WFL Publisher
Science and Technology
Food, Agriculture & Environment Vol.2 (2) :348-352. 2004
www.world-food.net

Environment

Use of dry olive-mill wastewater like organic amendment in soil for horticultural greenhouse crop

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Received 18 December 2003, accepted 15 April 2004.

Abstract

The elimination of olive-mill wastewater (OMW) is one of the main environmental problems related to the olive oil industry of Mediterranean countries. The OMW is collected in lagoons with the aim of reducing the volume by evaporation to obtain the dry olive-mill wastewater (DOMW). To solve the problem of OMW elimination, both purification and recycling processes have been the most suitable procedure. Manure application as organic amendment of horticultural crops under greenhouse cultivation could be substituted by DOMW. This material is an unbalanced fertilizer. However, by means of fertigation the soil solution can be balanced. The experiment was carried out by growing pepper plants (*Capsicum annuum* L. Lamuyo var. Drago) in a polyethylene-covered greenhouse located in La Cañada, Almería, Spain. The trial included three replications of four amendment treatments:1) W without organic material, 2) DOMW dry extract of olive milk wastewater (13.1 kg m^{-2}), 3) DOMW (6.5 kg m^{-2}) + peat (4.6 kg m^{-2}) and 4) M manure (10 kg m^{-2}). Water fraction, organic material and mineral elements in amendment materials (DOMW, peat and manure) and their saturated extracts were analyzed. During the crop production irrigation water, nutrient solution and soil solution obtained by suction cups were analysed for pH, E.C., nitrate, phosphate, sulphate, chloride, potassium, calcium, magnesium and sodium. Fruit production was evaluated by quality. It was concluded that DOMW is sustainable as soil amendment for horticultural greenhouse crops without reduction in the production, and even improves the fruit size. DOMW amendment produces a moderate reduction in the soil solution pH, potassium and chloride concentrations are similar, calcium higher and sodium lower than by manure application.

***Key words**:* Suction cups, greenhouse, peat, manure, *Capsicum annuum* L., saturated extract, fertilization, nutrient solution, soil solution, nutrients.

Introduction

The elimination of olive-mill wastewater (OMW) is one of the main environmental problems related to the olive oil industry of Mediterranean countries. The production of this waste is very high, about 30 million m^3 $year^{-1}$ and is generated during a short period of time (November-February). This liquid waste comes from raw olive oil production and contains dark-coloured juice, fruit washings, cooling water from machinery and hot acid leach-ate waters. Additionally, there is usually suspended matter consisting of olive pulp, mucilage, pectins, oil, etc., in a relatively stable emulsion[1].

OMW is collected in lagoons with the aim of reducing the volume by evaporation, which leads to the formation of sludge. To solve the problem of OMW elimination, both the purification and the recycling processes are the most suitable procedures[2]. From the standpoint of the waste recycling for agronomical uses, the direct disposal onto soil has been taken into consideration[3-5]. The characteristics of OMW that are used as fertiliser are the following: pH 5.0, solids 120 mg kg^{-1}, organic substances 105 mg kg^{-1}, mineral substances 15 mg kg^{-1}, N 2 g L^{-1}, P 0.5 g L^{-1}, K 3.6 g L^{-1}, Mg 0.2 g L^{-1}, polyphenols[6] 10 g L^{-1} and chemical oxygen demand (COD)[7] O_2 50,000 mg L^{-1}. The advantages of its use in plant production are the high contents of potassium and organic substances. The disadvantages are high salinity, low pH and abundant polyphenols[8], topics often related with inhibition of seed germination[9] and suppression of plant growth[10]. The manure application as organic amendment of horticultural greenhouse crops in the Mediterranean area presents some problems like heterogeneity and weed seeds[11]. Segura et al.[12] studied the use of peat as organic amendment with a similar behavior to manure and without its disadvantages. The dried olive-mill wastewater DOMW is an unbalanced fertilising agent. However, by means of fertigation the soil solution can be balanced. The aim of this study was to investigate the characteristics, recycling posibilities and use of DOMW for amendment in greenhouse production of pepper (*Capsicum annuum* L.).

