Oil-Mill Wastewater (OMW) in the West Bank

- Olive Oil Business Structure, Waste Formation and Treatment Options -

ARAVA Institute

CTWM Research Report

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1. Introduction

Olive farming and the production of olive oil has been applied in the Mediterranean area for more than 7000 years already and is widely common in Palestine. At this, it plays an important role in the Palestinian society. As olive trees are able to attain very old age, they are inherited from generation to generation creating strong bonds between trees and land owners. In Palestine olive oil forms the major cooking oil source and is used in large quantities. However, the oil extraction generates great amounts of organic waste and requires large amounts of process water due to the application of more effective extraction techniques since the second part of the 20th century. Thus, the oil extraction produces waste water which is enriched with high organic loads and various phytotoxic organic compounds. In Palestine this water is usually not treated but discarded uncontrolled to wadis and rivers posing a major threat to aquatic ecosystems as well as to surface and ground water resources. In doing so, besides untreated sewage discharge olive mill waste water (OMW) causes one of the major contributions to water pollution. Since the olive oil production and consumption is increasing and urban areas are spreading surface and groundwater resources are more and more endangered. Subsequently, measures need to be adopted in order to stop adverse impacts of OMW production and discharge. This paper summarizes information on the olive oil business structure, the formation and properties of olive wastes, available and tested management options for OMW and tries to give recommendations for the treatment of liquid (in Arabic called "Zbl") and solid (in Arabic called "Gft") olive waste in the West Bank.

2. Olive Farming in the Palestinian Territories

2.1. Business Structure of the Olive Sector

The olive production presents the major agricultural sector in the Palestinian Area. Approximately 45 percent of the total agricultural land are covered by ca. 10 Mio. olive trees (Oxfam International, 2010), providing up to 120,000 t of olives per annum (Shaheen & Karim, 2007). In good years the amount of produced olive oil can be as high as 34,000 t. In those years the olive sector contributes between 15 and 29 percent to the total agricultural sector depending on the considered scientific reference accounting for US$ 160-190 Mio. (Khatib & Aqra, 2009 / Oxfam International, 2010). The entire Palestinian agriculture contributes about 10 percent to the national GDP. However, in bad years the production might only result in 5,000 t of oil. The average annual yield between 2001 and 2009 was about 17,000 t and US$ 100 Mio. 95 percent of all harvested olives are processed to olive oil. The remaining 5 percent are used for pickles, table olives and other products such as soap and cosmetics. (Oxfam International, 2010) In comparison, in Israel ca. 20,000 ha of land are covered with olive trees resulting in the production of about 2,000 (bad years) to 9,000 (good years) tons of olive oil per year (Laor & Raviv, 2010).

Most Palestinian farmers depend at least partially on the farming or processing of olives as it is often a secondary basis of livelihood. This is especially relevant for poor families depending on subsistence farming. More than 80 percent of all Palestinian olive farms are small or medium scale (≤ 25 dunums). The production is mainly carried out regionally in scattered villages. Interactions or joint co-operation between farmers and mill owners are very rare (Zereini & Jaeschke, 2010). Most orchards and presses are run as small family businesses depending on unpaid family members or low paid workers. At this, it is interesting to mention that around 1/3 of all working women in Palestine are employed in agriculture sector. 15 percent of employed women are active in the oil business (ITC et al., 2013). Available technical equipment is usually rather poor, which renders olive production less efficient and very labor intensive. Subsequently, the olive business sector provides jobs for about 100,000 people. ITC et al. (2013) states ca. 49,000 families to be involved in the cultivation of olive trees. Besides the farming, the subsequent production chain including oil presses, bottling and trading creates additional jobs. It is assumed that in 2009 490 officially registered employees worked in oil mills throughout the Palestinian area. However, the number of private, non-registered workers in olive mills is not known. (Oxfam International, 2010)

Within the West Bank the main focus of olive farming is in the north and it declines south- and eastwards mainly due to changing climatic conditions (Figure 1). Important centers are Jenin, Nablus and Tulkarem. Here up to 200 trees per hectare can be found. In Gaza olive farming is of secondary importance due to the high population density and relatively little available agricultural land. (ITC et al., 2013)

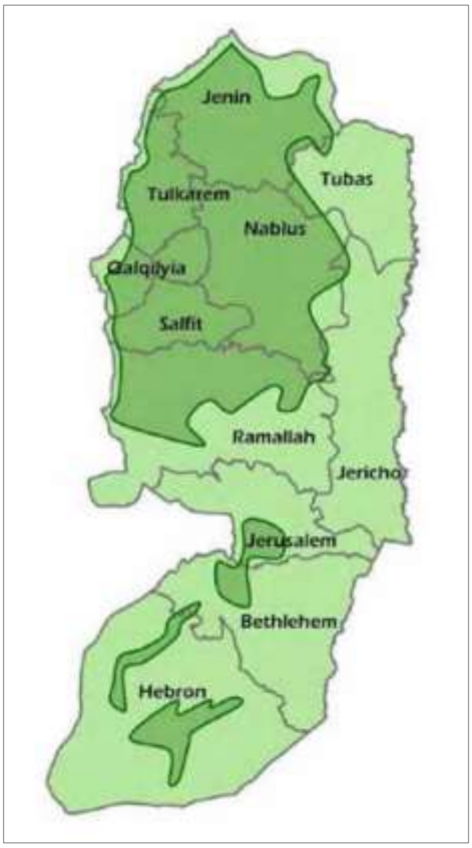


Figure 1: *Productive regions of the West Bank for olive cultivation: more productive regions in darker green (ITC et al., 2013)*

2.2. Consumption and Trading

On a global scale the olive oil sector is increasing. Between 1984 and 2011 the worldwide olive oil production increased from 1.85 Mio. tons to 3.4 Mio. tons (Tsagaraki et al., 2007) and the export market for virgin olive oil almost tripled between 2001 and 2008 (IOOC, 2004 / ITC et al., 2013). More than 90 percent are produced in the Mediterranean region (Shaheen & Karim, 2007). However, compared to international figures the Palestinian olive market is rather small (Figure 2). This is partly due to low production capacities, big deficiencies in product research and education, missing product quality management and a very limited branding and international market knowledge (ITC et al., 2013).

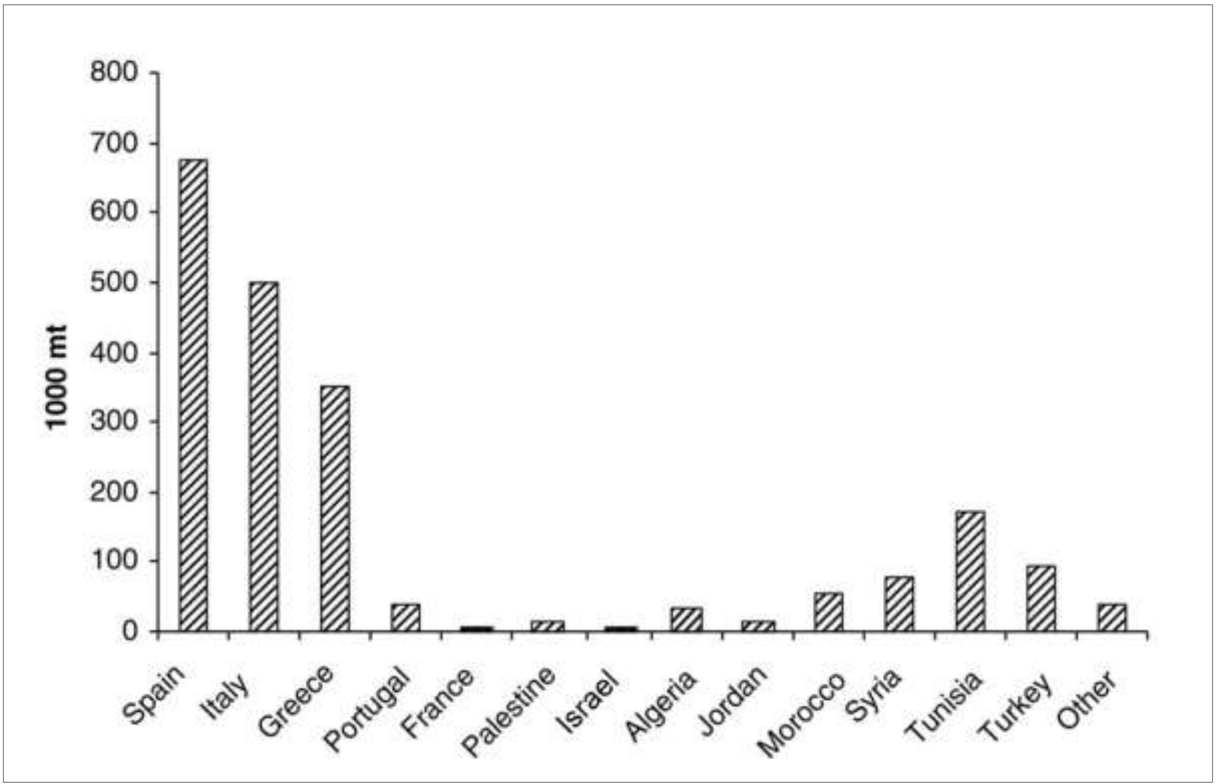


Figure 2: *Olive oil-producing countries and oil yields (International Olive Oil Council, 2004; modified)*

The local olive oil consumption in Palestine meets about 3.5 kg per Person and year accounting for approximately 12,000 t per annum. Thus, the local market is the main consumer of Palestinian olive oil. In good production years excess production can be exported. The average annual export is 4000 t. 80 percent of the Palestinian inhabitants purchase their oil, 20 percent use their own one. In bad years additional imports might be necessary to cover the local demand (ICT et al., 2013). Between 1993 and 2013 the local oil production could cover the domestic demand in 15 of 18 years (Figure 3). Main export regions for Palestinian olive oil are Gulf countries, Europe, North America and East Asia. (Oxfam International, 2010) Between 2007 and 2010 virgin olive oil was the fourth largest export good in Palestine, creating earnings of US$ 11.1 Mio per year and 2 percent of the total domestic export benefit, respectively (ITC et al., 2013). Prior to the 2nd Intifada Israel was the main importer for Palestinian olive oil. Israel used to obtain up to 2/3 of its total olive oil imports from Palestine. Until 2007 and 2008 Israel remained Palestine’s main sales market. However, after those imports shrunk dramatically and new export markets such as Western and Arabic states had to be found (Figure 5). The amounts imported by other countries tend to be very fluctuating and barely predictable causing economic risks for the producers and exporters. (ITC et al., 2013). In comparison, the olive oil consumption in Israel increased from ca. 7,000 to 17,000 tons per year between 2000 and 2010 (Laor & Raviv, 2010) and is subsequently dependent on imports (compare chapter 2.1).

