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Effect of olive mill wastewater land-spreading on soil properties, olive tree performance and oil quality

Salam Ayoub[a,*], Khalid Al-Absi[b], Saleh Al-Shdiefat[a], Doaa Al-Majali[a], Danial Hijazean[b]

[a] Olive Research Department, National Center for Agricultural Research and Extension, P.O. Box 639, Baqa 19381, Jordan
[b] Department of Plant Production, Faculty of Agriculture, Mutah University, P.O. Box 7, 61710, Jordan

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ABSTRACT

The application of fresh olive mill wastewater (OMW) to the soil surface of an olive (*Olea europaea*, L.) orchard was studied for three consecutive years (2011, 2012 and 2013). The experiment was conducted at a private olive orchard located in Raba area at Al-Karak governorate. Olive mill wastewater was applied to olive orchard with 15-year-old trees (cv. Nabali Muhassan) in winter at five application rates: control (no application of OMW), 5 L m^{-2} one dose, 10 L m^{-2} one dose, 20 L m^{-2} one dose and 20 L m^{-2} at four equal doses at monthly intervals. The effect on soil properties, plant performance, fruit set, yield, oil content and oil quality was studied. Results of the study indicated that, there was no negative effect of OMW application on soil properties. The concentrations of K, organic matter, phenolic compounds and total microbial count were significantly higher in OMW-treated soil as compared to the control soil. Olive mill wastewater applied at 10 L m^{-2} and 20 L m^{-2} gave significant increase in shoot growth, photosynthesis, fruit set and fruit yield. No negative effects were observed for OMW application on oil quality parameters throughout the experimental period. Results of this study indicated that the annual application of OMW at 10 L m^{-2} is recommended to improve soil fertility and plant performance.

1. Introduction

Olive is the main agricultural crop in Jordan. Increasing demand for olive oil motivated a fast increase in the planted area of about 5% annually over the last 15 years. Approximately 130,000 ha of olives are grown in Jordan. There are approximately 130 olive mills in Jordan serving olive plantation and generating around 200,000 m^3 of OMW annually (Ministry of Agriculture, 2012).

The reuse of treated wastewater in agriculture is considered as an alternative source of irrigation water and expected to increase significantly in countries, which suffer from shortage in fresh water resources. Many types of effluents suitable for reuse are produced in large quantities. Olive mill wastewater (Ben Rouina et al., 2006), municipal (Shdiefat et al., 2009) and textile and steel reclaimed effluents (Bhati and Singh, 2003; Al-Absi et al., 2009) have been evaluated for use in agriculture and crop production. The olive oil extraction industry is an important activity in Mediterranean countries, producing a large amount of olive mill waste during oil extraction. Olive mill wastewater (OMW) is the liquid by-product obtained from olive oil processing either by pressure or centrifugation systems. The most common extraction process yields three phases of products: an oily phase, a solid residue and an aqueous phase. The latter, when combined with the washing water process forms OMW. The average volume of OMW discharged, depends on the extraction type, from 0.5 to 1.5 m^3 ton^{-1} of processed olives (Monteoliva-Sanchez et al., 1996). The overall annual production of OMW in the Mediterranean region is estimated to be over 30 million m^3 (Cabrera et al., 1996; Ballesteros et al., 2001) creating a significant problem concerning their proper disposal.

Olive mill wastewater generated by the three-phase process has extremely high biological (BOD) and chemical (COD) oxygen demand (as high as 100,000 and 220,000 mg L^{-1}, respectively), high concentrations of fats, oils and greases (FOGs), and several to 10 g of total polyphenols per liter (Azbar et al., 2004). The presence of phenols as well as short- and long-chain fatty acids is believed to contribute to the phytotoxic (e.g. Cassa et al., 2003) and antimicrobial (Isidori et al., 2005) nature of these wastes. These characteristics of OMW prevent their direct discharge into municipal sewage systems. In addition to the high organic load and toxicity, a major constraint to OMW treatment is the fact that it is being produced only during a relatively short harvest period (mostly mid-October to mid-January). Presently, most of the OMW in Jordan are without adequate treatment, thus threatening the quality of the valuable and scarce water resources.

* Corresponding author. Tel.: +962 777492541; fax: +962 64726099.
E-mail addresses: sayoub@ncare.gov.jo, salamayoub@hotmail.com (S. Ayoub).

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Several chemical, physical and thermal methods have been developed for OMW purification. The viability of these technologies is questionable as they are fairly expensive and/or do not produce high-quality effluents. Contrary to the classical "wastewater treatment" approach, multiple studies advised the controlled spreading of OMW on cultivated soil as a viable recycling approach and suggested that OMW could be considered as a useful, low-cost soil amendment and fertilizer (Tomati and Galli, 1992; Saadi et al., 2007). The Italian law, for example, already permits annual spreading of up to 80 m^3 ha^{-1} (Rinaldi et al., 2003). In this respect, OMW is considered as a natural fertilizer at which, proper application rate, is not harmful to crops and can be disposed of without causing environmental damage.

The olive mill wastewater application significantly increased yield, grain yield, N, P, and K uptake by the wheat in the Cutanic Luvisol. Furthermore, significant increases in organic carbon, aggregate stability, total N, available K, cation-exchange capacity, oxygenation and hydraulic retention were observed in Mediterranean agricultural soils (Colucci et al., 2002; Lopez-Pineiro et al., 2006).