Experimental

The experiment was carried out in a polyethylene-covered greenhouse located in La Cañada (Almería, Spain), with a total area of 1200 m^2 with an orientation E-W (longitudinal axis). The plantation frame was 0.5 m x 1.7 m and plantlets were in the beginning were 0.15 cm tall. Pepper plants (*Capsicum annuum* L. Lamuyo var. Drago) were grown from 15 August to 20 April. Fertigation with drip irrigation was used at one drip per plant, flowing rate 3 L h^{-1} and the irrigation doses and frequency were 1.5 L $plant^{-1}$ each 48 h. The characteristics of irrigation water and the nutrient solution are shown in Table 1.

The soil used in the trial was a traditional artificial soil commonly used in the area under consideration. This consisted of three layers[13]: 1) bottom layer (thickness 0.30 m) clay loam soil (Orthid according to Soil Taxonomy), 2) intermediate layer (thickness 0.02 m) organic amendment and 3) top layer (thickness 0.10 m) sand. The particle-size distribution and chemical properties of the layers are shown in Table 2.

The trial included four amendment treatments with three replications. Organic amendment materials were applied between top and bottom layers. The amendment treatments were as follows: 1) W without organic material, 2) DOMW dried extract of olive-milk wastewater 13.1 kg m^{-2}, 3) DOMW 6.5 kg m^{-2} + peat 4.6 kg m^{-2}, 4) M manure 10 kg m^{-2}.

For analysis of composition (water fraction, organic material and mineral elements) of amendment materials (DOMW, peat and manure) and their saturated extracts[14], four samples were taken by each material. Samples of water and nutrient solution were taken three times (four replicates per sampling): in the beginning of production, during the top production and in the end of the production period.

Soil solution was sampled using ceramic suction cups 60 mm long and with outer diameter 21.4 mm, with an air entry value of 261 kPa (Irrometer, CA). The suction cups were fitted on PVC-pipes 0.36 m long for a sampler depth of 0.25 m. The installation procedures were described by Lao et al.[15] and a suction value of -70 kPa was applied one day prior to taking four samples by replication and treatment for each periods. The analysed parameters were pH, electrical conductivity (E.C.), nitrate, phosphate, sulfate, chloride, potassium, calcium, magnesium and sodium. The analytical methodology described by MAPA[16] was followed.

Fruits were collected weekly from all the plants in the middlelines of each replication and treatment. All the fruit collected was classified by category: GGG, GG, G, M, MM and unmarketable[17]. The classification was carried out by hand calibration by function of the maximum diameter of the equatorial section, which is achieved by passing the fruit through a rigid ring without pressure application. After the classification of the fruit its fresh weight was determined with weighing scales COBOS C-400-CS.

Analysis of variance was by ANOVA and means separation by LSD test.

Results and Discussion

Composition of amendment materials: The composition (water fraction, organic matter and mineral elements) of amendment materials (DOMW, peat and manure) is shown in Fig. 1. Peat presented the highest content of organic matter and DOMW the highest content of mineral fraction.

Composition of saturated extracts of amendment materials: The results of saturated extracts of amendment materials are shown in Table 3. The saturated extract of DOMW presented a high E.C., low pH and high concentrations of Cl^- and K^+ with regard to the other analyzed materials. These results are in agreement with those obtained by Gonzalez et al.[18] for WMO, which had a high concentration of K^+ (70 mmol L^{-1}) and a pH value of 5.5. Numerous authors also found high E.C.[1, 9, 19], but chloride which can cause additional toxicity problems[20] was not included in analyses done.

