



SOIL PROPERTIES AFTER APPLICATION OF OLIVE OIL MILL WASTEWATER

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SUMMARY

The irrigation of soil with high doses of olive oil mill wastewater, OOW, may be advantageous. OOW spreading caused an increase of soil fertility that could allow agronomic use of the soil. After three years of irrigation only minor changes in soil organic-C, Kjeldahl-N, nitrate-N, exchangeable-K and E.C. were detected below 50 cm depth. However, special attention must be paid to hydrogeological characteristics of soil in order to avoid sodium salinization of the watertable.

Keywords: Olive oil wastewater, land treatment, waste utilization, salt leaching.

INTRODUCTION

Extraction of olive oil yields oil (20%), a solid residue (30%) and an aqueous liquor (50%). The latter comes from the vegetable water of the fruit and the washing waters from olive processing. Olive oil mill wastewater (OOW) also contains soft tissue from olives and oil in emulsion. The olive oil industry produces up to 10 million m³ per year of this residue, which, due to its high organic load (BOD 10-100, COD 40-200 g L⁻¹) and salt content (E.C. 8-22 dS m⁻¹) causes severe environmental problems in the Mediterranean region.

Current technologies for the treatment of OOW are based on natural or intensified evaporation in ponds, thermal concentration and physico-chemical or biological processes. Some of these methods have been reviewed by Fiestas and Borja³. The high organic load of OOW usually makes it necessary to combine several treatment steps to achieve a satisfactory BOD; for instance, sometimes a chemical treatment is used with a flocculant and a coagulant, followed by ultrafiltration and inverse osmosis. In addition, most of these processes generate sludge, which

needs a subsequent treatment. Factories are reluctant to install such systems because of their high investment and maintenance costs.

Direct irrigation of the soil with OOW with the aim of saving water and fertilizer has long been proposed, normally using doses lower than 800 m³ ha⁻¹. Tomati and Galli² and López³ recently reviewed the agricultural reuse of OOW. Limitations of this use derive mainly from the phytotoxicity of OOW due to its polyphenol and salt content^{4,5}. However, moderate doses of OOW have beneficial effects, increasing soil fertility and microbial population, especially N₂-fixers, and improving soil aggregate stability and sometimes crop yield. When soil and land characteristics (low permeability, deep watertable) and climatic conditions are favourable, the use of high doses of OOW (5000 m³ ha⁻¹) could be advantageous. The low costs of both irrigation system and necessary land would allow small or medium-sized factories to make use of this procedure without heavy investments. In a previous work, López *et al.*⁶ found that a 2 m soil layer in lysimeters almost completely removed the organic matter, phosphorus and potassium of OOW when doses of ca. 5000 m³ ha⁻¹ were employed. These high removal efficiencies were maintained even when the treatment was repeated during 3 years. The present paper deals with the effects of applying high doses of OOW on soil chemical properties under field conditions.

MATERIALS AND METHODS

During three years an experimental plot (1000 m²) was irrigated with OOW by mean of two lines of sprinklers (the procedure was patented in Spain). Annual doses of the OOW added to soil are shown in Table 1. After the first year, the two lines of sprinklers were brought closer together and an overlapping zone received a double dose of OOW (dose 2). During the second and third years, the two lines irrigated alternately, so that the effective irrigation days for dose 2 were double those for dose 1. Each year the addition lasted from December to February coinciding with the short harvesting period. Total length and effective days of irrigation are also shown in Table 1. Samples of OOW were taken monthly and analysed according to APHA methods⁷ in terms of their pollutant and fertilizing capacity (Table 2).

The experiment was carried out in a soil very common in the regions of Spain where olive trees are cultivated (pH 7.2; CaCO₃ 42%; silt 37%, clay 55%; porosity 27-38%; permeability K=10⁻⁵-10⁻⁷ cm s⁻¹). A complete description of the soil and the experimental plot was reported previously⁶. Each year, integrated soil samples were taken between 0-50 and 50-100 cm depth before and just after the irrigation period. Before taking soil samples, the plot was mouldboard ploughed. The E.C. and soluble salts in saturated paste extract, the CEC and exchangeable cations, organic carbon, and Kjeldahl and nitrate nitrogen were determined in soil samples following official Spanish methods⁸. Duplicate analysis was made for each sample.