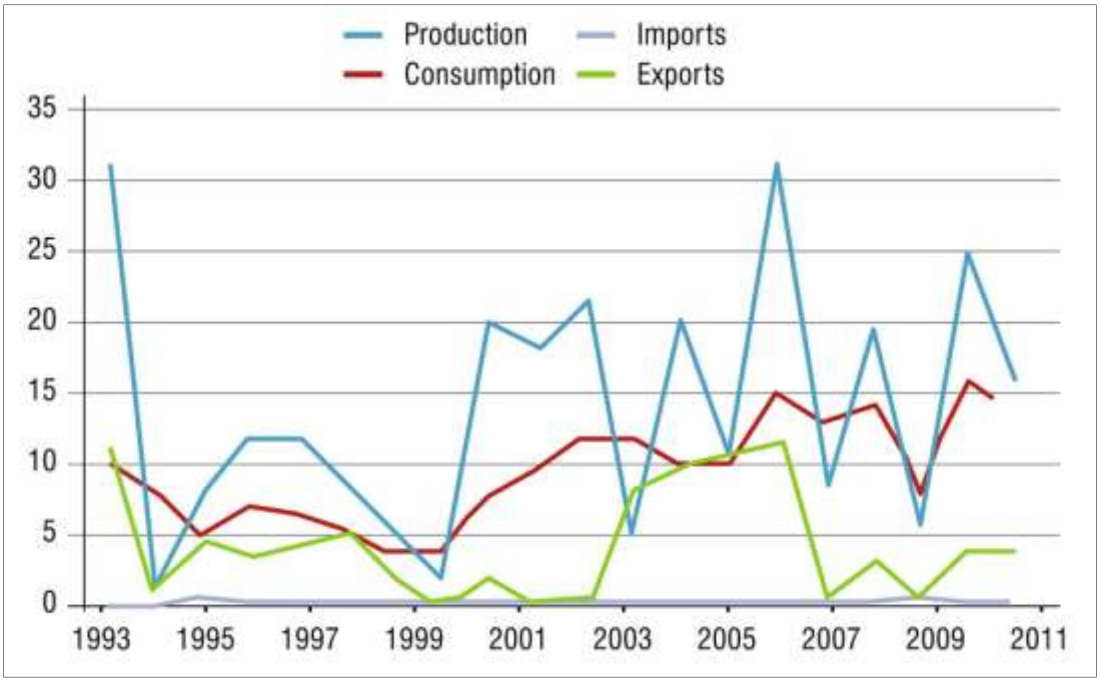


Figure 3: *Palestinian olive oil supply and demand, 1993-2012 (in thousands of tons) (ITC et al., 2013)*

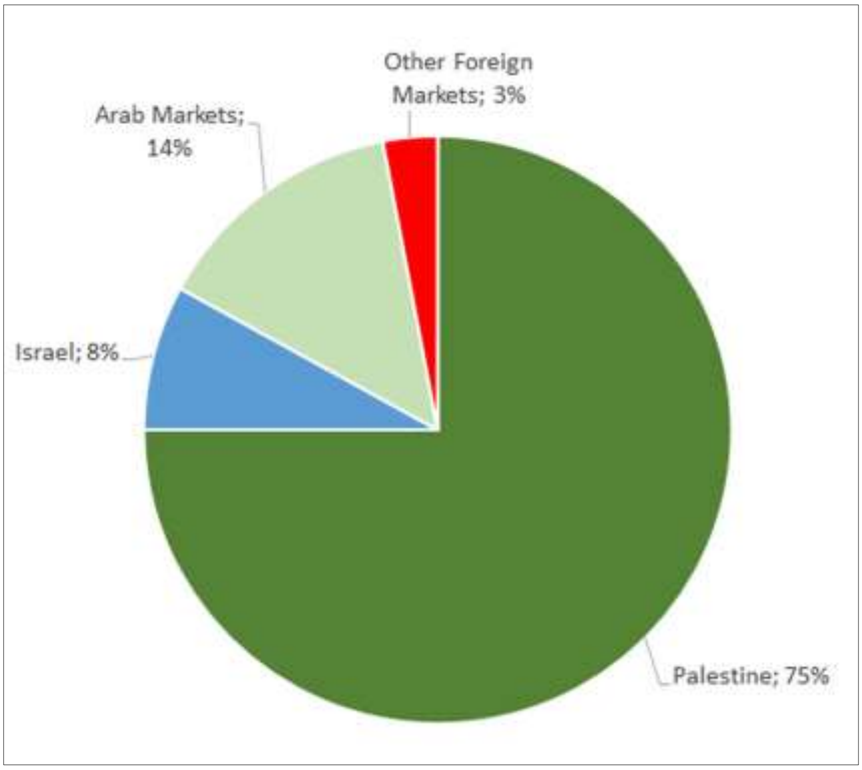


Figure 4: *Typical distribution of markets for Palestinian olive oil 2012-2015 (ITC et al., 2013)*

2.3. Problems and Trends of the Olive Sector

2.3.1. Natural Constraints

The olive oil production is a seasonal business and most labor is needed during the harvest and the pressing for 60-90 days between October and January (Shaheen & Karim, 2007). However, poor oil extraction equipment might extend the operating time (Shaheen & Karim, 2007). Further, it is crucial to understand that the yields of olive trees tend to fluctuate naturally. In the Palestinian area the 2009 harvest was for instance only about 27 percent of the 2008 harvest (Figure 5). Compared to Israel or European countries the fluctuations in the Palestinian groves are stronger, since they are much more exposed to natural uncertainties such as extreme climate or diseases due to a lack of irrigation systems, technical equipment or pesticides. Whereas most groves in Palestine are rain fed almost all Israeli olive farms are based on cultivated irrigated crops (Laor & Raviv, 2010). However, even though fluctuations are lower, they also occur in Israel (Figure 6) and their origin is not clearly solved, yet (Neot Smadar, 2016). On one side, fluctuations and seasonality cause economic problems for the families and employees involved in the olive sector. On the other side, the alternating yields have a direct impact on the amounts of olive mill waste, which is formed during the oil extraction process. These unreliable numbers form a major challenge for economically sustainable treatment plants, since there is a lack of workload in years of low olive yield. (Oxfam International, 2010)

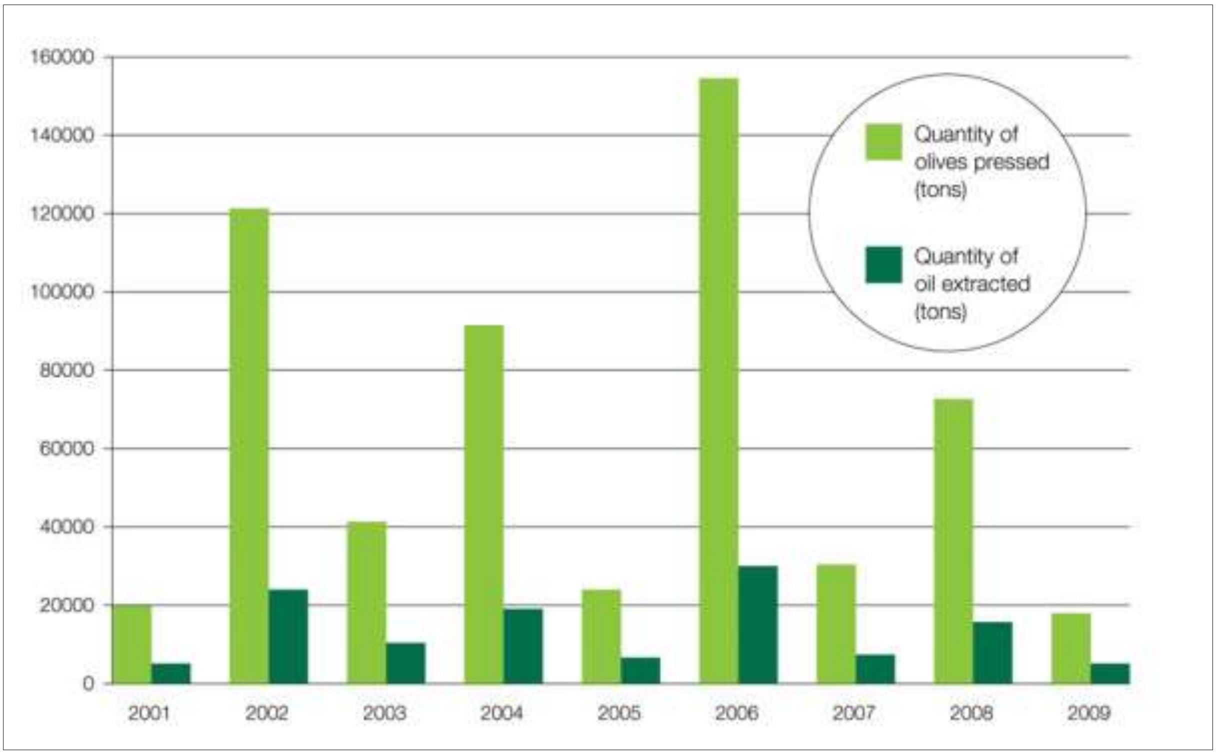


Figure 5: *Quantity of olives pressed and oil extracted in the Palestinian territory, 2001-2009 (Oxfam International, 2010)*