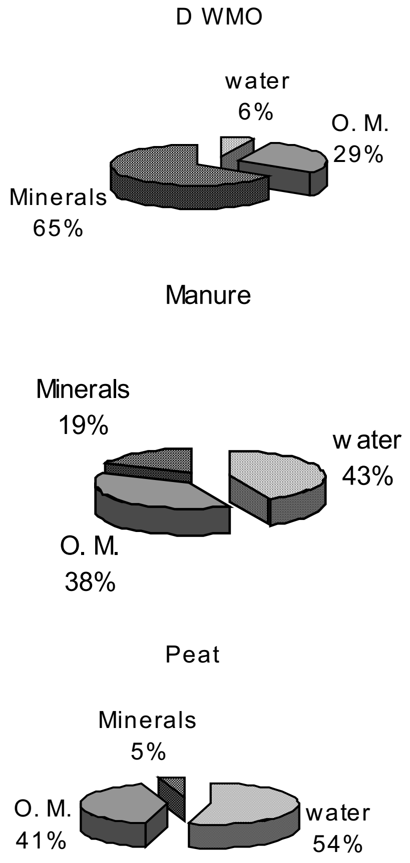

Figure 1. Composition of dry olive-mill wastewater, peat and manure.

Composition of soil solution: There were differences ($p<0.05$) between treatments in pH only in the third sampling (Fig. 2). The lowest value found in DOMW treatments may be due to the characteristics of the amendment material (Table 3).

In the first sampling the E.C. was superior ($p<0.05$) in the treatments with organic amendment and in the second sampling of the treatments with DOMW and manure (Fig. 2). The highest E.C. in the third period corresponded to the treatment DOMW and can be attributed to the presence and solubilization of more insoluble salts such as $CaSO_4$[21].

The organic amendment treatments presented a superior concentration of NO_3^- in the soil solution. However, in the second sampling the differences between treatments disappeared due to the contribution of fertigation (Fig. 2). In the third sampling the concentration was highest in DOMW+peat treatment and the lowest was without an organic matter application. Torres et al.[22] considered the possible N immobilization by soil microorganisms due to organic matter amendment. In our study the concentration differences might be related to the N uptake of crop.

There were no significant differences between treatments in phosphorus concentration of soil solution (Fig. 2). Nogales et al.[23] did not find any increase of P in plants amended with WMO containing a high amount of P. These results differ those of Gallardo-Lara et al.[24] who found higher phosphorus bioavailability after treatment with WMO. In this case, the decrease of soil pH after application could increase the dissolving of insoluble phosphate[25]. In our study the treatment

Table 1. Nutritional parameters of water irrigation and nutrient solution (N.S.) during the trial (mmol L^{-1}; E.C. dSm^{-1}).

	pH	E.C.	NO_3^-	$H_2PO_4^-$	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	HCO_3^-	Na^+	Cl^-
Water	7.2	1.5	1.0	0.0	1.5	1.6	1.4	2.7	1.0	9.1	9.2
N.S. 1	4.0	2.9	6.8	3.3	5.9	1.6	1.4	2.7	0.0	14.1	9.2
N.S. 2	4.7	2.0	11.0	0.7	7.2	1.6	1.4	3.6	0.0	13.0	9.2
N.S. 3	7.3	2.1	8.9	1.0	6.8	2.6	1.4	2.7	1.0	9.1	9.2

Table 2. Particle-size fractions, cation exchange capacity and exchangeable bases percentage in the layers used to prepare the artificial soil.

	Sand (0-10 cm)	Soil (12-43 cm)
Particle size (mm)		Clay-loam
<0.002	-	27.55
0.002-0.05	0.5	46.09
0.05-0.5	17.9	25.42
0.5-2.0	67.0	0.94
>2.00	14.3	-
CEC (cmol kg^{-1})		8.3
Na (%)		4.8
K (%)		5.5
Ca (%)		61.7
Mg (%)		28.0

Table 3. Nutrient parameters of saturated extracts of amendment materials (mmol L^{-1}; E.C. dSm^{-1}).'

	pH	E.C.	NO_3^-	$H_2PO_4^-$	SO_4^{2-}	Cl^-	K^+	Ca^{2+}	Mg^{2+}	Na^+
Manure	8.7	20.2	3.4	0.7	13.7	160	131.2	3.5	2.9	51.9
DOMW	5.7	30.1	5.5	0.7	25.0	320	286.5	29.2	11.5	12.5
Peat	4.1	3.6	16.2	0.7	11.0	2	31.2	3.0	2.3	1.5

Table 4. Pepper plant production by categories, total production and unmarketable fruits (g).

