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Effect of Soil Management on Olive Yield and Nutritional Status of Trees in Rainfed Orchards

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Studies on the effect of groundcover treatments on perennial tree crops have been common in recent decades. However, few have included leaf analysis as an aid to understand the effects of groundcover treatments on tree crop growth and yield, in particular in rainfed olive orchards. Field experiments took place in northeast Portugal, over the course of eight consecutive years, in two commercial orchards selected on the basis of their contrasting situation regarding the floor-management system before the trial started. An orchard located in Bragança, currently managed as a sheep-walk, received the following treatments: sheep-walk (SW), where the natural vegetation was managed with a flock of sheep; mechanical cultivation (MC), which consisted of two tillage trips per year in the spring; and glyphosate (Gly), where the herbicide was applied once during the first fortnight of April. Another orchard near Mirandela, currently managed by tillage, received the following treatments: mechanical cultivation (MC); glyphosate (Gly); and residual herbicide (RH), where an herbicide with a residual component was applied late in the winter. The trees that underwent Gly treatments produced the greatest tree crop growth and olive yield. The worst results were achieved with the SW and MC treatments in the Bragança and Mirandela experiments, respectively. Leaf nitrogen (N) and boron (B) concentrations were significantly higher and lower, respectively, in the treatments that caused the higher and lower olive yields in both experiments. In the Mirandela orchard, where the leaf potassium (K) concentrations were close to the lower limit of the adequate range, the leaf K levels followed the pattern registered for N and B. The results showed a strong link between tree crop nutritional status and tree crop growth and olive yield. The groundcover treatments that facilitate nutrient absorption by olive trees yielded more crops.

Keywords Cover cropping, leaf nutrient concentration, leaf sampling date, *Olea europaea* L.

Introduction

Olive trees are extensively distributed in the Mediterranean basin. In spite of the recent increase in irrigated areas, most of the olive orchards are still cultivated under rainfed

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conditions. This practice will not change quickly, because of the natural limitation in water resources that characterizes the Mediterranean climate. Thus, it seems crucial for the olive sector in many regions to improve both the sustainability and profitability of dry-farmed orchards.

Dry-farmed orchards are often planted in shallow soils on sloping terrain. In these soils, the water-holding capacity is low and the effective rooting area is restricted to the thin top layer of soil. This shallow rooting of olive trees does not allow the plants to make the most efficient use of either plentiful winter rains or scarce summer rains. Thus, in spite of several defense strategies against water stress (Bosabalidis and Kofidis 2002; Bacelar et al. 2007), olive tree growth and olive yields are usually poor under rainfed conditions.

Mineral nutrition may also be a problem in the dry-farmed orchards. The natural pool of essential elements in the soil tends to be scarce (Rodrigues, Arrobas, and Bonifácio 2005), and the long dry periods may limit nutrient absorption (Restrepo-Diaz et al. 2008). Although olives are considered hardy plants that tolerate poor growing conditions, especially soils of poor fertility (Connell and Vossen 2007), soil fertility and tree crop nutritional status must be monitored regularly (Fernández-Escobar 2001; Freeman, Uriu, and Hartmann 2005). It is recognized worldwide that fertilization regimes that improve the nutritional status of trees may mitigate the alternate-bearing cycle of olive (Connell et al. 2002; Sibbett and Ferguson 2002).

In fruit farming, the floor-management system has great influence on tree crop growth and yield and is also decisive in preventing environmental problems (Tisdall 1989; Lipecki and Berbeć 1997; Pastor et al. 2001). Cover cropping is the most advocated floor-management system for irrigated orchards, even if some yield reduction occurs (Anderson, Bingham, and Hill 1992; Hornig and Bünemann 1993). The benefits of cover crops may include reduced soil erosion and increased soil fertility and biodiversity (Lipecki and Berbeć 1997). In dry-farmed olive orchards, the ground must be managed to save water and improve nutrient-use efficiency. In these orchards, cover cropping may be a high-risk option, because of the possibility of severe competition for resources. Thus, this technique must be carefully analyzed and compared with other alternative groundcover systems.

There are many published studies on the effect of groundcover systems on tree crop growth and yield in the context of irrigated fruit farming. The work that has been carried out in rainfed olive orchards is comparatively limited but also relevant. However, few studies have included leaf analysis as an aid to understand the effect of soil-management systems on dry-farmed olive orchards. Thus, this work focused not only on the effects of groundcover on tree crop growth and yield, but also on leaf composition with regard to the most relevant nutrients in olive nutrition. In addition, since the resting period of winter has been considered as a reliable sampling period for diagnosing the nutritional status of olive orchards, the nutrient concentrations of leaf samples taken in the summer and in the winter are also compared.

