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Field-grown olive trees (*Olea europaea* L.) with composted sewage sludge. Effects on the nutritional status of the tree

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INTRODUCTION. – The regulations on residues are constantly being revised at the present time. Most countries in which the agricultural application of sewage sludge is legislated condition its use to the maintaining of certain levels of heavy metals, above which it would be considered dangerous (ALLOWAY, 1990). To this end, the amount of sludge applied to the soil is limited and dependent both on the toxic metal concentration in the residue and on the receiving soil and its pH.

The application of sewage sludge as a source of organic matter for agricultural soils has already been studied on many occasions (SOMMERS, 1977; POLO *et al.*, 1997), as well as its capacity for use as a nitrogenous and phosphorus fertilizer (COKER *et al.*, 1982; VERDU *et al.*, 1992).

Soil losses due to erosion in the Mediterranean area, very often linked to the poor content of organic matter in its soils, are among the highest in Europe (LANE *et al.*, 2001). The erosion rates are of special concern in olive groves, frequently located on steep slopes and presenting a large soil surface with no plant cover so that there is no protection against erosion processes. Under these conditions, the soil loss may reach 80 Mg ha^{-1} per year (PASTOR & CASTRO, 1995). This is why the agricultural use of sewage sludge can be especially advisable in this type of crop.

This work has aimed to study the effect of the application of composted sewage sludge on the growth and nutritional status of an olive grove as opposed to traditional fertilization, mixed fertilization (urea + sludge) and a non fertilized control.

MATERIALS AND METHODS. – In February, 1999, a field trial was conducted to observe the effects of the application of composted sewage sludge as an organic amendment in an olive grove (*Olea Europea* L., Picual variety), around 50 years old, located in Córdoba (Spain). The plantation density of the grove was 70 trees per ha. The experimental design chosen consisted of complete random blocks, with four treatments and four replications per treatment. The treatments trialled were: a) a non fertilized control (Control-C), b) fertilization with 1 Kg N per tree in the form of urea (Urea-U), c) application of 0.5 Kg N per tree in the form of urea and 10 Mg ha^{-1} of composted sludge (Mixed-M), d) adding 20 Mg ha^{-1} of sludge (Sewage Sludge-SL). The sludge was distributed with a manure spreader and the urea manually, adding both to the first 0.15 m of soil with a disk harrow. These treatments were repeated in February, 2000, in the same manner as above.

The composted sludge, with 20% moisture and 31% organic matter, was supplied by the firm Beta Nutror S.A.. The raw material for the compost mix came from six wastewater treatment plants belonging to the Integral Sanitation Plan of Madrid (PSIM). The soil in the olive grove was a typical vertisol, classified as Chromic Haploxererts (SOIL TAXONOMY, 1999). Table 1 shows the characteristics of the soil in the trial plot on the horizon from 0 to 0.20 m and the mean values of the chemical composition of the sludge applied in the trial. The highest concentration limits of heavy metals permitted both in sludge and in the receiving soil for the fertilization of soils with pH > 7 (Council Directive 86/278/EEC) are also shown in Table 1.

Nitrogen is a fundamental element in olive tree fertilization. Applications of 1 Kg N per tree have proved to be satisfactory for maintaining the level of this nutrient in leaves (FERNANDEZ-ESCOBAR, 1997). The dosage of 20 Mg ha^{-1} of composted sludge is equivalent to this dose of N, taking into account the moisture in the residue, the percentage of total N in the sludge and considering a net mineralization of 20% in the first year (U.S. EPA, 1983).

In mid-July of 1999 and 2000, samples of leaves were collected from the different treatments in the field trial. The samples from each experimental plot were composed of around 100-150 leaves from the middle portion of the current seasons shoots (FREEMAN *et al.*, 1994). In July, 2000, as well as leaves from the current seasons shoots, in treatments C and SL samples of the old olive tree leaves were collected.

These leaves were washed in deionized water and dried at 80°C for 48 h. They were then ground and analyzed. The nitrogen was determined by the Kjeldahl procedure. The ashes resulting from combusting the sample in a muffle furnace at 600°C for 12 h were dissolved with HCl 0.1 N. Total P and B were determined by colorimetry, while K, Na, Mg, Ca, Zn, Mn, Fe and Cu were measured using a Perkin-Elmer 1100 B atomic absorption spectrophotometer. For the analysis of the heavy metals found in lower concentrations, a digestion with HNO_3 and $HClO_4$ was carried out and subsequent measurements were taken by atomic absorption with a graphite camera.

