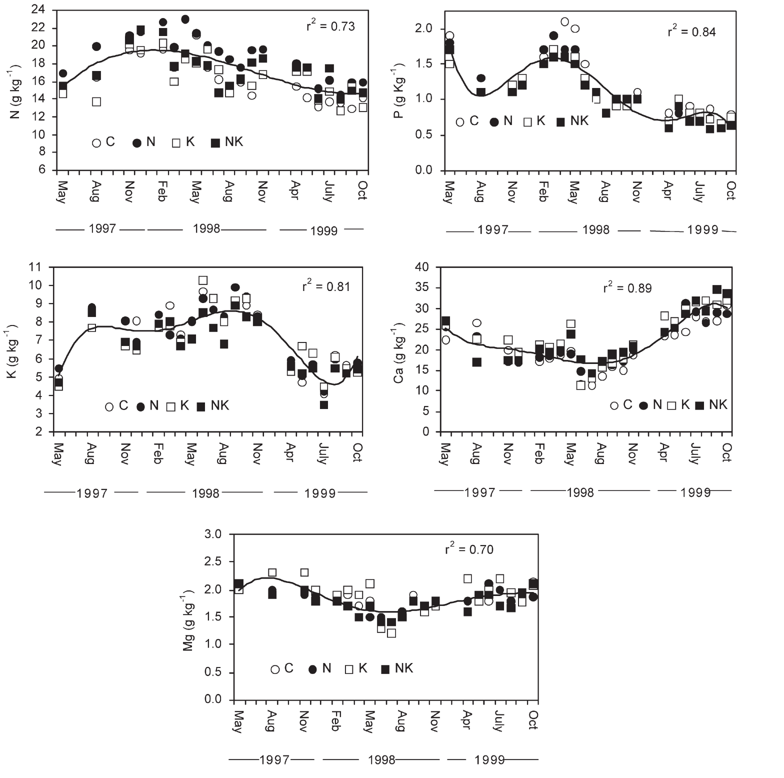

Figure 2. Seasonal variations of leaf macronutrients throughout the experimental period. Each point is the mean of three composite samples.

determined in May, June, and July for all treatments were compared (Table 6). Nitrogen, P, and K were significantly lower in a heavy crop year (1999), and the remaining nutrients, with the exception of Zn, were greater.

Evaluation of leaf chlorosis was made using SPAD readings. Trees fertilized with N (N treatment) showed higher values of SPAD in several selected dates (Figure 4). SPAD readings can be used to estimate leaf N in the same dates, because a positive and liner regression was obtained between SPAD readings and leaf N concentration (Figure 5).

DISCUSSION

Fertilization Effects on Seasonal Variations

A strong seasonality effect is clear (Figures 2 and 3) for almost all leaf nutrients, independent of fertilizer addition. An important year effect on the nutrient concentrations in the flowers of irrigated *Citrus* trees were also

