Soil based wastewater treatment

Effective utilization of olive mill wastewater in Israel and Palestine

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Cultivated since ancient times, the olive tree is native to Israel and the Palestinian Authority. Around 375 olive mills in the region are operated by a three phase continuous centrifugation process which yields pomace, olive oil and olive mill wastewater (OMW). The Project "Wastewater from Olive Oil Mills in Israel and Palestine: Interactions with Soil, Organic Contaminants and Mechanisms of Incorporation into Soil" (DFG: SCHA 849/13) investigates locational and seasonal dependent application scenarios of OMW to soil. The general objective is to understand processes and mechanisms of OMW-soil interaction affecting soil quality and their temporal dynamics in order to optimize OMW soil application for minimal negative effects.

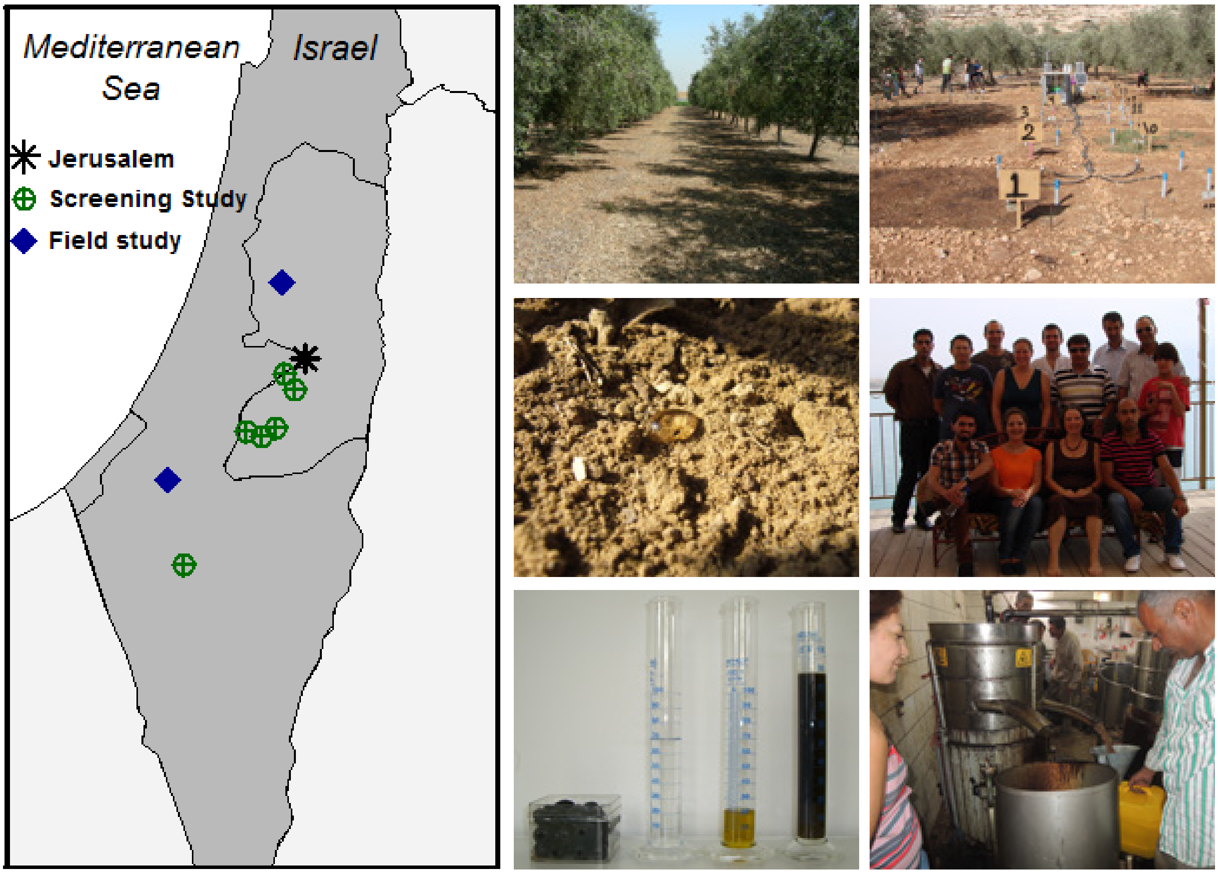
1. Liquid waste from the olive oil production

Cultivated since ancient times, the olive tree is native to Israel and the Palestinian Authority. As the olives are not eaten raw, the use of the fruits depended on the development of olive-oil extraction techniques since 8,500 years and was initially based on mill stones [1, 2]. In 2014, 25,000 tons of olives were produced in Israel for further olive oil processing [3] and around 100,000 tons in the Palestinian Authority [4].