Materials and Methods

Site Description

The field experiments were carried out in northeastern Portugal in two commercial olive orchards, cv. Cobrançosa, grown in rainfed conditions. One experiment was located in Bragança (41° 48′ N; 6° 44′ W) in a mature orchard (≈60 years old) with 200 trees ha^{-1}. The other experiment was located in Mirandela (41° 31′ N; 7° 12′ W) in a younger olive orchard (13 years old) with 240 trees ha^{-1}. The orchards were selected based on their contrasting situation regarding the floor-management system before the start of the trial.

The Bragança orchard had been managed in the past under a sheep-walk, whereas the orchard of Mirandela had been managed under mechanical cultivation.

Mirandela experiences a typical Mediterranean climate, hot and dry in the summer season, whereas Bragança is located at the northern limit for olive, with a cooler and wetter climate. Mean annual temperature and annual precipitation in Mirandela and Bragança are 14.2 °C and 11.9 °C and 520 mm and 741 mm, respectively. The orchards are both planted in Leptosols derived from schist. The orchard of Bragança is planted in a soil with a slope of 2% (E–W) and with an effective depth of about 30 cm. The Mirandela orchard is planted in a soil with a slope of 4% (N–S) and with an approximate depth of 20 cm. In October 2001, in the Bragança and Mirandela orchards, the soil organic carbon (C) was 5.8 and 3.7 g kg^{-1}, respectively, pH (soil/water, 1:2.5) of values were 6.0 and 5.5, extractable phosphorus (P) (Egner-Rhiem) amounts were 24 and 23 mg kg^{-1}, extractable potassium (K) (Egner-Rhiem) was measured as 67 and 48 mg kg^{-1}, exchangeable calcium (Ca) (ammonium acetate, pH 7) was found to be 11.4 and 3.16 $cmol_c$ kg^{-1}, exchangeable magnesium (Mg) (ammonium acetate, pH 7) was 3.2 and 2.4 $cmol_c$ kg^{-1}, and soluble boron (B) (boiling-water and azomethine-H procedure) was 0.13 and 0.11 mg kg^{-1}.

Experimental Design

The orchards were divided into three plots to accommodate the different groundcover treatments. In the Bragança orchard, the treatments were sheep-walk (SW), where a permanent sward was grazed with a flock of sheep; mechanical cultivation (MC), the conventional method in the region, which consisted of two tillage trips per year with a cultivator (in spring and early summer); and glyphosate [360 g L^{-1} of active ingredient (a.i.)] (Gly), a nonselective herbicide applied once during the first 2 weeks of April at a rate of 4 L ha^{-1}. In the Mirandela orchard, three treatments were also established: mechanical cultivation (MC), maintaining the current groundcover system of the farmer (similar to the methodology implemented in the Bragança orchard); glyphosate (Gly), similar to that of the Bragança experiment; and residual herbicide (RH), an herbicide with a nonselective component (glyphosate, 150 g L^{-1} a.i.) plus a residual component (diuron, 212.5 g L^{-1} a.i. + terbuthylazine, 237.5 g L^{-1} a.i.), applied annually late in the winter in a rate of 6 L ha^{-1}.

Ten and 12 similar trees per treatment were preselected, respectively, in the Bragança and Mirandela orchards. This preselection of trees was performed in October 2001, before the groundcover systems had been established, and was based on the size and the similarity of the tree canopies. The objective was to reduce the experimental variability associated with the different size of the trees, a very common aspect of dry-farmed orchards.

Crop Husbandry

The fertilization of the Bragança orchard included 1.5 kg $tree^{-1}$ yr^{-1} of a compound 10:10:10 (10% N, P_2O5, K_2O) fertilizer and borax (11% B) at the rate of 7.7 g B $tree^{-1}$ yr^{-1}. In the Mirandela orchard, the compound 10:10:10 fertilizer was applied annually at the rate of 1 kg $tree^{-1}$, and borax was applied at the rate of 5.5 g B kg^{-1}. The fertilizers were ground applied under the canopies. The Bragança orchard was pruned in March 2003 (≈15% of foliage removed) and March 2006 (≈25% of foliage removed). The Mirandela orchard was pruned (≈33% of foliage removed) in February 2002 and March 2006. The harvest was made in December of each year, and the crops were recorded per individual tree. The harvest of the Bragança orchard was performed by conventional means, using wood sticks to pull the fruit down and sheets on the floor to recover it. In the Mirandela orchard, the harvest was performed by a trunk-shaker machine.

Tree Crop Performance Measurements

In December 2001, an initial harvest was made to check the homogeneity and the yield potential of the preselected trees of the different plots. This first harvest was performed before the establishment of the groundcover systems. Thereafter, seven more harvests (Dec 2002 to Dec 2008) were made to compare the effect of the three groundcover systems that were established in each of the orchards.