	GGG	GG	G	M	MM	Total production	Unmarketable fruits
Without O.M.	0 b	1008 c	10140 b	2800 a	60 d	14008 b	1108 b
DOMW	325 a	1472 b	12975 a	2450 a	0 d	17222 a	2108 a
DOMW +peat	0 b	1967 a	11958 a	1337 c	200 c	15462 a	1517 ab
Manure	0 b	735 d	12835 a	1693 b	260 c	15523 a	1352 b

* Mean separation in files by LSD ($p < 0.05$)

DOMW did not largely affect soil solution pH and the bioavailability of phosphorus. Sugar is an organic component of the DOMW[26, 27] and can stimulate the growth of heterotrophic microorganisms able to carry out processes of solubilization of P[28]. However, the presence of $CaCO_3$ (calcareous soil) can be the fundamental factor in the solubility of phosphorus[24].

Initial concentrations of potassium in the soil solution were very low and without differences between treatments ($p<0.05$). However, in the third sampling there was a higher concentration of K^+ in the organic amendment treatments (Fig. 2) that can be attributed to their contribution and distribution in the soil.

There were no significant differences in sulphate concentration in the soil solution between treatments in the first and third sampling (Fig. 2). However, in the second sampling the treatments with DOMW presented a higher concentration of soluble sulphate ($p<0.05$) that corresponds to the high quantity of S in this material (Table 3). Our results agree with those obtained by Barrow[29] who found high bioavailability of S from decomposing organic materials. Also Elseewi et al. [30] using urban solid waste, found increments of S content in diverse species. However, Nelson[31] found a contrary effect that when there was a high availability of soil S, additions of organic materials caused an immobilization of S. A similar depressive effect was also found by Pérez and Gallardo-Lara[32]. They considered that the S immobilization promoted by WMO amendment was based on its low pH which made $CaCO_3$ (calcareous soil) soluble and caused precipitation of insoluble $CaSO_4$.

Calcium concentration in the soil solution was higher ($p<0.05$) in the treatments with DOMW (Fig. 2) due to the high contribution of the element in this amendment material (Table 3) and the solubilisation of $CaCO_3$[32]. It is possible to suppress the Ca^{2+} application by fertigation in calcareous soils with DOMW amendment.

The concentration of Mg^{2+} in the soil solution was lower than Ca^{2+} but both cations were balanced, especially in the treatments with DOMW (Fig. 2). The evolution of magnesium concentration was similar to Ca^{2+} and can be justified by the solubilisation of $MgCO_3$, an important constituent of dolomite present in the soil together with $CaCO_3$[13]. The concentration of sodium was highest in the treatment with manure (Fig. 2). The high level of sodium can generate toxicity in the crop[20].