In the three-phase milling process, the harvested olives are washed, milled, beaten and subsequently decanted under water addition in a horizontal centrifuge in order to remove solid residues (pomace). Then they are subjected to vertical centrifugation separating the two liquid phases. Around 375 olive mills (i. e. more than 90 % of all mills) in the region are operated by this three phase continuous centrifugation process which yields pomace, olive oil and olive mill wastewater (OMW) [5, 6]. Besides the energetic disadvantages of this process compared to two-phase extraction systems, it results in increased water use and in turn higher amounts of OMW. Sacrificing part of its extraction efficiency, the two-phase process consumes less water and separates the olive paste into two phases, oil and wet pomace. Oil from the wet pomace can be further extracted after drying using hexane. The dry pomace is also a challenging agricultural waste, but treatment of both extraction systems options and soil application are known to be not as negative as OMW [7, 8].

The brownish and turbid OMW suspension has acidic characteristics. Moreover, its high salinity and amount of phenolic compounds, fatty acids, nutrients as well as oxygen demand present a challenge for wastewater treatment and recycling strategies. Other important factors are its decentralized production with low local amounts and its relevance for a short harvest period (3 months) [9]. Consequently, sewage treatment plants do not allow discharge of OMW into the sewage network and illegal discharge leads to sealed pipes, collapsed pumping stations and treatment plants. Solutions to overcome these challenges were composting, flocculation systems, bio-gas reactors and dissolved air flotation systems. All these systems failed to overcome the existing challenges due to high costs for chemicals and transportation, low efficiency, low intake capacities or the final treated wastewater did not fulfill the local water regulations. Illegal discharge or uncontrolled disposal of OMW is therefore the current strategy of many farmers in the region and reduces soil and water quality [5].

The high organic load and amounts of plant nutrients of OMW favor its use as soil fertilizer or organic amendment to infertile soils which the olive oil producing countries abound in (e. g. [10]). A soil based OMW treatment is a promising and inexpensive approach to reuse the wastewater, and transform this waste into a resource at a local level. Soil aggregation, structure and stability are known to be positively affected by OMW. Moreover, soil plays a key role in the biodegradation and transport of pollutants and can filter, store and transform OMW constituents. However, this soil based OMW treatment is discussed controversial [10]. Highlighted negative effects of OMW land disposal are phytotoxicity and soil salinization as well as acidification and long-term effects are not known.



Left column:
Map of Israel and the Palestinian Authority with the study regions within the trilateral project. Green points from left to right: Revivim, Dayr Samet, Abu Alkamra, Alkom, Battir and Bayt Rahal. Blue points from left to right: Gilat and Bait Reema. Incubation study was conducted with soils from Gilat and Bait Reema in Landau, Rhineland-Palatinate, Germany. **First row:** Field experiment in Gilat (left) and Bait Reema (right). **Second row:** Water repellent soil with a penetration time greater than 1 hour (left); Part of the trilateral group during a meeting at the Dead Sea (right). **Third row:** Proportion of olives (100 g), added process water (≈ 70 mL), gained olive oil (≈ 20 mL) and OMW (≈ 90 mL) (left); Olive mill in Bait Reema with freshly pressed olive oil and OMW (right)

2. Objectives and project

We aim to elucidate the relevance of chemical incorporation, degradation, physical immobilization and reversible sorption of OMW constituents with the objective to identify compound groups undergoing the respective mechanisms and affecting soil wettability, phytotoxicity and sorption of organic chemicals, respectively. The general objective is to understand processes and mechanisms of OMW-soil interaction affecting soil quality and their temporal dynamics in order to optimize OMW soil application for minimal negative effects.

In the Project "Wastewater from Olive Oil Mills in Israel and Palestine: Interactions with Soil, Organic Contaminants and Mechanisms of Incorporation into Soil" (DFG: SCHA 849/13) we investigate locational and seasonal dependent application scenarios of OMW to soil. With a shift from the main application season in winter to spring we expect a more efficient degradation of OMW-organic matter (OM) and reduced negative effects.