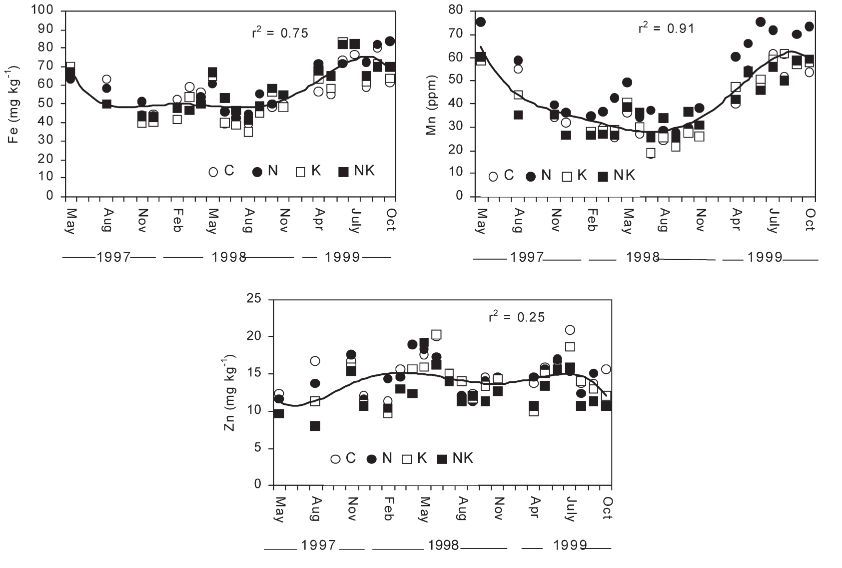

Figure 3. Seasonal variations of micronutrients throughout the experimental period. Each point is the mean of three composite samples. The model describes the combined data (all the treatments as one).

observed by Pestana et al. (2004). The observed decrease in the mobile nutrients (N, P, and K) between 1998 and 1999 (Figures 2 and 3; Table 2) may be explained by the very low soil water availability during that hydrological year (Figure 1). In this orchard, only 250 mm of rain were recorded in that period, leading to a decrease in leaf area index and a complete suppression of shoot growth in 1999 (Correia and Martins-Loução 2004). Under these water-stress conditions, soil nutrient acquisition is reduced. Growth and maintenance is thus assured by labile pool nutrients remobilization with consequent dilution in leaves. Only the more static elements such as Ca, Fe, and Mn may

Table 3. Leaf nutrients seasonal variation affected by fertilization treatments

		Fertilization treatments			
Leaf nutrient	P	C	N	K	NK
N (g kg^{-1})	0.004	16.2 b	18.7 a	16.4 b	17.2 b
Zn (mg kg^{-1})	0.009	15.3 a	14.5 a	13.8 ab	12.6 b
Mn (mg kg^{-1})	0.050	38.6 b	49.8 a	38.4 b	39.5 b

Notes: In each row, means (each sampling date was considered a repetition for statistical analysis) followed by the same letter are not significantly different at $p < 0.05$ as estimated using DMRT, $n = 21$.

Table 4. Regression models and correlation coefficients (r^2) between leaf (x) and fruit (y) mineral concentrations

Nutrient	Equation	r^2	*P*
N	$y = 0.2614\ x + 10.873$	0.09	0.349
P	$y = 0.3895\ x + 0.8588$	0.88	0.000
K	$y = 0.2660\ x + 11.509$	0.31	0.061
Ca	$y = 0.0175\ x^{1.8141}$	0.59	0.003
Mg	$y = 0.207\ x + 0.400$	0.28	0.078
Fe	$y = 0.2182\ x + 9.173$	0.04	0.551
Mn	$y = 0.1891\ x + 7.913$	0.63	0.002
Zn	$y = -0.285\ x + 17.241$	0.40	0.029

Notes: Sampling dates of the fruit are those indicated in Table 2, and for leaves, values of the previous months were used.

have remained. Nevertheless, the results showed that N fertilizer treatments present a slightly higher leaf N content compared to other treatments (Table 3; Figure 2), which is in accordance with previous studies on carob orchards (Correia and Martins-Loução 1997). Leaf N concentration was already found to be an indicator of seedling productivity (Cruz, Martins-Loução, and Lips 1993) and carob yield (Correia and Martins-Loução 1995). In *Quercus*, *Citrus*, and olive trees, crops that are distributed along the same edaphoclimatic conditions, similar increments of leaf N concentrations under water-stress conditions were observed (Carranca, Baeta, and Fragoso 1993; Marín Benlloch, and Fernandéz-Escobar 1995; Sabaté and Gracia 1994). Because N integrates the chlorophyll molecule (Mengel and Kirkby 2001), the positive effect of the application of N alone or with K was clear in the augment of SPAD readings (Figure 4), particularly in 1998. In spite of the decreasing trend of SPAD units from April 1998 until June

Table 5. Fruit production (kg $tree^{-1}$) for all treatments in 1997, 1998, and 1999