In the younger Mirandela, orchard the trunk circumference and the canopy volume of the trees were also measured. The trunk circumference of each tagged tree was measured annually at 50 cm above ground level. The measurements were taken from January 2002 to January 2009, providing seven records of the annual increase in trunk circumference. The effect of the groundcover treatments on the canopy volume was estimated in February 2008. It was assumed that, under the conventional pruning system of the region, the canopy of this cultivar develops a cylindrical shape. Thus, the volume of the canopy was estimated from the equation, $\boldsymbol{V = \pi r^2 h}$, where $\boldsymbol{V}$ is the volume of the canopy (cm^3); $\boldsymbol{r}$, the radius of the crown (m); and $\boldsymbol{h}$, the height of the canopy (m). The radius of the crown is the mean of four measures taken from the trunk to the external limit of the foliage in the four quadrants of the tree. The height of the canopy is the mean of four measures taken from the base to the top of the foliage, also in four quadrants.

Leaf Analysis

Leaf samples were collected regularly in summer and winter from summer 2003 to winter 2007, at a total of eight sampling dates. The winter samples were usually taken in early February, and the summer samples were collected in late July. The leaves were selected from the middle portion of the current-season shoots, equally distributed around the tree. Each sample consisted of leaves of each preselected and tagged tree. The leaf samples were oven dried at 70 °C and ground. Tissue analyses were performed by Kjeldahl (N), colorimetry (B and P), flame emission spectrometry (K), and atomic absorption spectrometry (Ca, Mg) methods (Walinga et al. 1989).

Statistical Analysis

The effect of the groundcover treatments on annual olive yield, trunk circumference increase, and canopy volume was determined by comparing the mean confidence limits. To compare the mean leaf nutrient concentrations among the different treatments, a t-test for independent samples was performed, because data from the different field plots are independent and have normally distributed random variables (large populations). The process consisted of the estimation and testing the null hypothesis, $\mu_1 - \mu_2 = 0$, against the alternative hypothesis $\mu_1 - \mu_2 \neq 0$. To compare the mean leaf nutrient concentration between winter and summer samples, a t-test for paired data was performed, because each pair of samples come from the same tree collected in a different time. The test consisted of the determination of the difference between each pair and the analysis of the differences. The null hypothesis is $\mu_d = 0$, and the alternative hypothesis is $\mu_d \neq 0$.

Results

Initial Harvest

In the Bragança orchard, the mean olive yields in December 2001, before the different groundcover treatments had been established, were 11.3, 9.4, and 10.6 kg tree^{-1}, respectively, in the plots of the planned Gly, MC, and SW treatments. In the Mirandela orchard, the first harvest provided mean olive yields of 7.2, 6.9, and 6.2 kg tree^{-1}, respectively, in the plots of the planned MC, Gly, and RH treatments. In each orchard, the mean olive yields were not statistically different when compared by the mean confidence limit (α < 0.05). Thus, one may assume that the groups of trees that were subjected to the different groundcover treatments had similar yield potential.

Olive Yield and Tree Crop Growth

The annual records of olive yields showed significant differences among treatments for almost all the years in both the Bragança and Mirandela orchards. Thus, the cumulative crops after a period of seven consecutive harvests (December 2002 to 2008), revealed great differences among groundcover treatments in both the Bragança and Mirandela orchards (Figure 1). In the Bragança orchard, the Gly treatment produced the most crop yields every year, whereas the SW treatment produced the least. In the Mirandela orchard, the mean olive yields of December 2002 and 2008 were not statistically different among treatments. However, in the other five harvests, the Gly treatment always produced significantly more crops than the other treatments. The mean crop yield of the RH plot was also often statistically greater than that of the MC plot.

The mean cumulative olive yields of the seven consecutive harvests (December 2002 to 2008) in the Bragança experiment were 119.4, 86.1, and 55.0 kg tree^{-1}, respectively, in Gly, MC, and SW treatments. The cumulative crops of the SW and MC treatments represented only 72 and 46% relative to that of the Gly treatment. The seven harvests of the Mirandela experiment produced mean cumulative olive yields of 31.3, 54.0, and 43.7 kg tree^{-1}, respectively, in the MC, Gly, and RH treatments. The crops of the MC and RH plots represented only 57.9 and 81.0% of those of the Gly plot.

The mean annual increase in the trunk circumference of the trees in the Gly treatment was significantly greater than that of the other treatments. Thus, the trees of the Gly plot showed the highest cumulative trunk circumference increase, whereas the trees of the MC plot exhibited the lowest increase (Figure 2). The mean cumulative values of the trunk circumference increase were 6.9, 13.2, and 9.0 cm, respectively, in the MC, Gly, and RH treatments. The increases in trunk circumference in the MC and RH plots represented only 52% and 68% of the values registered in the Gly plot.