3. Working program

A preliminary screening study was conducted to identify soil organic matter (SOM) quality parameters as useful proxies in order to estimate the extent of OMW pollution and the degree of its degradation and to quantify the effects of OMW pollution in Israel and the Palestinian Authority. In two field studies in Israel and the Palestinian Authority the degree and persistence of OMW effects were investigated as a function of soil depth and application season. A laboratory incubation study was conducted to obtain insights into degradation processes of OMW OM by identifying their dominant mechanisms under different environmental conditions. Furthermore, effects of OMW derived phenolic substances on phytotoxicity as well as ecotoxicity. The physicochemical properties of two representative wastewaters used in this project are shown in **Table 1**.

4. Research sites and methods

4.1 Screening study

Six locations in Israel and the Palestinian Authority

Table 1:
Example of two OMWs produced in an olive mill in Bait Reema (OMW–BR) and Revivim (OMW-RV). OMW-BR was used in the study of Kurtz et al. [13], OMW-RV in the study of Steinmetz et al. [14]

Parameter	OMW-BR	OMW-RV
pH	4.6	4.6
EC [$mS \cdot cm^{-1}$]	10.8	9.9
Dry mass [$mg \cdot g^{-1}$]	53	88
DOC [$g \cdot L^{-1}$]	26	32
Phenols [$g \cdot L^{-1}$]	3.5	2.9
$SUVA_{254\ nm}$ [$L \cdot mgC^{-1} \cdot m^{-1}$]	1.3	0.6
BOD_5 [$g\ L^{-1}$]	21.3	82.3
K^+ [$mg \cdot L^{-1}$]	5290	3700
Ca^{2+} [$mg \cdot L^{-1}$]	252	203
Mg^{2+} [$mg \cdot L^{-1}$]	171	140
Na^+ [$mg \cdot L^{-1}$]	105	440
Cl^- [$mg \cdot L^{-1}$]	1278	1200
PO_4^{3-} [$mg \cdot L^{-1}$]	765	677
SO_4^{2-} [$mg \cdot L^{-1}$]	158	130

were selected in dependence on their contamination history due to partially uncontrolled OMW land disposal [11, 12]. At each location, OMW was applied annually since at least eight years. From each location OMW contaminated as well as uncontaminated soils were sampled at a depth of 0–3 cm. Soil physicochemical properties such as water repellency, sorption capacity towards agrochemicals, carbon isotope ratios ($\delta^{13}C$), thermostability and contact angle were measured.

4.2 Field study

The two field studies were conducted in Bait Reema (West Bank, Palestinian Authority) and in Gilat (South District, Israel) and are representative of two typical olive cultivation practices (partly published in [13, 14, 15]). The olive orchard in Bait Reema represents the traditional extensive and rain-fed olive cultivation (100 trees ha^{-1}) in hot-summer Mediterranean climate in a clay loam soil classified as a brown rendzina. The olive orchard in Gilat is typical for intensive olive cultivation featuring a high tree density (450 trees ha^{-1}) in a semi-arid climate in a sandy loam soil classified as light brown sandy loam. A drip irrigation system provides fresh water and fertilizers. OMW was applied in four different application scenarios into a) moderately moist and temperate soil in spring (SP), b) hot and dry soil in summer without irrigation (SU_{dry}), c) hot and moist soil in summer with irrigation (SU_{wet}), and d) cold and wet soil in winter (WI) with two applications at a rate of 140 $m^3\ ha^{-1}$. As control treatment, the same amount of fresh water was simultaneously applied under the same conditions. The soil was sampled one week before and at increasing time intervals up to 18–24 months following application in 5 depths down to 90 cm (Gilat) and 35 cm (Bait Reema). The effects of OMW towards chemical soil properties (e. g. pH, electrical conductivity, organic carbon, phenolic substances, cations, anions and the specific UV absorbance at 254 nm in aqueous extracts) and physicochemical properties (e. g. wettability and thermal stability) were measured. Furthermore, effects on soil biological activity using Berlese funnels and bait-lamina sticks were assessed.

4.3 Incubation study

In a 60 day incubation study the soils from Gilat and Bait Reema were investigated under controlled conditions simulating the same seasons as in the field study (4.2, [16, 17]). At 10 sampling points the same parameters as in the field study (4.2) were measured. Moreover, soil respiration and representative phenols isolated by accelerated solvent extraction were separated and analyzed. In addition, the ecotoxicity using Lepidium sativum and Folsomia candida were determined.