For the statistical analysis of the results obtained the general variance analysis for the experimental design of complete random blocks was used, with a significance level lower than 5% ($p < 0.05$). When the analysis results of the variance were significant we proceeded to the separation of averages using the Duncan multiple rank test (LITTLE & HILLS, 1972).

RESULTS AND DISCUSSION. – Table 2 shows the results of the leaf analysis carried out in new shoot leaves in July, 1999, in the first year of the treatment application. None of the elements analyzed presented any significant differences. This resistance to any change in the nutrient levels of the leaf coincides with that found by JORDAO *et al.* (1994), who applied mineral fertilizers (macro- and micronutrients) to an olive grove for a period of 4 years and only obtained differences with the control treatment (no fertilization) in the content of nitrogen in the leaf.

TABLE 1. – *Chemical characteristics of the soil (0-20 cm) and of the sludge used. (*) Maximum heavy metal limit for the application of sludge in soils with pH > 7. (**) Maximum heavy metal limit in sludge for amendment of soils with pH > 7.*

	Soil	Soil limit (*)		Sewage Sludge	Sewage sludge limit (**)
pH (soil: water 1:2.5)	8.15		pH (soil: water 1:2.5)	7.2	
Sand (%)	13.0		EC (dS/m) at 25°C	5.2	
Silt (%)	35.5		Moisture (%)	20	
Clay (%)	51.5		Na (%)	0.07	
OM (%)	1.11		OM (%)	31.3	
Organic N (%)	0.10		Total N (%)	2.2	
C/N	6.53		C/N	8.6	
Available P (ppm)	8.6		Total P (%)	4.2	
Available K (ppm)	452.5		Total K (%)	0.32	
Available Ca (ppm)	1102.5		Ca (%)	5.1	
Available Mg (ppm)	818.8		Mg (%)	1.2	
Fe (%)	2.09		Fe (%)	1.5	
Cd (ppm)	<0.5	3	Cd (ppm)	4.7	40
Cu (ppm)	31.0	210	Cu (ppm)	351	1750
Cr (ppm)	29.13	150	Cr (ppm)	355	1500
Hg(ppm)	0.19	1 5	Hg(ppm	2.9	25
Ni (ppm)	29.13	112	Ni (ppm)	53	400
Zn (ppm)	55.88	450	Zn (ppm)	1295	4000
Pb (ppm)	30.50	300	Pb (ppm)	625	1200

TABLE 2. – *Leaf analyses carried out in the field trial in July, 1999. There were no significant differences (p < 0.05). C-Control, U-Urea, M-Mixed, SL-Sewage Sludge. (**) FERNÁNDEZ-ESCOBAR (1994).*

	New Leaves				Adequate values
	C	U	M	SL	**
N (%)	1.43	1.47	1.41	1.40	1.5-2
P (%)	0.07	0.07	0.07	0.07	0.1-0.3
Ca (%)	1.81	1.80	1.72	1.73	>1
Mg (%)	0.28	0.33	0.30	0.29	>0.1
Na (ppm)	149.0	171.5	168.8	180.8	
K (%)	0.57	0.59	0.63	0.65	>0.8
Fe (ppm)	34.3	36.8	35.0	39.5	
Cu (ppm)	52.2	51.4	44.5	51.3	>4
Mn (ppm)	29.0	28.1	26.1	27.4	>20
B(ppm)	34.7	35 7	34.0	32.0	19-150
Zn (ppm)	12.4	11.8	11.9	13.5	>10

The nutrient levels in the leaf were adequate (right hand column) except for N and P which were found to be somewhat below the desirable values. K was found at low levels, probably due to the lack of moisture in the soil profile, given that from January to July 1999 only 125 l m^{-2} of rainfall were collected.

In the Autumn of 1999 apical necroses were detected in the old leaves of the olive trees treated with composted sewage sludge (Fig. 1). The symptoms appeared in clear relation to the sludge doses contributed to the treatments S L (20 Mg ha^{-1}) and M (10 Mg ha^{-1}).

The necroses consisted of apical brown spots increasing in size with time until they took up nearly half the leaf, at which moment the leaves turned yellow and dropped off. Between the brown spot and the rest of the unaffected leaf it was normally possible to distinguish a small dark brown strip perpendicular to the leaf nervation, behind which a second strip of a variable thickness and with tinges of yellow could be perceived joining up with the non necrosed leaf. The symptoms are similar to those caused by a lack of K and they could even be confused with a deficiency of B. However, none of these deficiencies were corroborated in the leaf analyses performed, either in the new current-season leaves or in the old ones.