Treatments	1997	1998	1999
C	16.7 ± 9.5 a	24.8 ± 9.7 a	39.9 ± 14.3 a
N	15.1 ± 6.1 a	31.9 ± 9.8 a	41.2 ± 12.9 a
K	22.2 ± 11.2 a	32.0 ± 11.4 a	40.2 ± 13.6 a
NK	21.8 ± 24.8 a	28.6 ± 22.7 a	40.7 ± 13.0 a
Year effect		**	

Notes: In each column, means (± standard deviation; n = 6) followed by the same letter are not significantly different at $p < 0.05$ as estimated using DMRT. Year effect was analysed by one-way ANOVA, combining all treatments,

**Significant at $p < 0.01$.

Table 6. Leaf nutrients concentrations observed in 1998 and in 1999

	Nutrients							
Year	N	P	K	Ca	Mg	Fe	Mn	Zn
1998	18.44	1.37	8.59	16.34	1.50	50.3	32.6	16.9
1999	15.33	0.83	5.08	27.59	1.92	73.0	58.1	16.3

Notes: The values used are referred to leaves collected in May, June, and July. All treatments were combined as one. All differences are significant ($p < 0.05$, according to the *F* test) except for Zn. Macro- and micro-nutrients are expressed as g kg^{-1} and mg kg^{-1}, respectively.

1999, mean values were similar to those obtained by Correia, Pestana, and Martins-Loução (2003) in hydroponic cultures. SPAD apparatus has been extensively used for estimating total leaf chlorophyll in fruit trees (Abadía, Poc, and Abadía 1991; Pestana et al. 2001). Thus, the model here established (Figure 5) can be used to assess N status under field conditions using nondestructive methods. Tagliavini et al. (1996) in peach and Intrigliolo et al. (2002) in *Citrus* also established similar models.

As observed previously by Correia (1996) in irrigated carob trees located in an acid soil, and or by Oliveira et al. (1996) in cork tree, leaf Mg concentration (Figure 2) did not change significantly over time.

Manganese concentration values are lower than those found for carob trees in acid soils (Correia 1996). This response is probably related to the competing effect of Ca and pH in alkaline soils (Mengel and Kirkby 2001) as occurred in this study (Table 1). In spite of some differences due to fertilization (Table 3), Zn variation was not clear, and the model was poor ($r^2 = 0.25$).

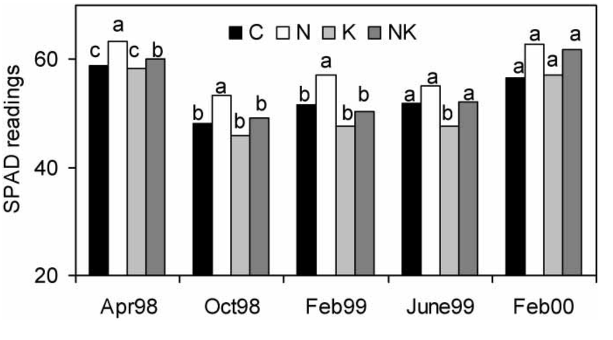

Figure 4. Variations of SPAD readings in mature leaves of all treatments. In each date, columns followed by the same letter are not significantly different at $p < 0.05$ as estimated using DMRT.

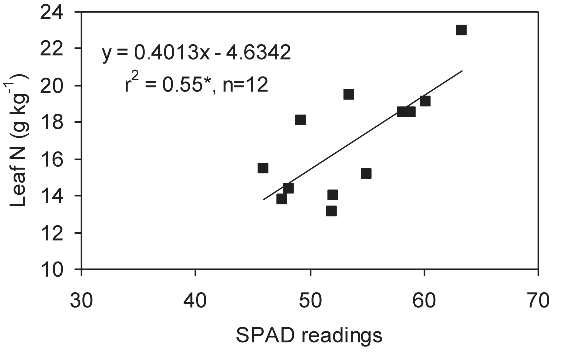

Figure 5. Regression between SPAD readings and leaf N. Measuring dates are the same as those indicated in Figure 4. For both variables, means were used. The year 2000 was excluded.