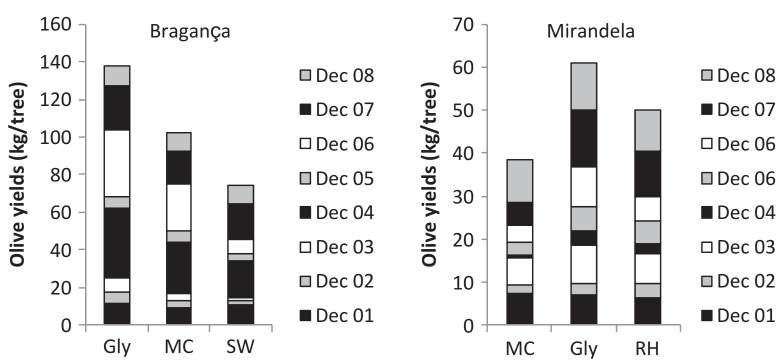

Figure 1. Mean annual and cumulative crops, including the initial one of December 2001 and the next seven crops (December 2002 to 2008), in both the Bragança and Mirandela orchards.

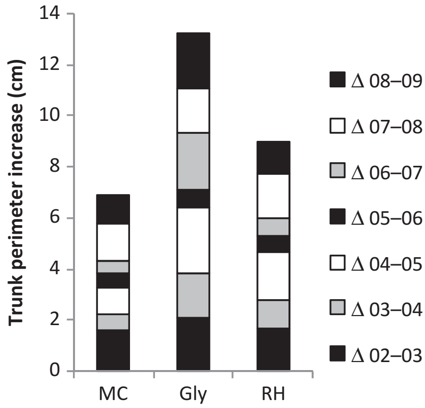

Figure 2. Mean annual and cumulative trunk circumference increase in the different treatments of the Mirandela orchard. Δ represents the variation in trunk circumference increase between two consecutive years.

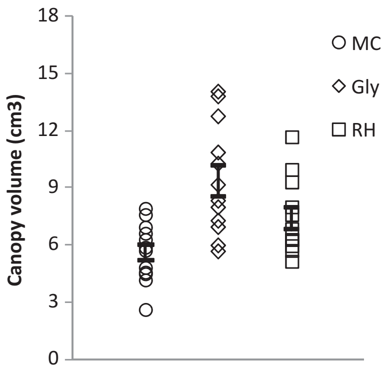

Figure 3. Canopy volumes of the trees grown under the different groundcover treatments of the Mirandela orchard in February 2008. Error bars indicate mean confidence limit ($\alpha < 0.05$).

The mean canopy volume was significantly greater in the Gly plot in comparison to the other treatments (Figure 3). Conversely, the lowest mean value was recorded for the trees of the MC plot. The canopy volumes of the trees of the MC and RH treatments represented only 59.8% and 78.7% of the Gly treatment. Thus, the groundcover treatments seem to have very similar effects on olive yields and tree crop growth.

Nutritional Status of Trees

The mean leaf nutrient concentration for the trees in each plot and experimental site varied greatly among sampling dates (Table 1). The mean leaf N concentration, for instance, varied from 16.94 to 21.13 g kg^{-1} during the experimental period in the Gly plot of the Bragança orchard. Great fluctuations in the leaf concentrations of the other nutrients were also observed over the course of the experimental period for all groundcover treatments. The fluctuations in leaf nutrient levels could be due to the crop load, pruning, rainfall, and other environmental factors.

Table 1

Mean leaf nutrient concentration of the trees of each groundcover treatment of both the experimental sites over the eight consecutive leaf sampling dates (leaf N, P, K, Ca, and Mg concentration are expressed in g kg^{-1} and leaf B concentration are measured in mg kg^{-1})

			Sampling date							
Orchard	Parameter	Element	Summer 2003	Winter 2004^{Off}	Summer 2004	Winter 2005^{On}	Summer 2005	Winter $2006^{Off, P}$	Summer 2006	Winter 2007^{On}
Bragança orchard	Glyphosate	N	21.13	20.99	18.51	16.94	19.33	17.92	20.24	18.91
		P	0.90	0.67	0.91	0.86	1.34	1.43	1.41	0.78
		K	9.46	4.30	5.02	4.20	15.06	5.99	8.78	4.65
		Ca	5.56	4.19	5.22	12.11	7.61	10.12	12.47	5.43
		Mg	0.89	0.90	0.49	2.01	1.31	1.84	1.27	0.41
		B	19.05	12.36	19.14	16.71	21.17	17.43	29.61	12.49
	Mechanical cultivation	N	20.29	20.20	17.30	16.37	17.61	16.51	19.26	18.56
		P	0.88	0.87	0.74	0.75	1.34	1.39	1.64	0.92
		K	15.07	6.08	4.57	3.81	11.74	5.29	8.75	4.24
		Ca	9.13	6.91	5.35	12.55	8.81	14.42	12.90	5.57
		Mg	2.50	1.05	0.81	1.36	1.52	1.72	1.41	0.63
		B	15.72	10.81	17.80	15.57	20.72	17.58	22.16	10.79
	Sheep-walk	N	18.26	20.34	15.29	16.33	14.03	15.56	20.44	20.46
		P	1.06	0.68	0.98	0.81	1.18	1.50	1.70	0.75
		K	14.48	5.53	4.91	4.23	12.82	6.51	8.71	4.60
		Ca	9.14	5.11	4.61	9.20	7.54	10.03	14.89	4.82
		Mg	1.38	1.19	0.73	1.26	1.23	1.07	1.13	0.43
		B	14.40	11.23	16.66	16.67	17.15	16.11	20.72	11.07
Mirandela orchard	Mechanical cultivation	N	16.17	17.74	12.65	15.81	12.02	13.31	14.79	15.58