In 5 years study of olive tree cultivation Marsilio et al. (2006) reported that the spreading of 100 and 300 m^3 ha^{-1} reduced or eliminated, respectively, the need of using chemical fertilizers. The olive fruits production was equal or higher than that obtained in control plots while the quality of the olive oil was the same. The chemical and microbiological properties of the soil were not negatively affected by the different treatments with OMW. Ben Rouina et al. (2006) found that annual application of untreated OMW in an olive orchard located on a sandy soil, at a rate of 100 m^3 ha^{-1} for 10 years, markedly improved soil fertility. They showed increased content of organic matter, nitrogen and potassium, while phosphate and pH remained stable. Organic matter content increased from 0.3% to 1.3% and caused an improvement of soil's water retention capacity and water permeability. According to Chartzoulakis et al. (2006), the application of raw OMW during winter for 3 years, in doses up to 416 m^3 ha^{-1} did not have any negative effects on the nutritional soil status, neither on the yield nor on the physiology of olive trees. The increased levels of soil K can be considered as a positive effect on soil fertility, while phenols were decomposed rapidly in the soil and no toxicity symptoms were observed in olive trees during the experiments.

However, some studies also cautioned against potential phytotoxicity and decline in soil microbial activity under high-dose applications (Piotrowska et al., 2006). Other studies pointed out to the potential pollution that can result from excessive OMW application (S'Habou et al., 2005). It is clear that wise application of OMW should take into account soil type, climate, crops and other geographical and environmental conditions (Zenjari and Nejmeddine, 2001). Such a holistic approach has never taken in Jordan and only partly considered in other Mediterranean countries. Conducting this research under semi-arid conditions as the case in Jordan will greatly increase the scope of its applicability.

Most soils in Jordan are very poor in organic matter which negatively affects their fertility. Adding OMW-organic matter and nutrients in a controlled manner is expected to positively affect soil fertility. Therefore, this research aims to optimize OMW application in olive orchards and to study the effect of its application on soil properties, plant nutrition and yield.

2. Materials and methods

2.1. Experimental site and olive mill wastewater source

The experiment was conducted for three consecutive years (2011, 2012 and 2013) at a rain-fed olive orchard located in Raba area at Al-Karak governorate in Jordan (31°14′9″ N, 35°44′15″ E, elevation 996 m above sea level). The climate in this part of the country is Mediterranean. The annual rainfall during the study years 2011, 2012 and 2013 was 288.2 mm, 303.5 mm and 326.0 mm, respectively. The soil of the experimental field was vertisols, silty clay texture, pH 7.9 and EC 0.35 dS m^{-1}.Olive mill wastewater was obtained from an olive mill operated by centrifugation system and located close to the experiment orchard. This long-term experiment was essential to ascertain that no accumulation of pollutants or any gradual detrimental processes occur.

2.2. Plant material

Uniform, 15-year-old 'Nabali Muhassan' olive trees, grown on their own roots, were used in the experiment. All trees were managed following the common agronomical practices used for olive orchards. Nabali Muhassan cultivar was selected for its widespread cultivation in Jordan.

The following treatments were applied throughout the three consecutive seasons:

1. No application of OMW (control).
2. Annual application of OMW at 50 m^3 ha^{-1} (5 L m^{-2}) as one dose in December.
3. Annual application of OMW at 100 m^3 ha^{-1} (10 L m^{-2}) as one dose in December.
4. Annual application of OMW at 200 m^3 ha^{-1} (20 L m^{-2}) as one dose in December.
5. Annual application of OMW at 200 m^3 ha^{-1} (20 L m^{-2}) at four equal doses at monthly intervals between November and February.

In all cases, fresh OMW (after 24 h sedimentation at the olive mill) was used. Olive mill wastewater was applied between the rows of olive trees at a distance of 70 cm from the trunk using a tractor with tank trailer (spreading machine). Tree spacing-density was 6 m × 6 m. The setup of the experiment provides two "inner" trees in each block that are completely influenced by the given treatment to be used for monitoring and data collection.

2.3. OMW analysis

Samples of the OMW were taken at the date of application after 24 h from production to allow sedimentation of solid materials and to reduce clogging of the spreading tank nozzles. Samples of OMW were sent to the laboratory for analysis of pH, electrical conductivity (EC), total solids (TS), total dissolved solids (TDS), chemical oxygen demand (COD), biological oxygen demand (BOD_5), dry matter (%), oil and fat content (%), total phenols, total nitrogen, NO_3, P, K, Ca, Mg, Na, Cl, SO_4, Fe, Zn, Cd and Pb. Analysis was carried out according to standard methods for water and wastewater analysis (Anonymous, 1998).

2.4. Soil and leaf analysis

Soil samples were taken after 1 month from the application of the treatments at two depths (0–30 cm and 30–60 cm). Soil samples were air-dried at room temperature and ground to pass a 2-mm sieve. Soil samples were analyzed for pH, EC, Na, Cl, Ca, Mg, N, P, K, Fe, Cu, organic matter (%), moisture content (%), total phenols, total microbial count and soil texture. Analysis was carried out according to methods of soil analysis (Anonymous, 1994).

Olive leaves from the middle of new shoots (full matured) were collected each year in July and analyzed for the nutrients: N, P, K,