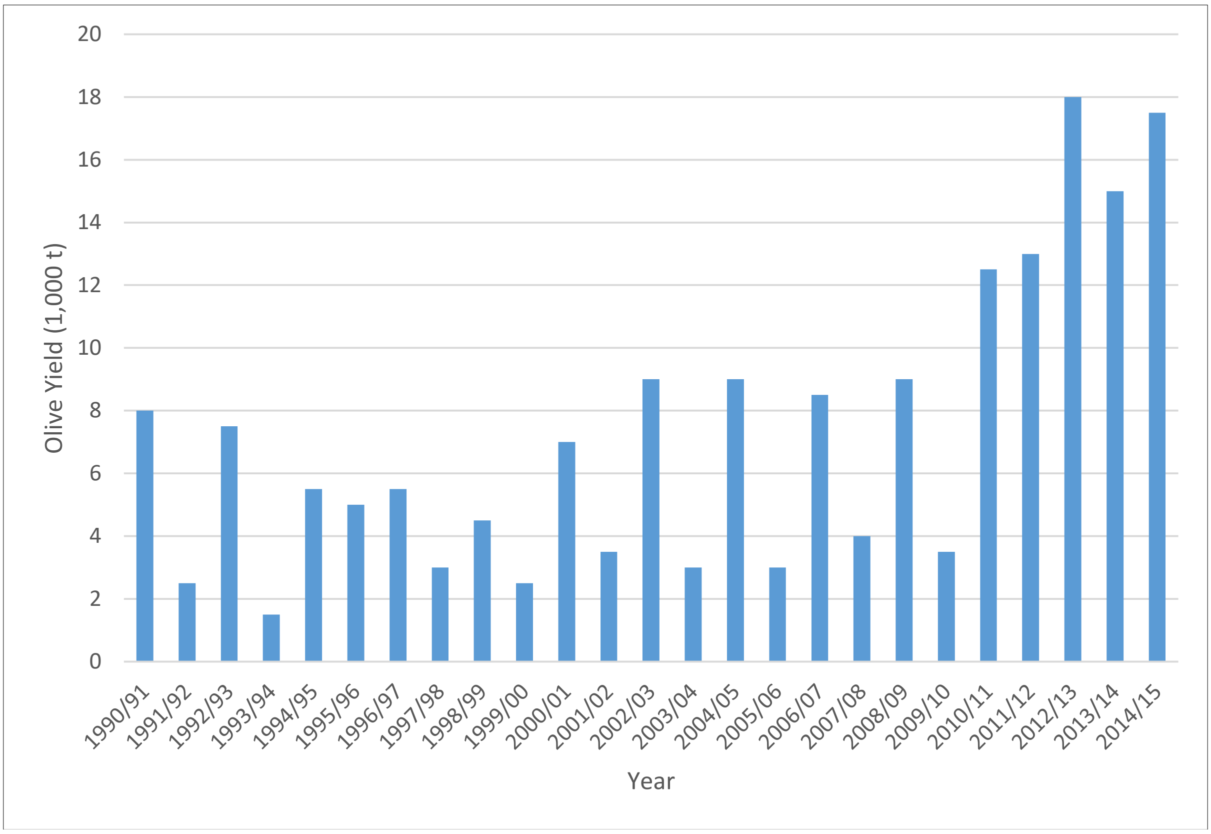


Figure 6: *Quantity of olives harvested in Israel, 1990-2015 (International Olive Oil Council, 2015)*

2.3.2. Governance and Problems Related to the Political Situation

There are a different political authorities and organizations involved in the Palestinian olive and olive oil sector. The responsible political representatives are the Ministry of National Economy (MoNE) and the Ministry of Agriculture (MoA) being liable for the implementation of the agricultural and rural development policy. Besides this, there exists an entire system of business and trade networks that are described in Figure 7.

However, these networks lack of power for adequate implementation and enforcement of development measures. One of the main reasons is the current political situation and the predominance of Israeli authorities. 63 percent of the Palestinian territory is under full Israeli control, whereas only 18 percent are fully controlled by the Palestinian Authority. As Palestine is not recognized as an independent state it cannot be a full member of the International Olive Council. Due to checkpoints, road blocks and the West Bank barrier many farmers cannot get reliable access to their lands in order to prepare the soils, take care of the trees or to harvest on time. In order to produce high quality olive oil the perfect harvest time and fast processing of the olives within view days is very important. Delays in this process are e.g. likely to cause elevated peroxide and acidity levels and thus lower market prices of the olive oil. Subsequently, the access limitations pose a severe threat for the economic success for many Palestinian olive farmers. Further, there are reports stating attacks and harassment from Israeli settlers against farmers and trees especially during the harvest time. Besides that, high bureaucratic barriers and a very limited market access for Palestinian exports create adverse effects on the business. (Oxfam International, 2010)

Other farmers complain about lacking financial state support of the business. In 2009 the agricultural budget of the Palestinian Authority was only 1.21 percent. Of this, 58 percent were spent for salaries and operational costs leaving little space for investment in modernization and improved disposal of OMW. Palestinian Authority (2009) There is low access to credit and unrealistic, unaffordable payment schemes on loans preventing farmers from extending orchards and investments in equipment. (Oxfam International, 2010)

Policy support	
Name	Function/role
Ministry of National Economy (MoNE)	The Ministry of National Economy is responsible for: • Standards and regulation enforcement • Duty draw back payments • Release of financial guarantees • Industrial licences • Renewal of industrial operating licences • Verification of names • Certification of a Certificate of Origin • Re-exporting transactions • Certified Exporter certificates
Ministry of Agriculture (MoA)	Implementation of state policy on agricultural and rural development supports the planning, development, and organization of the whole value chain of plant and animal products; supports post-harvest handling of agricultural products; and the food industry.

Business services network	
Name	Function/role
Palestinian Olive Oil Council (POOC)	Public-private council meant to coordinate and unify efforts to develop the sector and improve its competitiveness, through policy advocacy and technical advice along the value chain
Palestinian Federation of Industries (PFI)	The PFI facilitates industrial development as the basis for economic performance. PFI's representational role is to educate, advocate, and communicate the value of a developed, socially responsible and globally competitive industry.
Palestinian Chambers of Commerce and Industry (FPCCIA)	The Federation's main task is to help local chambers of commerce to meet the requirements of the global business environment. The FPCCIA is an advocacy institution, which aims to ensure that the private sector operates freely and has a voice in policy formulation at the national level. It also strives to create strong regional and international links to global markets and works with SMEs to improve their performance, focusing on market access, quality, costing and financial management.

Trade services network	
Name	Function/role
Palestinian Trade Centre (PalTrade)	PalTrade is the trade promotion organization of the State of Palestine with the mandate to develop exports. PalTrade's mission for the sector is improving trade competitiveness through trade promotion and capacity building; fostering international business practices and standards among professionals, firms and business organizations; and providing trade-enabling knowledge.
Palestine Polytechnic University (PPU)	Important potential source of skilled labour. Technical vocational education and training institution with colleges of engineering, information technology and computer engineering, applied science, administrative science and informatics, and applied professions.
Palestine Standards Institution (PSI)	PSI is considered the sole body responsible for issuing Palestinian standards: by providing accreditation for labs, granting the quality mark for products, and signing cooperation and mutual recognition agreements with other countries to facilitate trade.
Palestinian Central Bureau of Statistics (PCBS)	The responsibility of PCBS for the sector is: To serve the instrumental needs of businesses and their organizations for statistical information on states and trends. To participate effectively in building the different administrative records and central registers to meet the administrative and statistical needs of the Palestinian society. To publish a statistical yearbook annually.
Agricultural Development Association (PARC)	The Agricultural Development Association (PARC) is a leading Palestinian non-profit, non-governmental organization involved in rural development and women's empowerment. PARC provides advice, awareness support, services, and special consultancies for individuals, groups, and institutions involved in similar domains. PARC relies on the broad and efficient participation of its beneficiaries, and moreover, on developing the qualifications of its experts to better benefit and develop a democratic Palestinian civil society

Figure 7: *Palestinian policy support, business and trade network (ITC et al., 2013)*

2.3.3. Future Development Aims

In order to improve the international competitiveness, to support the economic development of the Palestinian territories as well as to enhance the production conditions of the olive sector future development goals have been formulated by the Ministry of National Economy, the Palestine Trade Center and the International Trade Centre. Those goals comprise the enhancement of the quantity and quality of the produced olive oil as well as improved response to special market demands such as organic production, certain sorts and regions. The olive oil production is to be increased annually by 10 percent reaching an average of 32,000 t per year in 2020. 50 percent are to be used domestically whereas 50 percent should be used for the creation of a stable export market. Markets of special interests should be the Gulf region, the EU, the USA, Canada and new markets such as Japan, Malaysia and Brazil. A major requirement for this development is the stabilization of the annual fluctuations of the yields. (ITC et al., 2013) Improved techniques, such as irrigation, improved tillage and fertilization cannot stop natural fluctuation entirely but they can help to stabilize the annual differences on a lower level and raise the average yield up to 35,000 t per year within the following decade. (Oxfam International, 2010) At this, the Spanish Agency for International Cooperation (2007) pointed out that the Palestinian olive groves fed by protected irrigation (ca. 2.3 % of total groves) contributed almost 50 percent to the total olive yields. Non-irrigated groves (ca. 87 % of total groves) contributed less than 25 percent.