(*Continued*)

Table 1
(Continued)

			Sampling date							
Orchard	Parameter	Element	Summer 2003	Winter 2004^{Off}	Summer 2004	Winter 2005^{On}	Summer 2005	Winter 2006$^{Off, P}$	Summer 2006	Winter 2007^{On}
		P	0.76	0.64	0.90	0.86	0.87	1.07	1.43	0.73
		K	6.62	3.74	3.31	7.97	4.13	5.78	7.29	4.60
		Ca	7.07	5.36	7.16	8.73	8.23	11.27	6.78	5.09
		Mg	1.85	1.07	2.05	1.10	1.46	1.59	1.14	0.32
		B	18.22	16.16	16.75	15.90	19.07	15.69	18.40	17.93
	Glyphosate	N	18.81	19.84	14.22	15.36	14.50	14.56	16.55	18.79
		P	0.73	0.68	0.89	0.74	1.31	1.32	1.50	0.83
		K	7.58	5.42	5.81	10.37	11.87	7.30	8.49	2.78
		Ca	5.41	5.90	6.42	7.63	7.03	8.89	5.25	4.58
		Mg	0.47	0.91	1.90	0.90	1.68	1.87	1.61	0.60
		B	23.17	17.35	20.96	16.70	19.50	16.41	19.61	20.31
	Residual herbicide	N	17.05	18.56	16.69	16.78	15.53	15.42	16.03	18.48
		P	0.92	0.94	0.78	0.84	1.11	1.09	1.29	0.71
		K	6.56	4.88	5.30	7.29	6.88	5.71	7.12	4.96
		Ca	6.10	4.74	5.01	7.95	8.96	10.58	5.58	4.90
		Mg	0.69	1.02	1.08	1.38	1.75	1.76	1.42	0.88
		B	20.66	17.12	18.74	15.60	18.57	14.64	16.39	18.57

Notes. ^{On}high, ^{Off}low, ^{F}fair crop load, and ^{P}pruning.

Table 2
Differences in the mean leaf nutrient concentrations among treatments of each orchard, determined by a t-test for independent samples (the t-test compared the groundcover treatments two by two)

	Bragança			Mirandela		
Nutrient	Gly-MC	Gly-SW	MC-SW	Gly-RH	Gly-MC	RH-MC
Nitrogen (g kg^{-1})	0.93***	1.66***	0.67*	−0.24	1.57***	1.81***
Phosphorus (g kg^{-1})	−0.10*	−0.05	0.05	−0.02	0.03	0.05
Potassium (g kg^{-1})	−0.26	−0.54	−0.28	1.36***	2.00***	0.64*
Calcium (g kg^{-1})	−1.24*	−0.33	0.91	−0.34	−1.07**	−0.73
Magnesium (g kg^{-1})	−0.19	0.12	0.31**	0.02	−0.05	−0.07
Boron (mg kg^{-1})	2.10**	2.74***	0.64	1.78***	1.99***	0.21

Notes. Significance (T ≤ t) at 0.05 (*), 0.01 (**), and 0.001 (***) levels.

In the Bragança orchard, the differences in leaf N concentration between Gly and MC, Gly and SW, and MC and SW were 0.93, 1.66, and 0.67 g kg^{-1}, respectively (Table 2). In the Mirandela orchard, the mean values of the difference were −0.24, 1.57, and 1.81 g kg^{-1} when Gly and RH, Gly and MC, and RH and MC were compared. In the Mirandela experiment, the treatments that provided greater yields also gave greater leaf N concentrations. In the Mirandela orchard, MC provided the lowest mean leaf N concentration, as well as the lowest olive yield and tree crop growth. The mean leaf P concentrations were not much dissimilar between the groundcover treatments. The difference in leaf P concentrations was only statistically significant when Gly and MC treatments of the Bragança orchard were compared (Table 2). The differences in leaf K concentration were statistically different between groundcover treatments only in the Mirandela orchard (Table 2). The difference reached 2.00 g kg^{-1} when Gly and MC treatments were compared. In the Mirandela orchard, the leaf K concentration was greater in the treatments producing the greater yields and vice versa. In the Bragança orchard, no significant differences were found in leaf K concentration between the groundcover treatments. The leaf Ca concentrations in the trees of Gly plots were lower than in the other treatments in Bragança and Mirandela orchards (Table 2). The plots where the greatest leaf N concentrations and olive yields were recorded showed the lowest leaf Ca concentrations. The mean leaf Mg concentrations were not very dissimilar among the groundcover treatments (Table 2). In addition, no coherent patterns were observed between the leaf Mg levels and the levels of the other nutrients or the tree crop growth and olive yields. In both Bragança and Mirandela orchards, the mean leaf B concentration was significantly greater in Gly than in the other treatments (Table 2). The trees in the SW and MC treatments, in the Bragança and Mirandela orchards, respectively, presented the lowest mean leaf B concentrations. The effect of the groundcover treatments on olive yield and on B nutritional status of trees demonstrated a similar trend in the Bragança and Mirandela orchards. The difference on leaf B levels between Gly and SW treatments reached 2.74 mg kg^{-1} in the Bragança orchard and 1.99 mg kg^{-1} between Gly and MC treatments in the Mirandela orchard.