In the first sampling the Cl^- concentration in the treatment

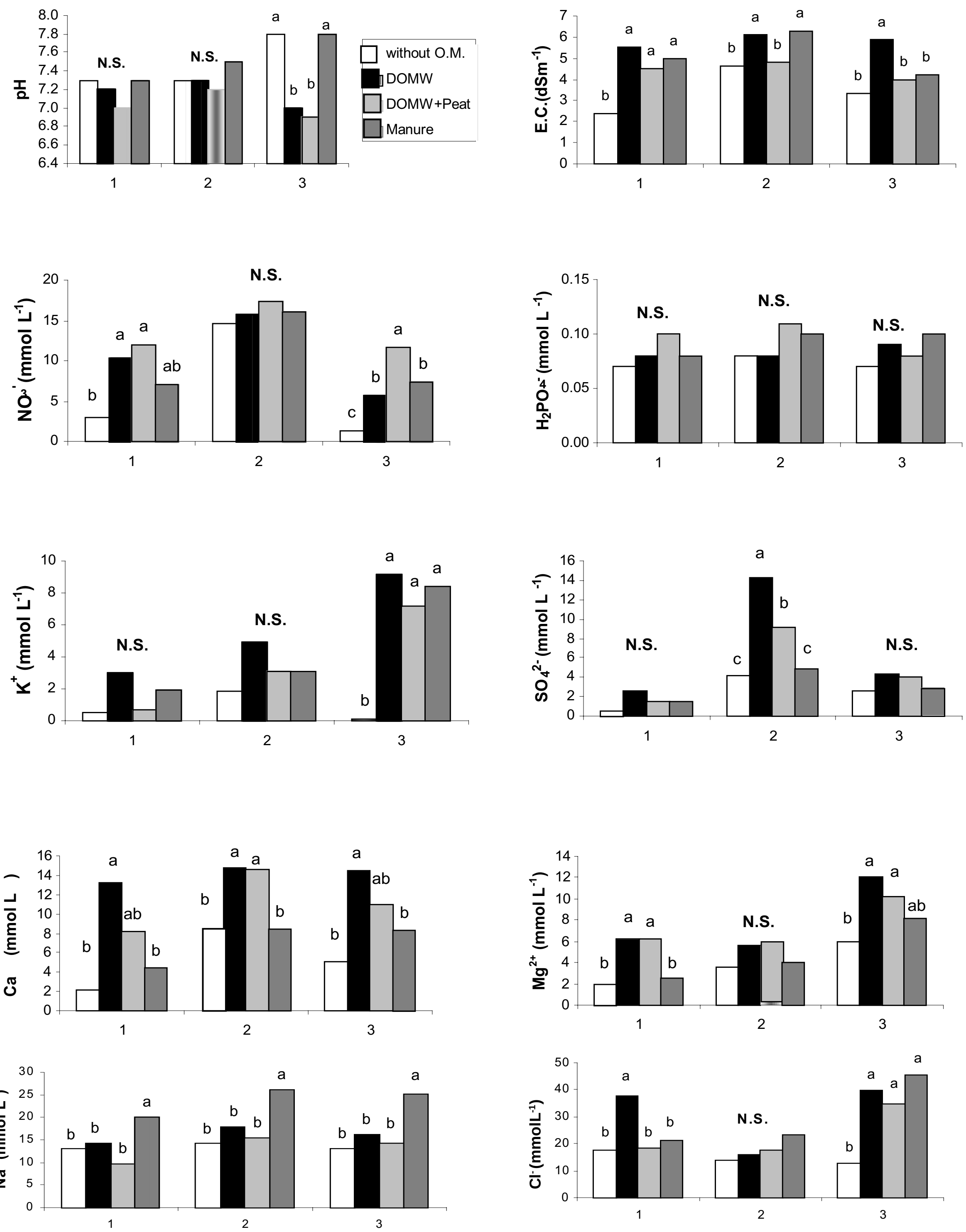

Figure 2. Evolution of the different nutritional parameters of the soil solution in three periods of crop: at the first of crop, top production and the end of production.

DOMW was highest (Fig. 2) due to the composition of this amendment material (Table 3). In the second sampling the concentration was low because Cl^- is a leachable element[21]. The Cl^- concentration in the third sampling was higher ($p<0.05$) in the treatments with organic amendments, due to solubilisation.

Fruit production: The data are presented in Table 4. Fruit production was higher ($p<0.05$) in all the treatments with organic amendment. However, there were no significant differences between these treatments. In the study of Nogales et al.[23] on pepper (*Capsicum annuum*, L. var. Dulce Italiano) grown in calcareous soil, there were equal amounts of yield with application of ash obtained from OMW supplemented with nitrogen and application of mineral NPK fertilization.

The treatments with DOMW presented superior tomato production in the categories GGG and GG, however, the percentage of unmarketable fruits was also superior in the treatments with DOMW ($p<0.05$). This could be result of the phytotoxicity of the amendment material[33], fundamentally due to the presence of polyphenols [34] and inhibition of growth[10].

Conclusions

The DOMW can be used as amendment of soil for horticultural greenhouse crops without reduction in production and may even improve the size of the fruits. The DOMW amendment produces a moderate reduction in the soil solution pH and concentrations of potassium and chloride similar to the manure and higher concentrations of calcium. However, the concentration of Na^+ is lower than in the manure amendment.

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