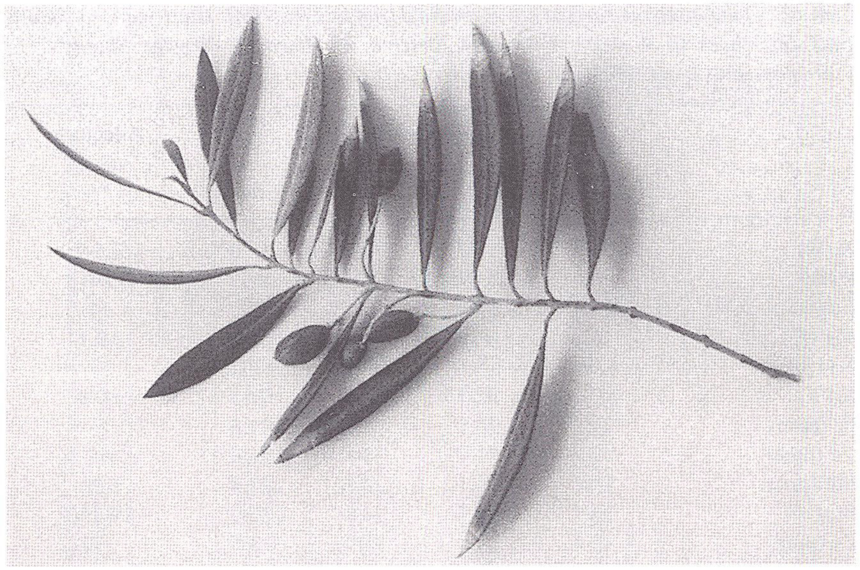

FIG. 1. – Localization of the apical necroses only found in previous year leaves. There were no symptoms in currentyear leaves.

In Table 3 the nutritional status of the olive grove in July 2000 after carrying out a second application of the treatments in February, 2000, can be observed. The N and P concentrations in the new leaves had recovered and were found to be within acceptable levels. Leaf K concentration had increased with respect to the previous year. It can be seen how leaf Ca and Mg contents had dropped, possibly due to interactions with K. Leaf Na, never reaching levels of 3900 ppm which cause damage to the tree according to KLEIN *et al.* (1994), dropped in the year 2000 in all the treatments.

The Mn concentration slightly decreased in the leaf analysis of July, 2000, while Cu underwent a notable decline. Both elements were always found to be within the levels recommended for olive groves. The leaf Cu concentration was highly variable although no cases of deficiency in this nutrient are known due to the use of fungicides composed of this element in the control of olive leaf spot (*Spilocea oleaginea*) in olive trees (FERNANDEZ-ESCOBAR *et al.*, 1999). The values of the Fe concentration in leaves also underwent a slight drop in the year 2000, although for the diagnosis of the nutritional status of the olive tr:e in this element leaf

TABLE 3. – *Leaf analyses carried out in the field trial in July, 2000, both in current year leaves and previous year ones. C-Control, U-Urea, M-Mixed, SL-Sewage Sludge. Values followed by different letters indicate signifcant differences (p < 0.05). (*) Indicates signifcant differences (p < Ø.1Ø). (**) Deficient and toxic concentration of trace elements in tissues of mature leaves for several species from (*KABATA-PENDIAS & PENDIAS, 1984*).

	New leaves				Old leaves		Deficient	Toxic
	C	U	M	SL	C	SL	levels (**)	levels (**)
N (%)	1.66	1.61	1.69	1.64	0.98	1.02		
P(%)	0.11	0.09	0.11	0.10	0.07	0.08		
Ca (%)	1.46	1.38	1.47	1.38	2.39	2.18		
Mg (%)	0.19	0.21	0.20	0.19	0.28	0.27		
Na (ppm)	68.2	102.7	80.9	111.1	80.8	82.6		
K (%)	0.74	0.74	0.76	0.80	0.41	0.46		
Fe (ppm)	33.0	30.9	33.9	33.2	36.6 a	44.9 b		
Cu (ppm)	25.4	25.1	22.9	23.2	36.1 a	55.3 b	2-5	20-100
Mn (ppm)	23.7	23.4	22.9	23.7	35.5	33.1	15-25	300-500
Cd (ppm)	0.12	0.11	0.06	0.08	0.06 a	0.28 b		5-30
Hg (ppm)	0.03	0.04	0.04	0.05	0.06 a	0.14 b		1-3
B (ppm)	47.1	57.5	48.7	54.1	34.0 a*	40.7 b*	5-30	50-200
Pb (ppm)	0.30	0.24	0.22	0.17	0.33 a	0.59 b		30-300
Zn (ppm)	10.8	11.7	11.4	11.9	9.5	9.9	10-20	100-400
Cr (ppm)	0.52	0.64	0.25	0.24	0.81 a*	1.36 b*		5-30
Ni (ppm)	0.78	0.73	0.66	0.57	1.02 a*	0.81 b*		10-100