The mean leaf N concentration was significantly greater in winter than in summer in the Mirandela experiment (Table 3). The mean values were 16.85 and 15.42 g kg^{-1}, respectively. However, the mean leaf N concentration in the Bragança orchard did not vary significantly between winter and summer samples. The mean leaf N concentration in

Table 3
Mean leaf nutrient concentrations for winter and summer leaf sampling dates

	Bragança		Mirandela	
Nutrient	Winter	Summer	Winter	Summer
Nitrogen (g kg^{-1})	18.26 a[a]	18.47 a	16.85 a	15.42 b
Phosphorus (g kg^{-1})	0.95 b	1.17 a	0.87 b	1.04 a
Potassium (g kg^{-1})	4.95 b	9.95 a	5.91 b	6.75 a
Calcium (g kg^{-1})	8.12 a	8.60 a	7.13 a	6.58 b
Magnesium (g kg^{-1})	1.15 a	1.21 a	1.21 a	1.33 a
Boron (mg kg^{-1})	14.09 b	19.69 a	16.82 b	19.17 a

Notes. Each value corresponds to the average of the four leaf samplings and all the three groundcover systems for each orchard. Winter includes the leaf samplings of February 2004–2007 and summer includes the sampling dates of July 2003–2006.

[a]Means followed by the same letter in the lines, separately for the Bragança and Mirandela experiments, are statistically different by Student's t-test for paired samples ($\alpha < 0.05$).

summer was even slightly greater than in winter. The mean leaf P, K, and B concentrations were statistically different between winter and summer samples. For these three nutrients, greater values were recorded from the samples taken in the summer. The mean leaf Ca concentration was significantly greater in winter than in summer only in the Mirandela orchard. No significant differences were found in leaf Mg concentration between winter and summer leaf samples for either the Bragança or the Mirandela orchard.

Discussion

Olive Yield and Tree Crop Growth

The SW treatment of the Bragança orchard produced the lowest olive yields of all the floor-management treatments. The flock did not provide an adequate control of vegetation in the spring and early summer, subjecting the tree crop to severe competition for water and nutrients in the most vulnerable growing phases, the period of flowering and fruit set. Lipecki and Berbeć (1997) noted that the first effects of the introduction of a permanent sward in an orchard is the decrease in tree growth and fruit yield, even in irrigated orchards. In an apple orchard, Hornig and Bünemann (1993) observed that in weed-free treatments (due to either herbicide or cultivation), trees developed more vigorous growth and yields, compared to cover treatments. In addition, groundcover competition for water and nutrients was not completely surmounted, even with irrigation and fertigation treatments. Studies in vineyards showed that when a cover crop was introduced in the interrows, the cover crop takes precedence in terms of water uptake from the soil surface beneath the interrow. Cover cropping forced the root system of the grapevine to explore deep layers (Celette, Gaudin, and Gary 2008). This would also be a major problem for root distribution and water and nutrient uptake in the Bragança orchard because the olive trees are planted in very shallow soil. Many other researchers reported a reduction in fruit yield in different agroenvironmental conditions with the introduction of cover cropping (Anderson, Bingham, and Hill 1992; Silvestri et al. 1999).

Mechanical cultivation is no longer used in intensive fruit farming, but it remains an entrenched practice in the most marginal rainfed areas of olive growing. In the present study, MC led to significantly lower results in terms of tree crop growth and olive yields in comparison with the Gly and RH treatments in the Mirandela experiment. In the Bragança experiment, the olive yields in the MC treatment were also significantly lower than in the Gly treatment. The poor results typically found in tilled plots are mainly attributed to the damage caused to the root system, which impairs the uptake of water and nutrients (Tisdall 1989; Anderson, Bingham, and Hill 1992; Pastor et al. 2001). In addition, many carbohydrates must be delivered from the leaves to regenerate the new root system. The destructive capacity of tillage can be particularly high in shallow soils, where almost the entire root system is destroyed.