5. Preliminary results

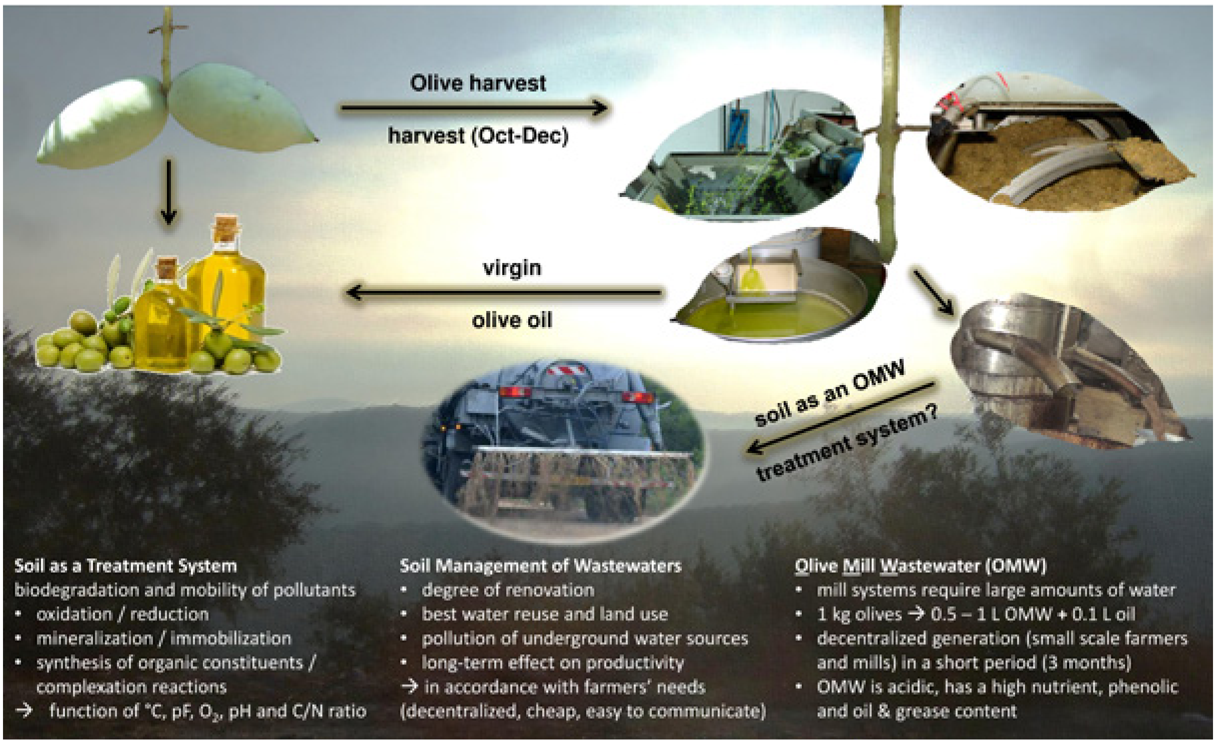
The screening study pointed out that, besides strong acidification, water repellency and salinization effects, uncontrolled OMW application increased the amount of organic carbon content, especially of non-aromatic compounds like fatty acids and sugars and lead to a depletion of $\delta^{13}C$. The observed changes in the top soil composition were also reflected in changes of the soil quality. The SOM became thermally less stable and its calorific value and the amount of water extractable organic carbon increased. Furthermore, the OMW pollution strongly reduced the wettability of the soils. Moreover, the additional OM content and the unique character of the OMW OM increased the soils sorptive capacity for agrochemicals. The described changes were stronger than those reported from studies of controlled OMW application [18, 19] including the two field studies of this project. This shows that the negative effects accumulate with repeated uncontrolled OMW application [12]. The study further demonstrated that the water drop penetration time obtained by a comparatively simple field method is a very sensitive parameter to identify OMW pollution that correlates with most parameters affected by OMW application. It has, therefore, the potential to be used for a fast assessment of soil quality. The more advanced methods like thermogravimetry and isotope ratio mass spectrometry were even able to assess the pollution history of soils treated with OMW. Simulating a worst case application scenario with a high application rate in a field experiment in Gilat, Steinmetz et al. [14] found that the prevailing environmental conditions during and after OMW application do influence soil-water interactions and physicochemical soil properties. OMW application in summer had severe effects, even after one rainy season following the application. Especially heat inhibited the degradation of OMW OM and led to immobilization. Also irrigation in summer did not compensate for negative effects like water repellency, concentration of phenolic substances and acidification.

