Journal of Environmental Management 171 (2016) 158–165

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Agronomic application of olive mill wastewater: Effects on maize production and soil properties

Majdouline Belaqziz [a,*], Abdelilah El-Abbassi [b], El Khadir Lakhal [c], Evita Agrafioti [d], Charis M. Galanakis [d]

[a] Center of Analysis and Characterization, Cadi Ayyad University, Boulevard Moulay Abdellah, Marrakech, Morocco
[b] Department of Biology, Faculty of Sciences Semlalia, P.O. Box 2390, 40 000, Marrakech, Morocco
[c] Laboratoiry of Automatic for Environment and Transfer Processes, Department of Physiques, Faculty of Sciences – Semlalia, P.O. Box 2390, 40 000, Marrakech, Morocco
[d] Department of Research and Innovation, Galanakis Laboratories, Skalidi 34, GR-73131, Chania, Greece

ARTICLE INFO

Article history:
Received 16 July 2015
Received in revised form
19 October 2015
Accepted 5 February 2016
Available online 15 February 2016

Keywords:
Olive mill wastewater
Phenolic compounds
Maize crops
Soil fertility

ABSTRACT

This study investigates the effect of direct amendment of olive mill wastewater (OMW) on the fertility of soil, described as poor in the area of Marrakech (semi-arid region) in Morocco. The treated plots were amended with untreated OMW generated by a traditional extraction process at the amount of 10 L/m^2/year during two consecutive years. Results of these two years treatments with crude OMW at relatively high dose reveal an important increase in soil physicochemical characteristics, namely electric conductivity (EC), Na^+, K^+, phosphorus, nitrogen, organic matter and soluble phenolic compounds. EC of treated soil was enhanced from 0.34 to 2.91 mS/cm as compared to the control soil. After spreading OMW in soil, the amounts of its nutritive elements increased by 81% for nitrogen, 66% for phosphorus and 88% for potassium. The accumulation of phenolic compounds and the increase of total peroxidase activity in plants provide evidence of their protective role against the physiological stress induced by OMW. However, this enrichment in mineral and nutritive elements decreased three months after OMW application, revealing OMW biodegradation in the studied calcareous soil. In parallel, an increase in the contents of the soluble phenolic compounds on the upper layer of soil was denoted and maize plants growth was efficiently raised. Significant amelioration was obtained notably in terms of fresh and dry weight of leaves, leaves area, spikes fresh and dry weight, 100 seeds weight and straw yield (37, 54, 27, 24, 14 and 9% respectively). Along with the correct choice of convenient soils notably calcareous ones and tolerant crops such as maize, this method could constitute an efficient approach for avoiding problems attributed to the uncontrolled disposal of these effluents and an effective strategy to regenerate degraded soils and represents an economical alternative that provides a local fertilizer.

1. Introduction

Every year, worldwide olive oil production generates in a short period (from October to March) more than 30 million m^3 of olive mill wastewater (OMW). The high amounts of produced OMW, along with its physicochemical characteristics cause severe environmental concerns and management problems to the olive oil industries. OMW composition is highly variable, depending on the regional characteristics, the ripeness of olives and oil extraction technology (traditional or continuous systems). OMW has high values of biological oxygen demand (BOD), chemical oxygen demand (COD), organic matter content, suspended solids, inhibiting substances (lipidic and phenolic compounds) and minerals, in particular potassium, phosphorus and calcium (Galanakis, 2011; Rahmanian et al., 2014). The high concentration of phenolic compounds is responsible for the dark color and phytotoxic effect of OMW (Magdich et al., 2012). Until now, several methods have been proposed for OMW treatment, such as flocculation/coagulation (Neffa et al., 2014), membrane technologies (El-Abbassi et al., 2013;

* Corresponding author. Center of Analysis and Characterization, Faculty of Sciences Semlalia, Cadi Ayyad University, Avenue Prince My Abdellah, P.O. Box: 2390, 40090, Marrakech, Morocco.

E-mail addresses: belaqzizmajdouline@yahoo.fr (M. Belaqziz), a.elabbassi@ced.uca.ma (A. El-Abbassi), lakhal@uca.ma (E.K. Lakhal), cgalanakis@chemlab.gr (C.M. Galanakis).

http://dx.doi.org/10.1016/j.jenvman.2016.02.006
0301-4797/

El-Abbassi et al., 2011; El-Abbassi et al., 2014) and biological methods (El Hajjouji, Fakharedine, Baddi, Winterton, Bailly, Revel, et al., 2007) among others (Paraskeva and Diamadopoulos, 2006). However, these solutions are not yet cost effective and most importantly sustainable.

An alternative, environmental friendly and economically feasible approach to manage OMW would take advantage of its valuable ingredients. OMW is an important source of organic matter, nutrients and water. Organic matter plays an essential role in various soil properties (e.g. water holding, pH buffering, ion binding, soil structure etc). In this respect, OMW could be considered as a soil amendment and natural fertilizer, when applied at appropriate application rates (Magdich et al., 2012; Moraetis et al., 2011). For instance, Alianiello et al. (1998) and Mellouli et al. (1998) showed that a controlled spreading of OMW can increase soil fertility. Recently, Gargouri *et al* (Gargouri et al., 2014) reported that the direct application of OMW in soil increased its organic carbon and nutrient content, while it improved its structure and subsequently enhanced its fertility. Other studies have pointed out the beneficial effects on crop growth induced by spreading fresh, stored or treated OMW on cultivated soil (Barbera et al., 2013; Belaqziz et al., 2008; Magdich et al., 2012). In addition, it is known that OMW can reduce water loss by evaporation (Mellouli et al., 1998), soil porosity and pesticides leaching (Cox et al., 1997). Nevertheless, the results of different studies are often contradictory, which constrains the development of a legal and safe fertilization method sitting. In fact, although application of raw OMW has been proved to be profitable for few species (Kokkora et al., 2015), its application has often been associated with phytotoxic effects (Buchmann et al., 2015).

