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Review

Olive mill wastewater as a source of organic matter, water and nutrients for restoration of degraded soils and for crops managed with sustainable systems

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ABSTRACT

Every year, worldwide olive oil production produces in a short period of time (late autumn-winter) vast quantities of olive mill wastewater (OMW). This product causes environmental and management problems due to its disposal into rivers and lakes. During the last years, OMW application (used either as crude, raw material, or as treated- with different methods- product, in order to decrease its phytotoxicity) was tested under field conditions as organic amendment; many times, the results with regard to the raise of plant growth, crop yields and enhancement of soil fertility were promising, while in some other cases phytotoxicity problems, groundwater contamination, decreased soil porosity, as well as enhanced electrical conductivity, salinity, increased soil acidity and decreased N mineralization rate occurred. On the other hand, OMW is a low-cost source of nutrients (especially N, P, K, Mg and Fe), water, and organic matter; thus, it can be successfully used for the restoration of degraded croplands, in hilly, eroded, poor in organic C, and/or semi-arid areas. Since one of the first steps in land restoration process is the enhancement of soil organic C, OMW is an excellent alternative solution for the: i) increase of organic matter, ii) improvement of soil physical properties, and iii) enhancement of productivity of degraded croplands. In addition, under certain conditions (use of treated, or diluted with water OMW in order to decrease phenol content, avoidance of exaggerate applications, suitable application rate(s) and season), OMW can be safely used as a soil amendment and low-cost organic fertilizer for crops, managed with sustainable systems. The basic purpose of this review was to present and thoroughly discuss all the beneficial aspects of OMW application with regard to: i) the restoration of degraded croplands, ii) sustainable crop management, based on the most important and recently published papers. In addition, the environmental consequences of exaggerate and untreated OMW applications, together with some solutions (strategies) adopted for eliminating soil and groundwater contamination and phytotoxicity are also presented in this review article.

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1. Introduction

Countries of the Mediterranean basin produce annually vast quantities of olive oil from thousands of olive mills. In Greece for example, the great majority of these olive mills operate under the three-phase extraction system, producing huge quantities of OMW within a short period of time (November-February) (Ouzounidou et al., 2010). Greece produces more than 1,500,000 t of OMW annually (Kapellakis et al., 2006), while in the Mediterranean countries OMW production varies from 7×10^6 to 30×10^6 m^3 (Kavvadias et al., 2010). Thus, OMW is the main residual product of olive oil processing (aqueous, dark, foul-smelling and turbid liquid) (Kavvadias et al., 2010) and its disposal is one of the most serious environmental issues in the Mediterranean basin. More specifically, OMW is characterized by high pollutant load, salinity and phytotoxic levels of polyphenols, while it consists also of a high amount of organic compounds and mineral nutrients. OMWs contain phenolic compounds in the form of monocyclic and polymeric aromatic molecules. The polyphenolic components of OMW are responsible for the dark color and the phytotoxic effects. Despite the fact that the chemical composition of OMW might cause water and soil contamination, as well as phytotoxicity, its use in agriculture as amendment is recently promoted because of its high nutrient content, especially of its high N, P, K, Mg and Fe concentrations, as well as of its rich organic matter content (Lozano-Garcia et al., 2011; Magdich et al., 2013). It was found that inorganic N, available P and B, exchangeable K and Mg, as well as extractable Cu, Mn, Zn and Fe were substantially increased after OMW disposal (mainly in surface soil layers) (Kavvadias et al., 2010, 2014). In addition, OMW may represent a low cost source of irrigation water (Piotrowska et al., 2006; Mechri et al., 2011) for dry areas, after separation of solid from the liquid phase of OMW, removal of its toxic fraction (i.e. phenols), and storing at −20 °C, until used.

According to Moraetis et al. (2011), the application of weathered OMW used in their study (1744 m^3 over the irrigation period) added the following concentrations of nutrients to the field: 11800 kg ha^{-1} yr^{-1} C, 1033 kg ha^{-1} yr^{-1} total N, 23.8 kg ha^{-1} yr^{-1} P and 4161 kg ha^{-1} yr^{-1} K. The maize field received 6 times more N, 50 times more K and 2 times less P than the recommended fertilization rates (Moraetis et al., 2011). In order to use OMW safely as amendment for crops, a variety of treatment methods have been suggested, including aerobic, anaerobic digestion and physico-chemical and biological treatments (Saadi et al., 2007; Mantzavinos and Kalogerakis, 2005; Azbar et al., 2004). However, all these technologies are not considered to be economically viable (Moraetis et al., 2011). It was found that production year affected N, K and P concentrations, as well as the total phenolic content of OMW. In contrast, protein content and total organic C were not influenced by production year of olives (Ntougias et al., 2013). According to the same authors, despite that nutrient concentrations and phenolic content were influenced by production year, they were not significantly affected by the harvest period (ripening stage of olive fruits).