Leaf–Fruit Pathways

Compared with leaves, and in a concentration basis, developing carob tree fruits have similar amounts of P and N, more K (almost twice), and less Ca, Mg, Fe, and Mn (Table 2). It is possible to assume that carob tree pods are strong sinks for the major macronutrients, in particular K, confirming the results of Cruz, Cabrita, and Martins-Loução (1988). This is also observed in nuts of *Pistacia vera* L. (Rosecrance, Weinbaum, and Brown 1996), a Mediterranean crop. The importance of K in the loading of sucrose is known (Mengel and Kirkby 2001), and this role is behind the high fruit K demand. In 1999, K was mobilized for fruits and K fertilization probably enhanced this response. In the same year, a decrease in P in the fruits of all treatments is clear. This fact may suggest that P dynamics was more sensitive to climatic conditions than K. Apparently the adverse climatic conditions affected negatively the movement of P to leaves and fruits, which explains the positive and significant relationship between leaves and fruit P (Table 4). Positive relationships may indicate that both organs act as nutrient sinks. Similar relations were obtained for Ca and Mn, but compared with leaves, fruits are weak sinks for these elements.

Heavy crop load in 1999 (Table 5) is also related to a decrease in leaf concentrations of the same elements in the period May, June, and July (Table 6). Thus, besides the effect of water-stress conditions already discussed, the high number of fruits in spring may also influence the dynamics of leaf nutrients such as N, P, and K, which decreased in a heavy crop year (1999) if no new soil nutrient is taken up because of water limitations. In mature, nonirrigated olive trees, (Fernández-Escobar, Moreno, and Garía-Creus 1999) also found that leaf N, P, and K contents were affected by crop load, showing lower values following the "on" year. Considering that in 1999 no vegetative growth occurred (also a nutrient sink demand) (Correia and Martins-Loução

2004), N and K were possibly translocated to fruits. The importance of N, P, and K in carob nutrition is supported by the model established by Correia et al. (2002), which allows yield estimations based on the concentrations of N, P, K, Mn, Fe, and Zn.

Under dry-farming conditions, autumn and winter precipitation is essential for carob tree growth. Tous and Battle (1997) indicate an amount of 500 mm per year to obtain reasonable yields. A limitative threshold level (250 mm) for this crop with respect to mineral composition of leaves and fruits can be established. Under this climatic stress, the major macronutrients were negatively affected in leaf tissue, but N and K were at least ensured for fruits. It would be interesting to know the possible effects on endogenous pools. However, under nonlimiting rainfall conditions, as occurred in 1997 and 1998, the application of – as proposed in this article may be enough to ensure tree endogenous pools. The increase of leaf N throughout the year (as observed in this study) is a reserve for the new spring flush, and for fruit set and enlargement. This cycle cannot be interrupted in low fertility soils, and carob tree presents several mechanisms to overcome nutritional and water stress. Nitrogen addition was already proven to be a good strategy for carob fruit yield improvement (Correia 1996), emphasizing the role of N on carob physiological responses at different ages and plant development (Cruz, Cabrita, and Martins-Loução 1988; Cruz, Lips, and Martins-Loução 2003). This knowledge shows the monitoring of leaf N concentrations is crucial under productive farm conditions. Thus, the use of a nondestructive method such as SPAD turns to be an important tool to screen possible deficiencies in carob orchards.

These observations may also be important in the establishment of forecast models of crop response to future climatic changes, knowing that water shortage is a possible scenario in southern Europe.

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REFERENCES

AOAC. (1990) Association of Official Agricultural Chemists. *Official Methods of Analysis*; Washington, D.C.