Further, education, local and international cooperation, the sector structure and organization as well as enhanced marketing, promotion and international visibility are to be improved (ITC et al., 2013). During the last years increasing foreign investments to the Palestinian olive and olive oil sector have been reported helping the economy to develop. Between 2008 and 2010 at least $ 10 Mio. of development aid were received (ITC et al., 2013). The European Union spent 5 Mio. Euros, the French Development Agency contributed 1.25 Mio. Euros and the Swiss Agency for Development and Cooperation gave $ 1.1 Mio. At this, there are some cases in which donors and support seemed to be misused as additional income without investment. However, those cases seem to be exceptions. (Oxfam International, 2010)

3. Olive Oil Extraction Methods

Different authors state slightly different amounts of olive mills to be active in the Palestinian territories. Oxfam International (2010) assumes a number of 235 mills in 2009. Al-Khatib et al. (2005) report an increase of mills from 227 in 1998 to 246 in 2002 and ITC et al. (2013) mentions 271 operating mills in 2011. At this, the number of active mills depends on the annual amount of harvested olives and is thus alternating depending on the yield. In comparison, Laor & Raviv (2010) mentioned a number of about 120 mills to be operating in Isarel.

In average each mill handles olives from ca. 300 ha of land. One tree can carry up to 300 kg of olives though the long term average is rather 20 to 30 kg. The oil yield is approximately 21 to 24 percent of the entire fruit showing an average ratio of 4.1 - 4.5 : 1 (olives : oil). Figure 8 illustrates the oil yield obtained from the olive harvest in different Palestinian arias in 2002 unveiling slightly different yields.

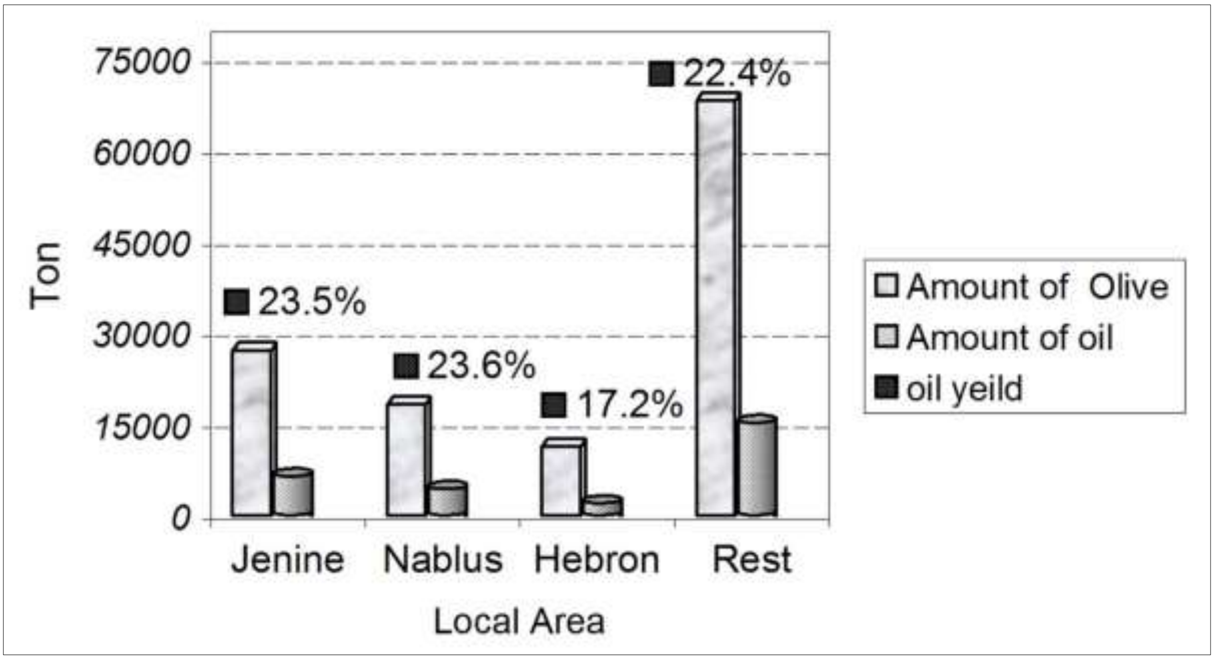


Figure 8: *Comparison of the amount of olives and olive oil produced in various parts of the West Bank and Gaza and the overall oil yield in the year 2002 (Khatib & Aqra, 2009; modified)*

(ITC et al., 2013) The remaining 76 to 79 percent of the olives contribute to the formation of liquid and solid olive waste. However, OMW does not only contain the unused parts of the olives, it also comprises additional water being used during the extraction of the olive oil such as washing and process water. In Palestine mainly three different extractions methods are applied: a) traditional (manual or semi-automatic) pressing b) continuous extraction in three-phase-decanters and c) continuous extraction in two-phase-decanters. Different extraction methods need different amounts of process water and result in different kinds of waste.

3.1. Traditional and Semi-Automatic Pressing

Prior to the oil extraction the harvested olives need to separate from leaves either manually or mechanically. After the olives are washed and pulped by a mile stone. The formed pulp is transferred to bags and nowadays mainly pressed during a vertical hydraulic semi-automatic process. In order to exclude solid matter the extracted oil is either filtered after or transferred to a settling tank where it remains several weeks or months. In some olive mills two settling phases take place after another. The produced oil is then ready to be bottled. At this, per ton of olives the oil yield is about 160 kg and the amount of waste water accounts for ca. 200 kg. The water content of the olive cake is approximately 25 percent (Shaheen & Karim, 2007).

Generally cold pressed virgin olive oil gains the highest market values. To fulfill the standards of this oil type, the process temperature must stay below 27 °C and the oil must comply with certain chemical properties. At this, light and oxygen exposure are likely to effect the oil quality adversely. As the traditional pressing is not a closed process one of its major disadvantages is the exposure to light and oxygen. The oil quality might also be effected by longer delays between harvest and pressing. Further, it demands more manual labor than continuous processes. However, the main advantages of the traditional method are lower investment costs, little demand for highly trained employees and reduced required process water resulting in lower amounts of formed OMW. (Tsagaraki et al., 2007) Further, the formed waste is drier than the one resulting from more modern extraction methods and thus more easily dryable (Neot Smadar, 2016). Never the less, referring to ITC et al. (2013) nowadays only view oil mills rely on the traditional extraction process in the Palestinian area.

3.2. Continuous Extraction Methods

In order to enhance efficiency and to reduce labor costs 88 percent of all oil mills in Palestine are using continuous fully automatic extraction methods (Tsagaraki et al., 2007). This includes the usage of three-phase or two-phase centrifuge decanters. 2-phase-decanters are more modern, were invented to reduce the amount of waste water and are widely considered to be more environmentally friendly for this reason. However, due to the business situation most mills in Palestine use three-phase-decanters (Khatib & Aqra, 2009) often originating from second hand sources being older than 10 years (Zereini & Jaeschke, 2010). Surprisingly, the three-phase decanters are also the predominant extraction form in Israel (Laor & Raviv, 2010).

3.2.1. Three-Phase Decanter

Three-phase-decantation is the most widely used extraction method in Palestine (Zereini & Jaeschke, 2010)/ (Khatib & Aqra, 2009). The initial phase of the continuous extraction is not different from the traditional one and comprises leaf separation and washing. After the olives are crushed by a milestone or by sharp knives (knife-edge spinal mills). Subsequently, the malaxation phase takes place: water is added and the pulp is slightly warmed up to ca. 32 °C. During this stage vacuoles are broken up and chemical processes are initiated. Modern malaxation modules try to utilize as little water as possible aiming for high quality standards. However, modern techniques is barely available in Palestine. After malaxation the pulp is transferred to a centrifuge decanter, which separates three phases: olive oil, liquid waste water and the solid olive cake. After an additional separator is used to exclude even small amounts of remaining water in the oil. This separator is another centrifuge rotating on a higher speed than the decanter. This step requires the addition of little amounts of heated water, which also contributes to the final amount of OMW. In analogy to the traditional extraction the oil is finally transferred to a settling tank for 2-4 months or it might be filtered. Figure 9 shows the simplified three-phase extraction process.

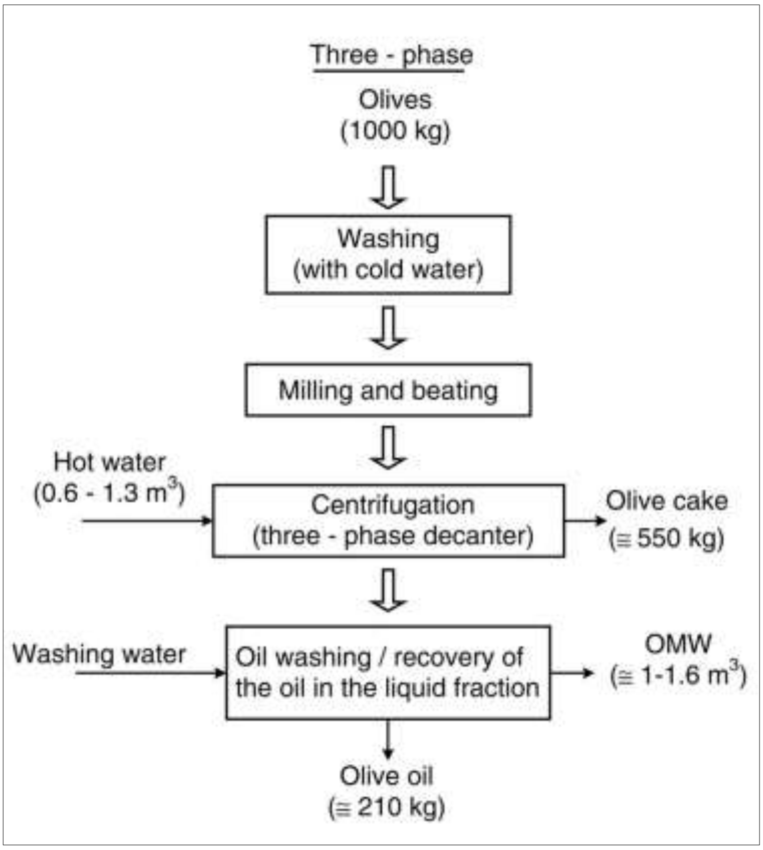


Figure 9: *Three-Phase Decanter centrifugation system for olive oil extraction (Tsagaraki et al., 2007)*