Table 1. Doses and timing of irrigation

	Dose 1 L m ⁻²	Dose 2 L m ⁻²	Length day	Effective irrigation		Rainfall L m ⁻²
				Dose 1 day	Dose 2 day	
Year 1	406	406	99	80	80	225
Year 2	330	660	75	30	60	85
Year 3	382	764	82	41	82	14
Cumulative	1118	1830	256	151	222	
Per year	373	610	85	50	74	

Table 2. Characteristics of OOW with respect to its pollutant and fertilizing capacity (g L⁻¹)

	Range	Mean		Range	Mean
pH	4.1-7.3	5.4	E.C.*	7.1-17.6	9.4
COD	71-146	106	BOD	31-72	48
Kj-N	0.10-1.38	0.43	P	0.04-0.26	0.15
K	0.8-4.8	3.0	Na	0.11-1.78	0.80

*dS m⁻¹

Table 3. Soil properties before and after 3 years of treatment.

		INITIAL	DOSE 1		DOSE 2	
			0-50 cm	50-100 cm	0-50 cm	50-100 cm
pH		7.3	7.5	7.5	7.2	7.2
Org-C	%	0.45	1.62	0.49	1.98	0.63
Kj-N	%	0.05	0.21	0.11	0.19	0.10
NO ₃ -N	mg kg ⁻¹	2.2	2.5	6.7	79.3	17.4
Available-P	mg kg ⁻¹	10.9	100	15.0	100	15.0
C.E.C.	meq kg ⁻¹	213	210	192	198	196
K _x	meq kg ⁻¹	1.3	53.3	8.8	60.0	12.8
Na _x	meq kg ⁻¹	7.9	6.5	7.5	8.9	8.5
SATURATED PASTE EXTRACT						
E.C.	dS m ⁻¹	0.90	2.08	1.18	3.20	1.43
Soluble-Ca	meq kg ⁻¹	3.1	9.7	8.4	11.9	11.2
Soluble-K	meq kg ⁻¹	0.4	4.4	0.5	10.7	1.1
Soluble-Na	meq kg ⁻¹	0.2	1.9	1.3	2.3	1.6
SAR		0.2	1.1	0.8	1.2	0.8

RESULTS AND DISCUSSION

Chemical properties of the soil before and after three years of treatment are shown in Table 3. Initial values are the means of the values for the 0-50 and 50-100 cm layers, as no significant differences were found between the values in each layer.

The net increments of the values of certain soil chemical parameters after three years of OOW application were calculated in kg m^{-2} using a soil density of 1.6 g m^{-2} (Table 4). Total loads were also calculated from mean values in Table 2 and cumulative doses of OOW in Table 1.

The changes in certain soil chemical properties during the experimental period are shown in Figure 1.

Generally, it was observed that soil organic-C content (Org-C) in the upper layer increased immediately after the OOW applications, decreasing later, probably because of the mineralization of the organic matter (Fig. 1). However, the increase of Org-C in the subsoil layer was significant only for dose 2 and only after the third year of treatment. At the end of the experimental period, an increase of Org-C was found for both doses in the upper layer, while Org-C values in the subsoil layers were only slightly higher than in the initial situation, and higher for dose 2 than for dose 1 (Table 3). The increase of Org-C in the first 1 m layer (9.6 and 13.5 kg m^{-2} for dose 1 and 2 respectively) was much lower than the calculated total load (45 and 73 kg m^{-2}). This is in agreement with the proportion of biodegradable matter of OOW (BOD/COD ratio 0.45). It seems that the clay content of this soil limits the downward movement of the OOW organic matter, causing its mineralization in the upper layer, as found for the lower dose ($373 \text{ L m}^{-2} \text{ year}^{-1}$). Flouri *et al.*⁹ also reported that the organic load in soil is strongly and rapidly reduced when OOW is applied in agronomic doses (ca. 200 kg m^{-2}).