Abadía, A., Poc, A., and Abadía, J. (1991) Could iron nutrition status be evaluated through photosynthetic pigment changes. *Journal of Plant Nutrition*, 14: 987–999.

Allison, L.E. and Moodie, C.D. (1965) Carbonates. In *Methods of Soil Analysis Part 2*; Black, C.A. (ed.); ASA, CSSA and SSSA: Madison, Wisc., 1379–1400.

Brady, N.C. and Weil, R.R. (2002) *Nature and Properties of Soils*; Prentice-Hall: Enaglewood Cliffs, N.J.

Carranca, C.F., Baeta, J., and Fragoso, M.A.C. (1993) Effect of NK fertilization on leaf nutrient content and fruit quality of "Valencia late" orange trees. In *Optimization of Plant Nutrition*; Fragoso, M.A.C. and Van Beusichem, M.L. (eds.); Kluwer Academic Publisher: Dordrecht, The Netherlands, 445–448.

Correia, P.J. (1996) *Efeito da rega e da fertilização com azoto na produtividade da alfarrobeira (Ceratonia siliqua L.)*; Ph.D. Thesis degree on Plant Biology. Universidade de Lisboa: Lisbon, Portugal.

Correia, P.J., Anastácio, I., Candeias, M.F., and Martins-Loução, M.A. (2002) Nutritional diagnosis in carob-tree (*Ceratonia siliqua* L.): relationships between yield and leaf mineral concentration. *Crop Science*, 42: 1577–1583.

Correia, P.J. and Martins-Loução, M.A. (1995) Seasonal variations of leaf water potential and growth in fertigated carob-trees (*Ceratonia siliqua* L.). *Plant and Soil*, 172: 199–206.

Correia, P.J. and Martins-Loução, M.A. (1997) Leaf nutrients variations in fertigated mature carob-trees (*Ceratonia siliqua* L.). *Tree Physiology*, 17: 813–819.

Correia, P.J. and Martins-Loução, M.A. (2004) Effects of nitrogen and potassium fertilization on vegetative growth and flowering of mature carob trees (*Ceratonia siliqua* L.): variations in leaf area index and water use indices. *Australian Journal of Experimental Agriculture*, 44: 83–89.

Correia, P.J., Pestana, M., and Martins-Loução, M.A. (2003) Nutrient deficiencies in carob (*Ceratonia siliqua* L.) grown in solution culture. *Journal of Horticultural Science & Biotechnology*, 78: 847–852.

Cruz, C., Cabrita, R., and Martins-Loução, M.A. (1988) Ion uptake, assimilation and allocation studies in young and mature carob (*Ceratonia siliqua* L.) plants. In *II International Carob Symposium*; Fito, P. and Mullet, A. (eds.); Generalitat Valenciana Conselleria d'Agricultura y Pesca Publishers: Valencia, Spain, 47–56.

Cruz, C., Lips, H., and Martins-Loução, M.A. (2003) Nitrogen use efficiency by a slow-growing species as affected by CO_2 levels, root temperature, N source and availability. *Journal of Plant Physiology*, 160: 1421–1428.

Cruz, C., Martins-Loução, M.A., and Lips, S.H. (1993) Effect of root temperature on carob growth: nitrate versus ammonium nutrition. *Journal of Plant Nutrition*, 16: 1517–1530.

Drouineau, J. (1942) Dosage rapid du calcaire actif des sols. *Annals Agronomy*, 1942: 441–450.

Fernández-Escobar, R., Moreno, R., and García-Creus, M. (1999) Seasonal changes of mineral nutrients in olive leaves during the alternate-bearing cycle. *Scientia Horticulturae*, : 82.

Freitas, M. and Graça, J. (2002) Evolução do pomar tradicional de sequeiro Algarvio. In *Valorização do pomar tradicional de sequeiro Algarvio*; Carvalho, A. and Madeira, E. (eds.); Universidade do Algarve: Faro, Portugal, 15–46.