Compared to the traditional process the three-phase-extraction shows a higher oil extraction efficiency (ca. 210 kg oil per t olives compared to 160 kg/t). However, due to the high amount of necessary process water the volume of OMW formed is much bigger (1-1.6 m^3 OMW/t olives compared to ca. 0.2-0.3 m^3/t). Thus, OMW treatment plants for three-phase-extractions need to be able to deal with very high waste water amounts. Further, the process water tends to dissolve big amounts of polyphenols from the olives, which can be found in the OMW subsequently. The remaining olive cake might be used as a source for the extraction of low quality olive pomace oils. At this, hexane can serve as an extracting agent. The secondary oil might be used in soap and cosmetics production industries or it could be refined and mixed with other oils in order to produce low quality cooking oil (Azbar et al., 2004). However, this process requires proper governance and effective economic networks and is barely conducted in Palestine due to the political and economic situation. (Tsagaraki et al., 2007 / Shaheen & Karim, 2007 / Bukhanovsky et al., 2015)

3.2.2. Two-Phase Decanter

After leaf separation, washing, crushing and malaxation the olive pulp is transferred to a decanter in analogy to the three-phase extraction process. However, in contrast to the three-phase decanter the two-phase decanter separates only two phases: oil and wet olive cake. The two-phase decanter is generally considered more modern and produces less waste water and has been introduced in order to reduce the required water consumption and thus the high OMW amounts from the three-phase decanter. At this, it needs to be mentioned that the three-phases oil extraction requires up to 1.3 ton of water per ton of olives, which is very high regarding the scarce water resources in the middle east (Tsagaraki et al., 2007/ Khatib & Aqra, 2009). The two-phase decanter needs much less water and creates an oil yield of approximately 180 to 200 kg per ton of olives. On one side, the amount of OMW formed is only 200 kg which is comparable to the traditional pressing method. On the other side, the mass of the olive cake is larger (ca. 800 kg) since it shows an elevated water content (Figure 10). (Shaheen & Karim, 2007 / Tsagaraki et al., 2007)

Generally, the lower generation of OMW is advantageous, since lower amounts need to be treated. However, the low water contents generate very high concentrations of problematic compounds in the OMW due to lower dilution effects. A potential treatment facility needs to be able to handle such highly concentrated OMW. Further, it is stated that the produced olive cake from two-phase-decanters is not ready to be reused in pomace oil extraction facilities and has be dried prior to the extraction because of the elevated water content. Nevertheless, as pomace oil extraction is less common in the Palestinian territories this has secondary relevance. (Shaheen & Karim, 2007) Furthermore, the two-phase-decanter extraction is barely applied in Palestine (Zereini & Jaeschke, 2010)/ Khatib & Aqra, 2009).

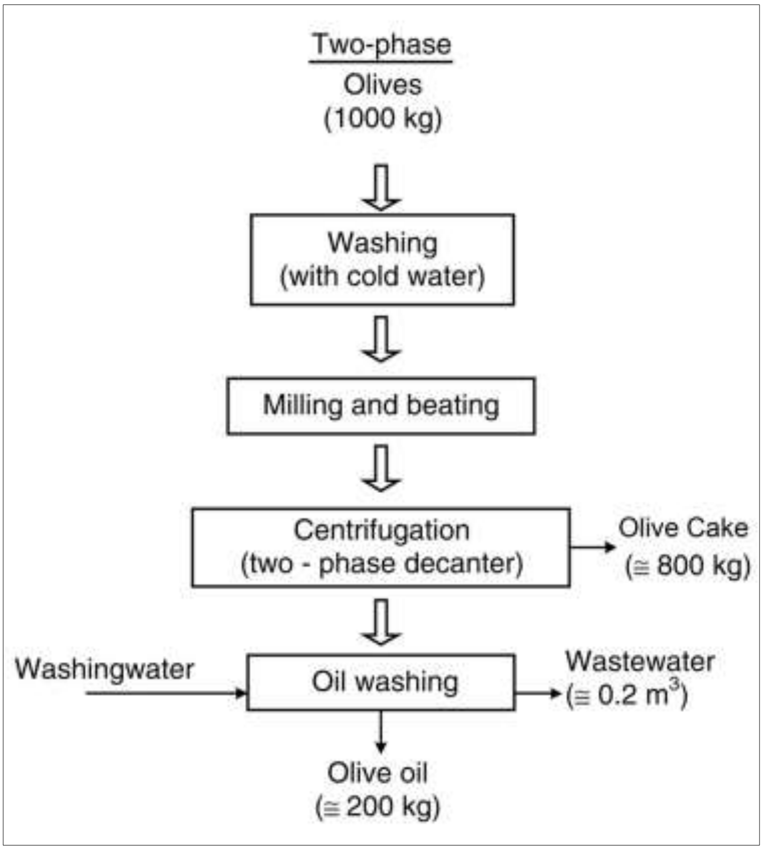


Figure 10: *Two-Phase Decanter centrifugation system for olive oil extraction (Tsagaraki et al., 2007)*

4. Properties and Current Disposal of Olive Waste in Palestine

The global production of OMW is stated to be about 5.4 Mio. m^3 per year (Khatib et al., 2009). Based on their research Khatib & Aqra (2009) assume an average production of 1.7 m^3 OMW per ton of olives in Palestine. Refereeing to the annual olive oil production rates of 5,000 – 34,000 t mentioned in chapter 2.1 the annual Palestinian OMW amounts could alternate between 8,500 and 57,800 m^3. The average of 17,000 t of olive oil might lead to the formation of 28,900 m^3 of OMW. The mass of produced olive cake could be as high as 2,750 to 18,700 tons per year or 9,350 tons in average, respectively. In comparison, Laor & Raviv (2010) assume ca. 50,000 m^3 of liquid OMW and 25,000 m^3 of olive cake to be formed in Israel per year. At this, global and Palestinian olive oil and OMW production rates (1:1.5 and 1:1.7)[1] show similar result, though Palestinian rates are slightly above average. Due to a lack of governance, legal enforcement, environmental awareness and economic strength most of the OMW formed in the Palestinian territories is discarded untreated into the surroundings such as adjacent fields or wadis and streams, partly mixed with sewage (Shaheen & Karim, 2007). The olive cake is often dried, pressed into briquettes and used as burning material. An interview with an oil mill owner in Beit Jala/ Palestine has unveiled market prices of about 400 NIS per ton of olive briquettes (Figure 11). Furthermore, olive cake might be used as animal feed (mixed with other materials), as additive of construction materials or as soil stabilizer (Shaheen & Karim, 2007).

Figure 11: *Olive cake briquettes at Beit Jala/Palestine cooperative oil mill (source: Markus Stein)*

The properties and implication of OMW discarded to the environment are very dependent on the type of the oil extraction method, the weather and climate, the type of olive, used pesticides and fertilizers, harvest time and level of maturity but also on the type of soil predominant in the region of disposal (Tsagaraki et al., 2007). There is a great need for improved treatment methods for OMW since the unregulated discharge effects surface waters, aquatic ecosystems and is likely to leach into ground

[1] Global: 3.4 Mio. t olive oil/ 5.4 Mio. m^3 OMW; Palestine: 17,000 t olive oil/ 28,900 m^3 OMW

water aquifers posing a severe threat to human drinking water supply (Bukhanovsky et al., 2015). In 2007 only 7 percent of the drinking water in Palestine complied with the standards determined by the WHO (Li et al., 2013).

As the oil production is a seasonal business the major pollution takes place between October and January. One can distinguish between two different types of OMW: a) washing water and b) water from the oil extraction. The extraction water itself contains added process water and natural water from the olive fruit. At this, the water content of the olive is about 40 percent (Khatib & Aqra, 2009). Generally, the washing water is only little polluted, whereas the extraction water contains high concentrations of different problematic compound. However, eventually both waste flows are usually mixed. (Shaheen & Karim, 2007)

In Palestine OMW contains approximately 83 percent water, 15 percent organics and 2 percent inorganics (Khatib & Aqra, 2009). It generates a strong offensive smell and contains very high amounts of organic compounds and solid matter including dissolved solids and suspended solids (total solids up to 20 g/l) but also phenols, sugars, tannins, polyalcohols, pectins, proteins and lipids forming fat, oil and grease (Figure 12). The high organic load creates COD values up to 220 g/l, BOD levels up to 100 g/l and COD : BOD ratios between 2.5 and 5. The high concentration of organic matter is directly linked to high loads of nutrients such as nitrogen or phosphorus compounds. Studies unveiled that these nutrients might lead to algal growth and eutrophication processes, odor and very serious adverse effects on involved ecosystems. The high BOD/ COD demand based on the high amount of available organic matter and nutrients is likely to decline the oxygen concentration in the water body changing the natural redox conditions. At this, OMW shows very low pH levels ranging between 2.5 and 5. Both altered redox potentials and declined pH values might mobilize harmful inorganic compounds such as certain heavy metals. (Fiorentino et al., 2004/ Khatib & Aqra, 2009).