In accordance to the Gilat experiment, also the field experiment in Bait Reema showed that with increasing duration of the hot and dry period directly after the OMW application (SP and SU_{dry} application) negative effects like acidification, salinization, repellency and elevated concentrations of phenolic compounds become more persistent because large parts of the OMW constituents accumulated in the top soil and are immobilized by abiotic mechanisms, e. g. by polymerization. But in contrast to the loamy Gilat field, for the finer textured clay loamy soil in Bait Reema, a strong relevance of preferential flow for the OMW effects was observed. Under wet conditions due to rain or irrigation, leaching of OMW compounds enhanced by preferential flow paths decreases the short term effects in the top soil but significantly increases the risk of groundwater contamination. Therefore, conditions which favor biological activity (SU_{wet}) and enhance the degradation of OMW compounds before the rain season starts are the most favorable for OMW soil application as long as preferential flow is prevented [15].

The extent of OMW induced effects and fate ot its constituents is triggered by soil texture, soil properties and field management Kurtz et al. [13]. Additionally, Kurtz et al. [13] and Steinmetz et al. [14] also showed that OMW negatively affects soil biological activity and alters soil biological communities in terms of abundance and composition. OMW revealed a potentially high acute and an also chronic toxicity but this could be also attributed to hot and/or dry conditions only.

Positive effects on soil chemistry were an altered soil potassium balance for more than one year after OMW application and could positively affect the olive trees since they are well known to have high potassium requirements. Moreover, it can result in a reduction in the application of potassium fertilizers. Too high potassium levels are known to decrease soil aggregate stability and enhance soil erosion [20]. Despite the high application rates, soil acidification, electrical conductivity and sodium, chloride and divalent ions were found to be unaffected by OMW application one year after the application.

In the lab incubation study, Buchmann et al. [16] found a three-step transformation of phenolic compounds including the transformation of easily accessible phenolic substances, metabolism of more stable phenolic substances



Project "Wastewater from olive oil mills in Israel and Palestine: interactions with soil, organic contaminants and mechanisms of incorporation into soil." (DFG: SCHA 849/13) and immobilization or incorporation of phenolic substances into the soil matrix. Phenolic substances as well as their transformation products were found to be responsible for phytotoxicity, however, their transformation or immobilization leads to a fast suppression of toxic effects. But it was also found that phenols are not degraded completely but immobilized and have the potential to remobilize, depending on environmental conditions.

6. Synthesis of the current state of findings

The seasonality and amount of OMW application are the key factors towards a sustainable and cheap solution. OMW stays a challenging agricultural waste water, but with an at least annual monitoring of some simple parameters (e.g. Germination, WDPT, pH), we provided some methods and knowledge to assess the risks. Moreover, the seasonality of OMW application affects its fate: It seems that negative effects were minor after spring application but not completely suppressed. In contrast, winter application will lead to lower effects on soil but it is highly suspected that leaching poses a substantial risk. Further thermal analyze and isotope ratio mass spectrometry of analyses gave us deeper insights in mechanisms of OMW OM fate and the toxic profile of OMW. The risk of reoccurring toxicity due to remobilization of phenols has to be further investigated. Based on the results of our project, controlled disposal of OMW to the land is favored against uncontrolled OMW disposal. On the one hand, soil seems to be a well suited treatment system allowing local farmers to have a cheap and feasible strategy for OMW disposal. For example, using an application rate of 140 m^3 ha^{-1} Israel would need 860 ha of olive orchards to recycle the accruing 120,000 m^3 OMW per year. This area accounts only for 2.8 % of the total olive cultivation area in Israel. Therefore, we see a high potential to reduce the application rate, alternate the selected fields annually and, as a result, provide a safe strategy for OMW disposal. However, effects have not to be linearly dependent on the OMW application rate and must therefore be further investigated. On the other hand, the negative impacts must be further monitored and OMW application strategies have to be adapted to the current soil and management situation. Especially soil texture and irrigation can strongly influence the fate of OMW constituents. Another reasonable approach to tackle the most prominent negative effects like water repellency issues could be to till the soil after the application. This might help to mitigate effects on water repellent top layers and enhance microbial degradation of OMW OM.

Check the references:

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