In both the Bragança and Mirandela orchards, olive yields were significantly greater in the Gly treatment as compared to the others. The trunk circumference increase and the canopy volume of the trees in the Mirandela orchard were also greatest in the Gly treatment. The Gly treatment allowed the maintenance of a green cover from the first rains in the autumn to the first 2 weeks of April, at the time of glyphosate application. The weeds that grew in the orchards in winter and early spring necessarily took up some water and nutrients. However, cover crops reduce runoff and increase water infiltration (Pastor et al. 2001; Celette, Gaudin, and Gary 2008). Thus, improved soil water replenishment during the winter may have compensated for the water used by weeds. After the second 2 weeks of April, the needs of trees for water and nutrients increase. At this time, the soil was covered by a mulch of dead plants, killed by the glyphosate application. This mulch remained on the soil surface during the summer, contributing to runoff reduction and promoting water infiltration. The unrestricted root growth may also have been responsible for the positive results achieved in the Gly treatment. Tisdall (1989) reported similar conclusions when tillage and permanent sod or mulch systems were compared in orchards in Australia.

A bare soil surface throughout the year was achieved with the introduction of the RH treatment in the Mirandela orchard. In this groundcover treatment, the olive yield, the trunk circumference increase, and the canopy volume were more than in MC treatment but less than in Gly treatment. Tisdall (1989) pointed out that untilled bare soil sometimes exhibits increased yield as compared to tilled plots because roots are undamaged, which improves water and nutrient uptake. On the other hand, the soil surface temperature may also influence tree crop growth and yield. Tisdall (1989) reported previous work from a peach orchard in Australia where the temperatures recorded at 25 cm deep were very high under bare surface (52 °C) and tillage (49 °C) and comparatively much lower under permanent sod (24 °C). According to Tisdall (1989), higher temperatures increased water evaporation and reduced root activity, which explained the lower yields obtained under bare soil and tillage. A bare soil surface also reduces water infiltration rates (Goméz et al. 1999). The high slope and the clean surface of the RH plot of the Mirandela orchard would offer poor physical conditions for water infiltration.

Tree Nutritional Status

Despite the eight consecutive harvests, where multiple alternate-bearing situations had occurred, the leaf nutrient concentrations were not clearly related to the sequence of crop loads. Notably, Sibbett and Ferguson (2002) did not find a clear effect of crop load on leaf N concentration. However, some authors reported greater levels of major nutrients (N, P, and K) on olive leaves associated with the years of lower yields (Rouina, Trigui, and Boukhris 2002; Soyergin and Katkat 2002).

In both the Bragança and Mirandela orchards, the groundcover treatments associated with greater yields were also associated with greater leaf N concentrations and vice versa.

For both orchards, the mean leaf N concentrations were within the adequate range of 1.5 to 2.0% (Freeman, Uriu, and Hartmann 2005), though greater in the Bragança orchard. In olive, when the leaf N levels are within the adequate range, a lack of response to N additions is often reported (Fernández-Escobar and Marín 1999; Sanchez-Zamora, Marin, and Fernández-Escobar 1999). However, Jasrotia et al. (1999) reported a significant increase in growth and productivity in response to varying levels of N fertilizers. In the present study, all plots received the same level of N application, but the amount of N taken up by the trees subjected to the different groundcover systems certainly varied. It is not possible to isolate the contribution of the N nutritional status of trees to growth and yield but, based on these results, one may speculate that it was one the major involved factors.

Phosphorus deficiency is not typically observed in olive orchards, and the response to P fertilizers is considered practically nonexistent (Fernández-Escobar 2001; Freeman, Uriu, and Hartmann 2005). Thus, P additions are not usually recommended. In the Bragança orchard, the mean leaf P concentrations were within the adequate range of 0.1 to 0.3% (Freeman, Uriu, and Hartmann 2005). In the Mirandela orchard, the mean leaf P concentrations were close to the lower limit of the sufficiency range. In both orchards, the difference in leaf P concentrations between groundcover treatments was usually not statistically significant. In agreement with other studies, and considering the great differences in tree crop growth and productivity observed among the groundcover treatments, P seemed not be a major nutritional problem of these trees.

Adequate leaf K concentration is more than 0.8%, and deficient concentration is less than 0.4% (Freeman,, Uriu, and Hartmann 2005). In the Bragança orchard, the mean leaf K levels were usually within the adequate range (Table 1), and no significant differences between treatments were found (Table 2). In the Mirandela orchard, the mean leaf K levels were lower, sometimes below the adequate range (Table 1), and dependent on the groundcover system (Table 2). This orchard is planted in a shallower soil that also presented lower levels of extractable K. The dry periods in Mirandela are much longer, which may make the nutrient uptake difficult, in particular K uptake (Restrepo-Diaz et al. 2008). In addition, the fruit tree crops usually respond to K fertilizers, and positive relationships between leaf K levels and fruit yields are commonly reported (Righetti, Wilder, and Cummings 1990; Fernández-Escobar 2001; Freeman, Uriu, and Hartmann 2005). Thus, it seems that the K nutritional status of trees had great influence on tree crop growth and yield in the Mirandela experiment. The groundcover treatments that permitted root proliferation in the soil surface had great comparative advantages relative to the other treatments.