Other studies have shown a special enrichment of OMW with potassium. Depending on the predominant soil conditions this might alter the cation exchange capacity and thus the soil fertility due to the replacement of magnesium bonds by potassium. (Tsagaraki et al., 2007)

	Reference							
Property	Azbar et al. (2004)	Niaounakis and Halvadakis (2004)	Borsani and Ferrando (1996)	Paredes et al. (1999)	Sierra et al. (2001)	Galiatsatou et al. (2002)	Eroglu et al. (2004)	Al-Malah et al. (2000)
pH	3–5.9	4–6		4.8–5.5	4.5–6	4.9–6.5	4.86	4.52
Water (%)			83					
BOD (g/L)	23–100	35–110			35–100	15–120	17.88	13.2
COD (g/L)	40–220	40–220			40–195	30–150	72.20	320
Carbohydrates (%)			2–8	3.37–32.91		2–8		
Polyphenols (g/L)	0.002–80	0.5–24		1.32–3.99%	3–24	1.5–2.4	0.13	3.12
Fats, oils (g/L)	1–23		0.03–1%	0.55–11.37%	0.3–23	1.3		
Pectins (%)			1–1.5			1–1.5		
VOC (g/L)		25–45						
TS (g/L)	1–102.5						42.24	
SS (g/L)							3.48	2.17
N (g/L)	0.3–1.2			0.58–1.13%	5–15	0.5–2%		
K (g/L)		4	0.87% K_2O	3.30–6.94%	2.7–7.2		7.81	
P (g/L)			0.22% P_2O_5	0.06–0.32%	0.3–1.1			
Ca (g/L)				0.32–0.53%	0.12–0.75		0.55	
Na (g/L)				0.04–0.48%	0.04–0.90		0.41	
Mg (g/L)				0.06–0.22%	0.10–0.40		0.28	

Figure 12: *Literature data on properties of OMW (Tsagaraki et al., 2007)*

Further, olive waste has been reported to be hardly biodegradable and toxic to most microorganisms and inhibitory for the germination and growth of many examined plants. Zenjari & Nejmeddine (2001) found negative effects on plant-growth (cress seeds) even when OMW is very much diluted (< 0.25 % OMW). Most studies assume the high content of polyphenols (up to 80 g/l) and some organic acids (acetic and formic acid) within the OMW to be responsible for this. But also tannins, lipids and certain aromatic compounds might influence microbial growth adversely (Khatib et al., 2009). However, some species seem to be more resilient concerning the exposure to OMW. This might have implications for ecologic distribution patterns of species and the stability of natural equilibria. (Tsagaraki et al., 2007/ Fiorentino et al., 2004 / Rinaldi et al., 2003)

The slow biodegradation rates render OMW a very persistent pollutant. Sierra et al. (2001) examined soils that were exposed to uncontrolled OMW discharge for more than 10 years and found thick horizons of organic matter, enriched amounts of NPK-nutrients, an elevated biological activity and elevated rates of salinity and phenolic substances. Lopez-Pineiro et al. (2006) found a correlation between OMW application and non-humified organic matter in soils. Bukhanovsky et al. (2015) concluded that the time for recovery of OMW affected soils increases most probably with time of OMW application, if possible at all. Other scientist unveiled that soils being treated with OMW show a strongly reduced hydraulic conductivity, hydrophobicity (water repellency) and thus low infiltration rates. This creates elevated levels of surface runoff and soil erosion (Mahmoud et al., 2010 / Bukhanovsky et al., 2015).
Concerning treatment options one might think about the discharge of OMW to municipal waste water treatment plants. However, a mutual treatment of sewage and OMW is generally not economically feasible due to very different chemical properties and the toxicity of OMW to microorganisms involved in the sewage treatment process (Rinaldi et al., 2003). OMW is considered to comprise one of the highest organic loads compared to other waste flows. Its COD and BOD are about 200 to 400 times higher than the values for domestic sewage (Bukhanovsky et al., 2015). Thus, 1 m^3 of OMW is comparable to 100 to 200 m^3 of domestic sewage in terms of its pollution effect. (Khatib & Aqra, 2009/ Fiorentino et al., 2004) Furthermore, OMW tends to clog and to corrode sewer pipes due to its high content of solids and its low pH respectively (Bukhanovsky et al., 2015).

One the other side, there is view literature available stating positive effects of agricultural OMW application. Chartzoulakis et al. (2010) examined sites that were exposed to controlled OMW disposal of max. 420 m^3 per hectare and year. They found an increased soil fertility, increased water supply and no adverse effects on plant growth. Azbar et al. (2004) applied 1000 m^3 per hectare and year and measured increased organic matter (cation exchange capacity), nitrogen, phosphate and other nutritious salts. But they also found increased heavy metal contents and an allocation of sodium into deeper soil layers, which is why the authors recommend a maximum application of 100 m^3 OMW per hectare and year. Subsequently, regulated and controlled application of treated OMW might be a useful surrogate for low cost water and fertilizer (Tsagaraki et al., 2007).

5. Legislation and Governance Concerning OMW

5.1. Palestine and Israel

The general network of governance being involved in the olive oil network has already been described in chapter 2.3.2. Concerning environmental standards the Ministry of Environment cooperates with the Palestinian Water Authority and the Palestinian Standard Institute. Mutually they are responsible for the enforcement of treatment standards and regulations regarding waste water from industries and municipalities. At this, the Israeli government plays an important role as it controls the main decisions on water issues. Due to reasons already described in chapter 2.3.2 the Palestinian authorities lack of power for proper enforcement of legislation and many regulations are not practically applied yet. However, there are no thresholds and standards adopted in Palestine concerning the disposal of OMW and its definition as waste. (Zereini & Jaeschke, 2010)

In Israel uncontrolled discharge of OMW is prohibited whereas a controlled application of 50-100 m^3 per hectare and year on agricultural land is legal except of highly sensitive hydrologic areas and drinking water protection areas (Bukhanovsky et al., 2015). Laor & Raviv (2010) mention a maximum land spreading of 40-50 $m^3 ha^{-1} a^{-1}$ limited by the Israeli Ministry of Environmental Protection. At this, reports are required documenting physio-chemical properties such as electric conductivity and nitrate or phenol contents. Nevertheless, further research should be conducted concerning the legal background of water issues and OMW disposal in Palestine and Israel.

5.2. Jordan

Due to a lack of legal regulation concerning OMW disposal in the Palestinian territories many authors refer to Jordanian legislation. Figure 13 compares typical chemical properties of OMW with maximum legal thresholds for different disposal options in Jordan.

Parameter	Unit	OMW Characteristics Min.-Max.	Maximum Allowable Limit- Jordanian Standards		
			Disposal to wadis and rivers	Reuse for irrigation	Discharge to sanitary systems
pH	SU	5.48-5.91	6.8-9.0	6.5-8.4	5.5-9.5
COD	mg/L	78536-160096	150	undetermined	2100
BOD_5	mg/L	23248-63271	50	undetermined	800
TSS	mg/L	14207-46188	50	100	1100
TDS	mg/L	16984-80355	3000	2000	
FOG	mg/L	2008-13118	5	5	50
Phenol	mg/L	1739-4432	0.002	0.002	10

Figure 13: *Characteristics of OMW in Jordan and comparison with Jordanian standards (Khatib et al., 2009)*

5.3. Europe

Prosodol & Life (2012) published a very comprehensive study addressing the legal framework of the European Union and several member states concerning the disposal and agricultural utilization of OMW. The authors unveiled a very complex network affecting the application of OMW depending on its specific use and its definition as waste or a product.

As OMW contains phenolic compounds it is generally considered potentially hazardous. If OMW is defined as a waste it falls under the Waste Framework Directive. If it is considered a byproduct, reused or not defined as waste it falls under the REACH directive on the "Registration, Evaluation, Authorization and Restriction of Chemicals", where it is defined a natural product.

OMW that is simply discarded into aquatic systems has to comply with certain regulations of following directives:

- Water Framework Directive (2008/32/EC)
- Groundwater (Directive 2006/118/EC)
- Urban Waste Water Treatment Directive (91/271/EEC)

"The discharge of biodegradable waste water from certain industrial sectors that does not enter urban waste water treatment plants is to be treated appropriately before receiving waters."
(Directive 91/271/EEC; introducing part)

However, OMW that is reused in agriculture needs to comply with different directives such as:

- Nitrate Directive (Directive 91/676/EEC)
- Groundwater Directive (2006/118/EC)
- Drinking Water Directive (98/83/EC)
- Sewage Sludge Directive (86/278/EEC)
- Regulation on fertilizers ([EC] No 2003/2003)

Besides these examples other legal regulations might be important dependent on the actual use of OMW. At this, the integrated pollution prevention and control directive (96/61/EC) addresses fundamental principles concerning the creation of legal thresholds and emission limit values. According to this, thresholds should take into account*:*

"the protection of the environment as a whole and should be based on the best available techniques, without prescribing the use of any technique or specific technology, but taking into account the technical characteristics of the installation concerned, its geographical location and the local environmental conditions."
(IPPC Directive; Article 9, paragraph 4)

5.3.1. Italy

In Italy the agricultural utilization of OMW, especially the wet olive cake from two-phase-decanters, is permitted under certain conditions. At this, European law is transferred to national legislation. Law n° 574/1996 regulates the application of OMW in agriculture. Subsequently, up to 50 m^3 per hectare and year from traditional presses and up to 50 m^3 per hectare and year from continuous systems might be applied. In doing so, agronomic reports to the responsible municipality have to be submitted at the latest 30 days before spreading. Surface runoff is to be avoided. However, in case of environmental risk municipalities are entitled to adjust the legal thresholds and Law n° 574/1996 prohibits the spreading of OMW under following conditions:

- < 300 m from drinking water preservation areas
- < 200 m from inhabited area
- on soils for vegetable crops
- on soils where groundwater distance < 10m
- on soils that are: frozen, snow covered, water saturated, awash

Besides that, other laws and directives formulate different constraints such as the prohibition of the mixing of OMW with other waste water and the application in certain areas:

- < 10 m from river banks
- < 10 m from sandy shores or lakes
- on land with slope > 15 %
- in woods
- in gardens and public areas
- in quarries
- mixing of OMW with other waste water and waste prohibited

The utilization of the olive cake is regulated in different acts and generally less strict as it is considered less dangerous. E.g. olive husk can be put on the market as fertilizer and energy resource. (Prosodol & Life, 2012)