Until now, little interest has been paid to the use of treated OMWs (free of high organic load and/or polyphenols) as amendment for soils and organic fertilizer for crops (despite their high nutrient content) in sustainable management systems. In addition, the application of OMWs in degraded and eroded (thus, poor in organic C) croplands could be of great ecological and economic (in order to increase the productivity of these soils and the crop yields, as well as to promote environmental sustainability and biodiversity) interest in the near future; however, unfortunately no attention has been paid until now on the restoration of degraded (hilly-eroded and/or semi-arid) agricultural lands with the use of OMW. The indiscriminate tillage often led to soil degradation, particularly in the Mediterranean areas, as result of losses of organic matter and desertification (Duran Zuazo and Rodriguez Pleguezuelo, 2008). This is why, according to our opinion, preservation and enhancement of soil organic C should be one of the first priorities and actions in the near future, in order to restore soil fertility and yields of marginal and degraded croplands. Thus, sustainability should be enhanced and sustainable crop management systems should be adopted in large scale programs. In addition, the pressure for cultivated land expansion (necessity for exploitation of marginal and eroded/degraded croplands) and food security (necessity for increased productivities and yields) due to increased global population was enhanced. So, according to our opinion, the role of OMWs (especially for the Mediterranean countries, where vast quantities of this waste by-product are produced each year) on degraded croplands' restoration and food increase (in order to sufficiently satisfy the nutrition of increased global population) in the near future will become crucial. With regard to the use of OMW in sustainable management systems, according to our knowledge, only Casacchia et al. (2012) studied the restoration of soil fertility after OMW application in sustainable olive orchards.

Thus, the basic purpose of our review was to collect, present and fully discuss all the beneficial aspects of OMW application on: i) the restoration of degraded and eroded croplands (for the enhancement of low organic C levels, since one of the first steps in land restoration process should be the increase of soil organic C), ii) sustainable management systems (as an important and cheap organic source of nutrients and water, in dry and semi-arid areas, since the prices of chemical fertilizers were dramatically increased during the two last decades and water demand significantly raised, in a global scale). In addition, in order to present a balanced point of view of OMW application, the most important negative environmental effects were also included in this review.

2. Can OMWs substitute chemical fertilizers for crop nutrition in sustainable systems and improve soil chemical and physical properties?

According to Ayoub et al. (2014) and Vella et al. (2016), OMW is a readily available and inexpensive source of nutrients (due to its high macronutrient content) that could replace the application of chemical fertilizers for crop nutrition. Marsilio et al. (2006) reported that in their 5-year study of olive tree cultivation the spreading of 100 and 300 m^3 ha^{-1} OMW reduced or eliminated, respectively, the need of using chemical fertilizers. Similarly, Ben Rouina et al. (2006) found that annual application of OMW in an olive orchard (located in a sandy soil), at a rate of 100 m^3 ha^{-1}, for 10 years, markedly improved soil fertility. Nutrient availability was significantly increased, especially in the surface soil layers, after OMW application (particularly increased inorganic N, extractable P, exchangeable K and Mg and available micronutrient concentrations) (Kavvadias et al., 2014; Chaari et al., 2014). In the study of Belaqziz et al. (2016) it was found that after spreading untreated OMW in soil, the amounts of nutrients increased by 81% for N, 66% for P and 88% for K. Particularly the increased soil K levels can be probably considered as the most positive effect of OMW application on soil chemical properties (Chartzoulakis et al., 2006; Ayoub et al., 2014). Generally, soil fertility is thoroughly enhanced and no serious negative effects on soil chemical properties have been referred (Chartzoulakis et al., 2010).

Despite the high inorganic N levels of OMW, organic N content of untreated OMW is usually low; this low organic N concentration (together with the high inputs of organic C in soil) may increase the ratio C/N in soil up to 50 (Di Serio et al., 2008). Under so high C/N values the mineralization rate is decreased, since N is required for bacteria (Mekki et al., 2009). Similarly, high C/N ratio after OMW application (due to the needs of soil microorganisms for