It was observed that soil Kjeldahl-N (Kj-N) increased constantly during the three years of OOW application. Table 4 shows that at the end of the experimental period the increase of Kj-N in the 1 m layer for both doses is higher than the total-N added with the OOW. For agricultural doses, other authors^{2,9} found that soil N increased up to 500 kg ha^{-1} . These increase are related to an enrichment in N_2 -fixing bacteria, which is a very important factor for soil fertility. In contrast, a rapid mineralization of the organic-N could produce high amounts of nitrate, with the well-known risk of pollution of groundwaters¹⁰. The maximum nitrate concentrations found in soil in these experiments (48 and $73 \text{ mg NO}_3\text{-N}$ for dose 1 and 2 respectively in the 0-50 cm layer) are common in many agricultural soils. After the second year, nitrate concentration in soil increased after the end of the irrigation period and decreased during irrigation, even in subsoil (Fig. 1). A potential leaching of nitrate from the upper layer (0-50cm) during irrigation would increase nitrate in the 50-100 cm layer, which was not observed. Nitrate could be lost by denitrification during the irrigation. This is favoured in fine-textured soils that are highly water saturated and in presence of an available carbon source¹¹.

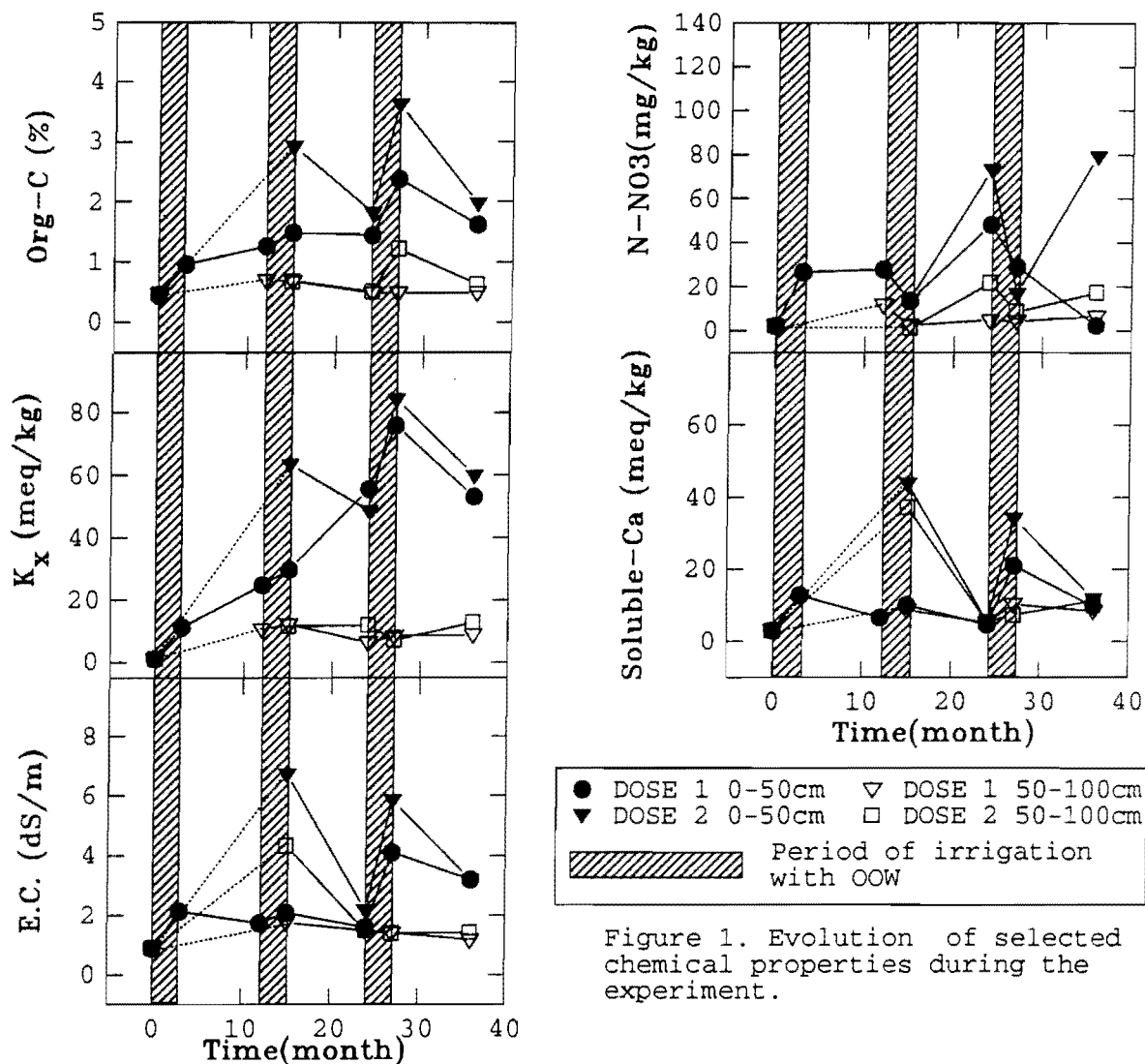


Figure 1. Evolution of selected chemical properties during the experiment.

Table 4. Increment of certain soil parameters after three years of OOW application ($kg\ m^{-2}$)

	Dose 1				Dose 2			
	0-50 cm	50-100 cm	0-100 cm	LOAD	0-50 cm	50-100 cm	0-100 cm	LOAD
Org-C	9.3	0.3	9.6	45*	12.0	1.5	13.5	73*
Kj-N	1.29	0.45	1.74	0.48	1.12	0.41	1.53	0.78
Avail-P	0.071	0.003	0.074	0.16	0.071	0.003	0.074	0.270
K_x	1.63	0.24	1.87		1.84	0.36	2.20	
K_s	0.13	0.00	0.13		0.32	0.02	0.34	