Intrigliolo, F., Giuffrida, A., Rapisarda, P., Calabretta, M.L., and Rocuzzo, G. (2002) SPAD as an indicator of nitrogen status in citrus. *Proc. Intl. Soc. Citriculture IX Congress*, Proceedings of the Int. Soc. of Citriculture, IX Congress: Agadir, Morocco, 665–667.

Isaac, R.A. and Kerber, J.D. (1971) Atomic absorption and flame photometry: Techniques and uses in soil, plant, and water analysis. In *Instrumental Methods for Analysis of Soils and Plant Tissue*; Walsh, L.M. (ed.); Soil Science Society of America: Madison, Wisc., 17–37.

Jaegger, B., Goldbach, H., and Sommer, K. (2000) Release from lime induced iron chlorosis by CULTAN in fruit trees and its characterisation by analysis. *Acta Horticulturae*, 531: 107–113.

Madakadze, I.C., Stewart, K.A., Madakadze, R.M., Peterson, P.R., Coulman, B.E., and Smith, D.L. (1999) Field evaluation of the chlorophyll meter to predict yield and nitrogen concentration of switchgrass. *Journal of Plant Nutrition*, 22: 1001–1010.

Marín, L., Benlloch, M., and Fernandéz-Escobar, R. (1995) Screening of olive cultivars for salt tolerance. *Scientia Horticulturae*, 64: 113–116.

Ph.D. Thesis. Martins-Loução, M.A. (1985. *Estudos fisiológicos e microbiológicos da associação da alfarrobeira (Ceratonia siliqua L.) com bactérias Rhizobiacea*; Universidade de Lisboa: Lisbon, Portugal.

Mengel, K. and Kirkby, E.A. (2001) *Principles of Plant Nutrition*; Kluwer Academic Publishers: Dordrecht, The Netherlands.

Oliveira, G., Martins-Loução, M.A., Correia, O., and Catarino, F.M. (1996) Nutrients dynamics in crown tissues of cork-oak (*Quercus suber* L.). *Trees*, 10: 247–254.

Pestana, M., David, M., de Varennes, A., Abadía, J., and Faria, E.A. (2001) Responses of "Newhall" orange trees to iron deficiency in hydroponics: Effects on leaf chlorophyll, photosynthetic efficiency and root ferric chelate reductase activity. *Journal of Plant Nutrition*, 24: 1609–1620.

Pestana, M., de Varennes, A., Goss, M.J., Abadía, J., and Faria, E.A. (2004) Floral analysis as a tool to diagnose iron chlorosis in orange trees. *Plant and Soil*, 259: 287–295.

Pitman, M.G. (1981) Ion uptake. In *The Physiology and Biochemistry of Drought Resistance in Plants*; Paleg, L.G. and Aspinall, D.T. (eds.); Academic Press, Inc.: London, 70–93.

Riehm, H. (1958) Die ammoniumlaktatessigsaure-methode zur bestimmung der leichtloslichen phosphosaure in karbonathaltigen boden. *Agrochimica*, 3: 49–65.

Rosecrance, R.C., Weinbaum, S.A., and Brown, P.H. (1996) Assessment of nitrogen, phosphorus, and potassium uptake capacity and root growth in mature alternate-bearing pistachio (*Pistacea vera* L.) trees. *Tree Physiology*, 16: 949–956.

Sabaté, S. and Gracia, C.A. (1994) Canopy nutrient content of a *Quercus ilex* L. forest: fertilization and irrigation effects. *Forest Ecology and Management*, 68: 31–37.

Tagliavini, M., Scudellazi, D., Marangoni, B., and Toselli, M. (1996) Nitrogen fertilization management in orchards to reconcile productivity and environmental aspects. *Fertilizer Research*, 43: 93–102.

Tous, J. and Battle, I. (1997) *El Algarrobo*; Mundi-Prensa Publishing: Madrid, Spain.

Walkley, A. and Black, I.A. (1934) An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science*, 37: 29–38.