The mean leaf Ca concentrations were more than the deficient limit of 0.3%, but usually less than the adequate range of >1% proposed by Fernández-Escobar (2001). The values were lower in the Mirandela than in the Bragança orchards, maybe due to the lower pH and exchangeable Ca in the soil of the Mirandela orchard. In both orchards, the mean leaf Ca concentration was lower in the most productive groundcover treatment, in contrast to the trend verified for N, K, and B. The result may be justified by the dilution effect on leaf Ca levels induced by the shoot growth increase as a response to the improved nutritional status of trees.

No significant differences in mean leaf Mg concentration were usually found between groundcover treatments. The mean leaf Mg concentrations were more than the adequate range of >0.1% reported by Fernández-Escobar (2001). This result agreed with the remarks reported by Freeman and Carlson (2005) that Mg nutritional problems in olive are rare.

Boron, with N and K, is the nutrient whose deficiency in olive is the most likely to be observed. Leaf B levels are at the adequate range within 19 and 150 ppm and deficient below 14 ppm (Freeman, Uriu, and Hartmann 2005). The mean leaf B concentrations were close to the lower limit of the adequate range in both Bragança and Mirandela orchards (Table 1). In both orchards, statistical differences in leaf B levels were found between the groundcover treatments (Table 2). The plots where the greater yields were recorded also exhibited greater mean leaf B concentrations. Taking into account the importance of B in olive nutrition (Tsadilas and Chartzoulakis 1999; Perica et al. 2002; Sibbett and Ferguson 2002), it appears that the B nutritional status of trees influenced the tree crops' growth and yields. Thus, the more effective groundcover treatments may have promoted B uptake.

Leaf Nutrient Concentrations in Winter and Summer

The comparison between the leaf nutrient concentration in summer and winter also has high practical importance, because many researchers consider the resting period of winter a reliable period for diagnosing the nutritional status of olive trees (Perica 2001; Marcelo et al. 2002; Soyergin and Katkat 2002; Pekcan et al. 2008).

The leaf N concentration is usually greater in winter than in summer (Fernández-Escobar, Moreno, and García-Creus 1999; Perica 2001; Rouina, Trigui, and Boukhris 2002), perhaps due to the strong sink competition for N associated with the spring flush, blossom and fruit development. The results of the Mirandela orchard, where the mean leaf N concentration was lower, support the general trend reported in the literature.

Mean leaf P and K concentrations were significantly greater in the summer. Chatzissavvidis, Therios, and Molassiotis (2005) reported similar values for K and a lack of a clear trend for P. Many factors could be advanced to justify the greater leaf levels of these nutrients, mainly K. Water stress seems to restrict the K uptake in fruit tree crops (Correia et al. 2008; Restrepo-Diaz et al. 2008), and the leaves that were sampled in the summer were developed during the spring flush when more water is available in the soil profile. In addition, the fertilizers were applied late in winter and, because of the low rates of nutrient usually applied, this would primarily have benefited the leaves developing during spring and collected in summer.

Leaf Ca and Mg concentrations are usually greater in winter (Fernández-Escobar 2001; Chatzissavvidis, Therios, and Molassiotis 2005). In this study, the mean leaf Ca concentration was significantly greater in winter only in the Mirandela orchard. Regarding the mean leaf Mg concentration, no significant differences occurred between the two sampling dates. According to the findings from these experiments, Mg would be one of the nutrients with less influence on tree crop growth and yield.

Mean leaf B concentration was markedly greater in summer. This is a fact well documented in the literature (Sibbett and Ferguson 2002; Chatzissavvidis, Therios, and Molassiotis 2005; Rodrigues and Arrobas 2008). Boron supplied as fertilizer would benefit the leaf B concentration in the summer samples. Conversely, drought during the summer and frost during winter may have contributed to the lower leaf B concentration in winter leaf samples, because factors reducing transpiration rate reduce B uptake (Mills and Jones 1996).

Conclusions

Soil surface management significantly influenced olive yield and tree crop growth. The Gly treatments produced the best results, whereas SW and MC, respectively in the Bragança and Mirandela orchards, produced the lower ones. Leaf N and B concentrations were greater in the most productive groundcover treatments. In the Mirandela orchard, where the K nutritional status of trees was poor, the greater leaf K concentrations were also associated with the most productive treatments. These results stressed the influence of the groundcover treatments on tree crop nutritional status and identified the nutritional status of trees as one of the major factor determining the tree crop growth and olive yield. The difference in leaf B concentration found in winter and summer samples seemed to be high enough to justify the establishment of different standards for B.

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