K_x+K_s	1.76	0.24	2.00	3.40	2.16	0.38	2.54	5.50
Na_x	-0.026	-0.007	-0.033		0.018	0.011	0.029	
Na_s	0.031	0.020	0.051		0.038	0.026	0.064	
Na_x+Na_s	0.005	0.013	0.018	0.89	0.056	0.037	0.093	1.46

*COD as equivalent Org-C

For both doses, exchangeable-K (K_x) in the upper layer tended to increase throughout the experimental period, while in the subsoil K_x increased after the first OOW application and remained approximately constant afterwards. The increase of total-K (exchangeable + soluble) in the 1 m layer at the end of the experiment did not reach the amount added with OOW (Table 4). Madrid *et al.*¹² found that ca. 50% of the K added was fixed in a non-exchangeable form. The increase of K_x produced a decrease of Ca_x and an increase of soluble Ca (Table 3).

Generally, slight increases of soluble- and exchangeable-Na (Na_x) were observed (Table 3). The increase of total-Na (exchangeable + soluble) in the 1 m soil layer after three years of treatment was negligible with respect to the amount added with OOW. Therefore most of the Na of the OOW seems to be leached down the soil profile.

Soil salinity (E.C.) increased in both soil layers, more in the upper than in the subsoil layer. However, this increase seems to be related to the increase of soluble Ca and K, but not to soluble Na (Table 3, Fig. 1).

In general, both doses of OOW promoted an increase of soil fertility that could allow the agronomic use of this soil between or after several years of OOW addition. After three years of irrigation with OOW in a low permeability soil, doses up to 610 L·m⁻²·year⁻¹ have promoted only minor changes below 50 cm depth, but special attention must be paid to hydrogeological conditions in order to avoid sodium salinization of the watertable.

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