analysis is not commonly used. The visual examination of the trees is the best method for this diagnosis (FERNANDEZ-ESCOBAR *et al.*, 1993). On the other hand, the leaf B concentration experienced a remarkable improvement in the year 2000, while the Zn did not undergo any notable changes. The concentration of all the elements analyzed, including heavy metals (Cd, Cr, Hg, Ni, Pb), in new leaves in 2000 was not significantly influenced by the different treatments.

In the leaf analysis of old olive tree leaves (Table 3) collected in July 2000 for treatments C and SL it can be observed how olive tree leaves, which had been amended with a dose of 20 Mg ha^{-1} for two consecutive years and which showed clear symptoms of apical necroses, had significantly higher ($p < 0.05$) levels of Fe, Cu, Cd, Hg and Pb than the control trees. The B and Cr concentrations were also higher in leaves with necrosis, although the significance level dropped ($p < 0.10$). The Ni content was greater in the control leaves than in the necrosed ones ($p < 0.10$).

On comparing the maximum concentrations of these trace elements obtained in the leaf analyses of olive trees with those reported by KABATA-PENDIAS & PENDIAS (1984) in Table 3, it was noted that only copper is situated in the interval considered to be toxic for plants. The relationship between the high levels of copper and treatments against olive leaf spot was mentioned previously. Values of up to 102 ppm were obtained by AGUILAR & GONZALEZ (1998) in a trial applying municipal solid waste in an olive grove.

After the recommended addition of composted sewage sludge, the olive trees continued to show these apical necroses in leaves from the previous year for at least two more years. These same symptoms have been observed in olive groves in Aranjuez, Toledo and Madrid subjected to applications of composted sewage sludge (MIRALLES DE IMPERIAL, R. & LOBO, M.C., personal communication). These apical necroses have also been detected in olive trees in Alicante, which had been fertilized with fresh dehydrated sludge (GOMEZ, I., personal communication).

CONCLUSIONS. – After the application of composted sewage sludge in an olive grove, together with mineral and mixed nitrogenous treatments for two consecutive years, no significant differences in the nutritional status of the trees were detected in the July analyses performed on the leaves of current year shoots.

There were differences in most of the nutrient concentrations in the two years of sampling, probably due to the difference in the rainfall recorded during the two trial years. Besides, 1999 was a year of poor production ('off' year) and 2000 was an 'on' year.

The apical necroses observed in the old leaves in treatments incorporating sewage sludge were clearly related to the dose of sludge used. The increases detected in most of the heavy metals analyzed in old leaves did not reach alarming levels. These symptoms found in old leaves are a warning against the use of composted sewage sludge in olive groves until the agent causing them has been isolated.

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SUMMARY. – A field trial was conducted for two years to test the effects of the application of composted sewage sludge on the nutritional status of an olive grove (*Olea Europea* L., Picual variety), located in Córdoba (Spain). Four treatments were tested: a) 20 Mg ha^{-1} of composted sewage sludge (SL), b) one kg of nitrogen per tree using urea (U), c) 10 Mg ha^{-1} of composted sewage sludge + 0.5 kg of nitrogen per tree using urea (M), d) control (C).

During the first year of the trial, brown necroses were observed at the top of older leaves, only in the treatments containing composted sewage sludge (SL and M). Nevertheless, in the leaf analysis carried out on new leaves (years 1999 and 2000), none of the elements analyzed (N, P, Ca, Mg, Na, K, Fe, Cu, Mn, B, Zn, Cd, Hg, B, Pb, Cr, Ni) presented any significant differences On old leaves (2000) significantly higher values of Hg, Cd, Pb, Cu and Fe ($p<0.05$) were found in the olive trees treated with sludge.