Morocco is characterized by severe water-deficient environments, whereas its soil typically lacks of organic carbon. Following the above considerations and taking in consideration our previous works on agronomic application of OMW (Belaqziz et al., 2008), the present study aims to evaluate the effect of OMW spreading at high amount (100 m^3/ha) on the fertility of marginal calcareous soil located in Marrakech region, by monitoring its impact on some soil chemical properties as well as on growth and production of maize plants. Some agronomic purpose was investigated taking to adapt the contributions of OMW to the plant needs for better growth and good productivity. This aim takes into account certain biochemical parameters, including phenolic compounds and peroxidase activities, as stress indicators.

2. Materials and methods

2.1. Olive mill wastewater collection

OMW was collected from a traditional mill (discontinuous press process), located in Marrakech-Loudaya (Morocco), which produces more than 80 m^3 OMW per year. After collection, OMW was kept in the field for one month and then it was applied in an airtight plastic tank. The physicochemical characteristics of the sample, in initial time and after 1 month storage, are presented in Table 1.

2.2. Field experiment

A series of field experiments was conducted in order to investigate the effect of OMW on maize production and soil properties for two consecutive years. The field experiments were held in the Marrakech-Loudaya area that is characterized by a semi-arid to arid climate with dry and warm summers (temperatures up to 38 °C) and humid and mild winters (temperature is no lower than 3.5 °C). The soil used for the current study is a calcareous soil with 57.3% sand, 24.2% silt, 16.2% clay, and 35.1% $CaCO_3$. The study consisted of two years' experiments, conducted in 3 m × 2 m plots. Fertilization was carried out in one application using a 10 L manual sprayer to apply 10 L of crude OMW/m^2 homogeneously within the plot boundaries without using any other fertilizers. The OMW was two-fold diluted before its application. Control plots received equivalent amount of water. The OMW − soil complex was periodically mixed to ensure a good homogenization. Then, it was allowed to incubate for six months. During this incubation period, sampling was carried out on the top 20 cm of soil with an auger. Samples were taken at the time of the addition of OMW (t_o), three months after (t_1) and six months after application (t_2). Maize was cultivated by sowing 120 seeds (20 seeds/m^2) of a local variety in treated and non-treated plots. Sowing was performed during the spring after six months of OMW spreading. The irrigation regime was 5 L/m^2 every 3 days.

Table 1
Physicochemical characteristics of the OMW used in the present study.

Parameter	Unit	Initial value	After 1 month
pH	(−)	4.72 ± 0.12	4.98 ± 0.15
EC	mS/cm	45.5 ± 1.21	42.56 ± 1.54
SS	g/L	71 ± 0.2	54 ± 1
TDM	g/L	197 ± 36	128 ± 25
FDM	g/L	109 ± 6	95 ± 3
VDM	g/L	88 ± 9	30 ± 5
COD	g/L	356.11 ± 94.42	264.43 ± 43.11
NaCl	g/L	7.61 ± 5.85	7.03 ± 3.78
Cl^-	g/L	4.62 ± 3.55	3.98 ± 5.23
P	g/L	0.1 ± 0.006	0.14 ± 0.002
PO_4^{2-}	g/L	2.77 ± 0.03	3.67 ± 0.012
$N{-}NH^{4+}$	g/L	1.88 ± 0.1	1.05 ± 0.021
NO^{2-}	g/L	5.43 ± 0.78	4.37 ± 0.77
Na^+	g/L	2.06 ± 0.41	1.84 ± 0.23
Ca^{2+}	g/L	0.24 ± 0.01	0.22 ± 0.03
K^+	g/L	2.45 ± 0.1	1.95 ± 0.02
Soluble phenols	g/L	9.37 ± 1.05	8.14 ± 1.32

Abbreviations: EC: electrical conductivity, SS: suspended solids, TDM: total dry matter, FDM: fixe dry matter, VDM: volatile dry matter, COD: chemical oxygen demand.

2.3. Soils sampling and analysis

Soil samples were taken from four random locations in each plot, from 0 to 20 cm depth using a 20 cm internal metalcore. Soil samples were sieved (<2 mm) and stored for analysis at −20 °C. Soil pH and electrical conductivity (EC) were measured in a 1:5 soil/water suspension according to Rayment and Higginson (1992). Organic carbon and total nitrogen were determined using the Walkley–Black method (Allison, 1965) and Kjeldahl digestion (Keeney and Nelson, 1982), respectively. Extractable soil phosphorus (Olsen P) analysis was conducted according to the method referred by Olsen and Sommers (1982), whereas exchangeable Ca^{++} and K^+ were extracted with ammonium acetate at pH 7 and measured by emission spectroscopy (Ross and Ketterings, 1995).

Soil soluble phenolic compounds were extracted three times with an equal volume of ethyl acetate. After evaporation of the organic phase, the residue was dissolved in pure methanol and kept at −20 °C until usage. In soil samples, phenolics were extracted with 80% methanol prior their purification and analysis as described by El Hadrami *et al.* (El Hadrami, Belaqziz, El Hassni, Hanifi, Abbad, Capasso, et al., 2004). Total contents of phenolic compounds were estimated using the Folin-Ciocalteu reagent (Singleton et al., 1999). Results were expressed in µg eq. (+)-catechin using a standard curve of (+)-catechin ethanolic solution. Phenolic compounds were identified with High-Performance Liquid Chromatography (HPLC), using Water 600E HPLC equipped with Waters 990 photodiode array detector and Millipore software