5.3.2. Spain

After the introduction of three-phase-decanters to the Spanish olive oil sector the country faced serious environmental problems due to the discharge of OMW. Subsequently, the legislation was improved, more than 1000 evaporation ponds were created and the three-phase-decanters were replaced by more modern two-phase-decanter stepwise. Nowadays about 90 percent of all oil mills use two-phase-decanters forming reduced OMW amounts. Decree 4/2011 focuses on agricultural application of OMW and sets a discharge limit of 50 m^3 per hectare and year. Surface runoff, leaching and damage to the water table are to avoided and spreading is prohibited at all under following conditions:

- < 500 m from urban areas
- < 100 m from public water protection areas
- < 100 m from shorelines

Further, olive mill owners need an authorization for evaporation ponds and spreading and Decree 46/1999, Decree 849/86 and Decree 258/1989 define legal emission limit values for the discharge of OMW into open water. (Prosodol & Life, 2012)

5.3.3. Greece

As Greece is a member of the European Union it has to comply with all the European legislation on waste water, ground water protection, fertilizer and general environmental protection. However, Prosodol & Life (2012) pointed out that there are no specific regulations regarding OMW in Greece. Nevertheless, OMW falls under various regulations concerning the discharge and utilization of agricultural and industrial wastes and byproducts. Based on law 1650/86 "For the Protection of the Environment'' olive mill owners need to provide an environmental impact assessment study of their business. Further, Greece legislation prohibits the application of untreated OMW on soils but does not formulate final limits for OMW on a national level. Those thresholds are rather determined by regional prefectures. At this, the prefecture of Iraklio prohibits the discharge of OMW to the aquatic environment, whereas the release of OMW to surface waters without any treatment was possible in the prefecture of Lesvos until recently. In contrast, the prefecture of Messina demands the exchange of three-phase-decanters by two-phase-decanters on order to improve the environmental situation. (Prosodol & Life, 2012)

Pollutant	Limit value – daily maximum (kg/ton of product)	Limit value –monthly average (kg/ton of product)
BOD	4.0	2.0
COD	6.0	3.0
Suspended solids	5.0	2.0
Oils	1.0	0.5

Figure 14: *Wastewater limit values for food industries in Greece (Prosodol & Life, 2012)*

5.3.4. Summary

Figure 15 summarizes and compares certain emission limit values (ELV's) concerning the discharge of OMW to surface waters and sewers defined in Italy, Greece and Spain.

Parameter	Italy	Greece	Spain
pH	5.5-9.5 (5.5-9.5)	6-9 (6-9.5)	5.5-9.5
BOD_5 (mg/l)	40 (250)	15-60 (250-500)	40-300
COD (mg/l)	160 (500)	45-180 (1000)	160-500
TSS (mg/l)	80 (200)	25-1000 (500-3000)	30-300
Oil/grease (mg/l)	20 (40)	5-40 (40-100)	20-40
Phenols (mg/l)	0.5 (1)	0.005-0.5 (5-10)	0.5-1
Total P (mg/l)	10 (10)	0.2-10 (10)	10-20
Total N (mg/l)	15 (30)	10-15 (25)	15-50
Free Cl (mg/l)	0.2 (0.3)	0.4-1 (5)	0.5
Nitrates (mg/l)	20 (30)	4-50 (20)	10-20
Nitrites (mg/l)	0.6 (0.6)	1-3 (4)	-

Figure 15: *Emission limit values for discharges to surface waters and sewers (in parenthesis) in Italy, Greece and Spain (Prosodol & Life, 2012)*

6. Treatment Options for Olive Mill Waste

Due to the adverse effects of uncontrolled OMW disposal for a long time scientists and engineers have tried to find good solutions for an effective waste treatment. For this reason, various treatment options have been developed and applied in pilot plants or real business. Generally, there are possibilities to manage OMW in an environmentally friendly way. However, often those options are limited by their environmental feasibility (e.g. water demand) or their economic applicability. The latter one might depend on different variables such as business structure, legal background, state support or financial capacity. Thus, not all treatment options are available in Palestine. Basically, all treatment options can be attributed to three different types of treatment: a) physical b) chemical c) biological. However, often combinations of all of these options are applied.

6.1. Physical Treatment Options

6.1.1. Thermal Process

One of the oldest ways of treating olive wastes is thermal processing. Dried olive cake has been used as an energy resource since ancient times. But thermal processes can also be used to reduce the harmful properties of OMW. One can distinguish between natural and anthropogenic heat sources being used for the thermal process. Following methods are examples for applied and tested thermal treatment options:

a) Natural Evaporation/ Lagooning

As mentioned in chapter **Error! Reference source not found.** the disposal of OMW in large evaporation ponds (lagoons) used to be a common treatment option. Here, natural evaporation is used to reduce the water content and thus the amount and mobility of OMW. Prosodol & Life (2012) assume a residence time of 7-8 months for the whole process when 2.5 m^3/m^2 OMW are applied. It is a very simple process with low energy costs and effective volume reduction up to 70 to 75 percent. Nevertheless, even though the immobilization of OMW can help to protect receiving waters, the actual pollutant decomposition in the remaining solid material is rather low. Subsequently, chosen disposal areas are likely to suffer from high pollution loads and adverse environmental effects. Depending on the presence and the kind of additional biochemical decomposition COD removal can range between 20 to 80 percent. Anaerobic processes might release climate-damaging CH_4 emissions and odor pollution. Further, there is a severe risk of ground water leaching.

b) Forced and Vacuum Evaporation

Shaheen & Karim (2007) consider natural evaporation economically limited and only applicable for small scale business as it requires a lot of space and time. In order to increase the feasibility of this treatment option forced evaporation has been introduced. At this, OMW is transferred to a dry air stream or exposed to a vacuum atmosphere and heated up using artificial energy resources. The remaining dry material can be burned, utilized in agriculture or processed further.

c) Combustion

As mentioned in chapter 4 combustion is the major disposal and secondary use option for dry solid olive cake. Depending on the production process olive briquettes show potentially better combustion properties than some coals and other bio masses (sulfur content: ca. 0.12-0,26 percent; LHV: 3922-4445 kCal/kg). At temperatures of 100°C the volatile fraction starts to decline considerably and at 250 to 260°C a mass reduction of 70 to 80 percent can be achieved. However, during different tests legal values for CO, NO_x, and particulate matter have been exceeded. Only sufficient air supply, secondary combustion of exhaust fumes and appropriate filter techniques can reduce these effects. For this reason, central combustion facilities should be favored. However, this requires great investment costs and improved infrastructure and governance. (Azbar et al., 2004)

However, combustion might not only be used for solid olive waste. It is also considered the most effective OMW treatment option, in terms of pollutant destruction. But whereas the combustion of dried olive cake is an exothermic process producing excess energy, the combustion of wet OMW requires a very high energy supply usually using fossil fuels. In analogy to the incineration of olive cake, it requires very complex filter technique in order to minimize the pollutant content of the emissions. At this, filters accumulate great amounts of pollutants that need to be disposed of appropriately. For that reason, environmentally friendly combustion is a very cost intensive treatment option which can only be run economically as large scale plants processing great amounts of OMW. It is not feasible for small scale regional business. Additional, the seasonality of the OMW production poses a major challenge for this treatment option. In order to avoid no-load phases, a combined combustion with constantly available material should be applied. However, the combustion process declines the nutritious properties and destroys contained precious materials of OMW. Subsequently, some authors reject combustion as the material should be used as a recycling basis. (Prosodol & Life, 2012)

d) Others

Other possibilities of thermal treatment are pyrolysis and distillation. However, due to the low relevance (due to economic limitations) for OMW treatment in Palestine those methods are not described in detail here.

6.1.2. Electrolysis

Azbar et al. (2004) mentioned electrolysis to be an alternative physical method of OMW treatment. In a pilot plant COD could be removed by 93 percent, TOC by 80 percent, volatile suspended solids by 99 percent and phenolic compounds by 99 percent after 10 hours of treatment. The energy demand for this was 12.3 kWh per kg COD. The authors consider electrolysis generally an effective treatment option. However, it requires high investment and operating costs and trained personal.

6.1.3. Membrane Process

Another OMW treatment option is filtration through filters and membranes. At this, ultrafiltration is most common but microfiltration and reverse osmosis have also been applied. During the process two different phases are obtained: a) the retentate and b) the permeate. The permeate is the purified liquid being ready for disposal in receiving waters. The retentate is the concentrated waste water, which contains colloidal particles, lipids and various macromolecules (molecular weights 10.000 to 100.000 Da). The process does not require additional agents or solvents and can reduce the waste amounts significantly (only 5-10 %). Further, regarding recycling processes, it is possible to separate lipids from salts, sugars and phenolic substances. According to Vlyssides et al. (1996) reverse osmosis can result in the reduction of organic matter by 90 percent.

However, this processes is very complex and requires expensive devices and highly trained personal. Membranes get harmed easily especially when huge amounts of OMW are processed. In analogy to the combustion filters, the filtered pollutants need to be disposed of eventually. For that reason, it is very cost intensive and thus not suitable for great amounts of OMW or small scale businesses. This is why this process is not recommended for the treatment of big amounts of highly concentrated OMW, but rather for the reclamation of precious materials such as polyphenols and flavoring agents. (Prosodol & Life, 2012)

6.2. Chemical Treatment Options

6.2.1. Neutralization, Precipitation and Flocculation

One of the major aims of the treatment of OMW is the depletion of solid and suspended organic matter. In doing so, flocculation processes can be used transforming dissolved or suspended organic matter into precipitates reducing BOD and COD levels (50-90 % COD removal) (Azbar et al., 2004). The flocculation substances serve either as catalytic triggers or they form complexes with the precipitate, which settles down in settling tanks and can be removed subsequently. Flocculation can also be applied to remove oil from the water body. Typical flocculation agents are e.g. ferric and ferrous chloride, ferric sulfate or aluminium sulfate. Another major problem of OMW is its acidity, as stated in chapter 4. In analogy to the flocculation process the pH can be increased substantially through the addition of alkaline substances such as lime, sodium hydroxide and potassium hydroxide. Lime treatment of OMW showed removals of TSS by 30-35 percent, organic matter by 40 percent (Vlyssides et al., 1996), volatile solids by 30-65 percent, oil and grease by 90-98 percent, phenolics by 65-76 percent (especially reduction of o-diphenols that are considered most phytotoxic) and COD by 32-60 percent (Azbar et al., 2004). However, even though flocculation can contribute to the improvement of the waste water quality, it does not actually decline the total waste amounts since the formed sediment is still to be disposed of creating additional labor and treatment costs. Furthermore, the used flocculation agents might accumulate in the precipitant posing a new environmental threat. Equally, the neutralization of acids is usually connected to the precipitation of a correlated salt, which can also be found in the created sediment. For this reason, the formed solid waste needs to be treated with care subsequently. Eventually, chemical methods require a high level of knowledge, which is why they should only be applied in centralized treatment plants. If conducted locally, the oil mill owner is highly dependent on a constant chemistry supply creating high additional costs. (Tsagaraki et al., 2007)

6.2.2. Oxidation Process

Another chemical treatment option are the utilization of oxidation processes. At this, special oxidation agents are added to the OMW effluent in order to include pollutants in stable chemical compounds and to reduce their mobility. Typical oxidation agents are:

- hydrogen peroxide
- ozone
- chlorine
- chlorinated derivatives (i.e. chlorine dioxide, sodium hypochloride)
- combination with UV-light

Pilot plants and studied showed partly good results. However, the method is expensive and poses additional environmental risks due to the application of partly toxic agents. Further, it has been pointed out that oxidation processes are not suitable for high organic loads. (Tsagaraki et al., 2007)

6.3. Biological Treatment Options

Biological treatment options make use of natural processes mostly involving microorganisms such as bacteria and fungi. There are also studies on the use of certain resilient plants in terms of phytoremediation but they are less common. The most important biological methods involve aerobic or anaerobic decomposition or a combination of both. These are the main biological treatment procedures also used in sewage treatment plants.

6.3.1. Aerobic Treatment

In order to treat OMW aerobic the effluent is transferred to a treatment basin which is provided with sufficient oxygen excluding anaerobic decomposition processes. During the aerobic composting process organic matter gets partly decomposed and transferred to stable humic forms. N_2 fixing bacteria (e.g. Azobacter) and different fungi enzymatically degrade phenolic compounds that are similar to lignin. At this, two main stages can be distinguished: a) the thermophilic phase and b) the mesophilic stage. The thermophilic stage shows quick bacteria growth and larger decomposition of organic matter, whereas the mesophilic stage is dominated by fungi growth, lower degradation rates and stabilization of humic compounds. The aerobic process shows limited complexity and is relatively easy to handle. Further results of studied aerobic OMW treatment are displayed in Figure 16.

However, most phenolic substances being removed are monomers only. The degradation of more complex phenols and polymerized molecules such as tannins is much slower or not possible. Further, the degradation rates of organic matter are very limited, many compounds cannot be decomposed completely and the process is suitable for low OMW feeds of about 1 g COD per liter only. Higher loads extend the process time substantially. Due to the low depletion of organic matter the process produces high amounts of organic sludge that needs to be treated further subsequently. Due to all these limitations the aerobic process should only be applied in combination with other methods or as pre or post treatment. (Tsagaraki et al., 2007) Nevertheless, even though the method might not be appropriate for pure OMW treatment, Vlyssides et al. (1996) considers co-composting together with other organic materials a very efficient treatment option.

Microorganism	Results	Comments	Reference
Aspergillus niger	35–65% COD reduction	Biofertilization	Cereti et al. (2004) Garcia et al. (2000)
Azotobacter vivelandii	90–96% COD reduction	Biofertilization	Piperidou et al. (2000)
Yarrowia lipolytica	2–42% COD reduction	Production of enzymes and microbial metabolites	Lanciotti et al. (2004)
Pleurotus ostreatus	Up to 78% phenol removal	Diluted or thermally processed OMWW	Fountoulakis et al. (2002) Aggelis et al. (2003)
Phanerochaete chrysosporium		Comparison concerning phenol removal capacity	Garcia et al. (2000)
Aspergillus terreus			
Geotrichum candidum	65% COD removal, 75% color removal	Fresh or stored OMWW	Assas et al. (2002)
Panus tigrinus		Removal of 4-hydroxy substituted simple phenols	D' Annibale et al. (2004)
Pycnosporus coccineus			Jaouani et al. (2003)
Pleurotus sajor caju	75% color removal		Jaouani et al. (2003)
Coriolopsis polyzona	75% color removal		Jaouani et al. (2003)
Lentinus tigrinus			Jaouani et al. (2003)
Candida tropicallis	62.8% COD removal; 51.7% phenols removal		Fadil et al. (2003)
Pleurotus pulmonarium		Production of *Pleurotus basidiomata* only diluted OMWW	Zervakis et al. (1996)
Pleurotus eryngii			
Ankistrodermus braunii	12% phenols reduction	Fresh OMWW or reverse osmosis fraction	Pinto et al. (2003)
Scenedesmus quadric cauda (*microalgae*)			

Figure 16: *Aerobic microorganisms studied for OMW degradation (Tsagaraki et al., 2007)*

6.3.2. Anaerobic Treatment

The essential feature of anaerobic treatment is the absence of oxygen during the decomposition of organic material. Basically, the process consists of four main phases: a) Hydrolysis, b) Acidogenesis, c) Acetogenesis and d) Methanogenesis. Each phase is dependent on certain bacteria and specific pH conditions.

Hydrolysis:

Hydrolysis is the first stage of anaerobic digestion. Organic matter is processed into liquefied monomers and polymers. At this, proteins, carbohydrates and fats are transformed to amino acids, monosaccharides and fatty acids, respectively. Subsequently, the pH starts to decline. Following equation shows exemplarily the degradation of organic matter into glucose:

$$C_6H_{10}O_4 + 2\ H_2O \rightarrow C_6H_{12}O_6 + 2\ H_2$$

Acidogenesis:

During the following stage, the acidogenesis, the products of the first phase are transformed into short chain volatile acids, ketones, alcohols, hydrogen and carbon dioxide. Typical products of the acidogenesis are e.g. propionic acid (CH_3CH_2COOH), butyric acid ($CH_3CH_2CH_2COOH$), acetic acid (CH_3COOH), formic acid ($HCOOH$), lactic acid ($C_3H_6O_3$), ethanol (C_2H_5OH) and methanol (CH_3OH). The acidogenesis is directly connected to a substantial decline of pH.

Acetogenesis:

Hereafter, during the acetogenic phase, the organic remains of the acidogenesis such as propionic acid, butyric acid and alcohols are transformed by acetogenic bacteria into carbon dioxide, acetic acid and hydrogen. At this, the amount of produced hydrogen plays a very important role, since acetogenic bacteria depend on a relatively low partial pressure of hydrogen. Thus, due to the formation of hydrogen the process harms itself, which is why the H_2 level needs to be watched during the process. Finally, the acetogenic bacteria are increasingly replaced by methanogens due to the created chemical conditions. Following equations are typical for the acetogenic phase:

a) $CH_3CH_2COO^- + 3\ H_2O \leftrightarrow CH_3COO^- + H^+ + HCO_3^- + 3\ H_2$

b) $C_6H_{12}O_6 + 2\ H_2O \leftrightarrow 2\ CH_3COOH + 2\ CO_2 + 4\ H_2$

c) $CH_3CH_2OH + 2\ H_2O \leftrightarrow CH_3COO^- + 2\ H_2 + H^+$

Methanogenesis:

The methanogenesis is the last stage of the anaerobic digestion process. Here, more H_2 tolerant microorganisms (strictly anaerobic methanogens) transform hydrogen and acetic acid into carbon dioxide and methane gas and the pH increases again. The formed CH_4 should be combusted in order to decline energy costs and to prevent the release of greenhouse emissions. Following equations are typical for the methanogenic phase:

a) $CO_2 + 4\ H_2 \rightarrow CH_4 + 2\ H_2O$

b) $2\ C_2H_5OH + CO_2 \rightarrow CH_4 + 2\ CH_3COOH$

c) $CH_3COOH \rightarrow CH_4 + CO_2$

Anaerobic digestion is considered most suitable for OMW treatment by different studies due to great volume reduction, low energy demand and CH_4 formation for additional energy supply. Azbar et al. (2004) pointed out different advantages of anaerobic treatment such as low sludge generation, a COD removal of up to 80-85 percent and an easy restart of the digester after shutdown for several months before the olive season. However, the oil content, antimicrobial phenolic compounds and acidic volatile fatty acids might harm the microbes rendering the process unstable. Further, OMW does typically contain only low amounts of nitrogen, which is why additional N sources and pretreatment might be necessary. Subsequently, anaerobic digestion is more complex than anaerobic digestion and the process needs to be monitored or controlled (e.g. addition of N sources and alkali substances for pH neutralization) since different bacteria and conditions are to be maintained during its steps. (Serna 2009)

6.4. Case Studies and Examples

6.4.1. Anaerobic Treatment

"There are several possibilities to design anaerobic digestion systems. A system can be as simple and cheap as a single static cylindrical digester or as complex and expensive as a multi digester system with moving parts and intelligent sensors that support the operation of the plant. The efficiency of the plant is directly affected by the type of system installed and the way it is managed. Simple plants are easy to design but require constant monitoring and are less efficient, while complex plants are designed to detect errors and warn operators, thus making them more efficient.

Although the microbial processes are the same for all anaerobic digestion processes, each plant is unique and should be designed according to its own input parameters and economic possibility. At the moment of designing a new plant, or making an old facility more efficient, several factors must be taken into consideration. Some of these factors are the capacity of the plant, the types of waste to be treated, the area available, the climate of the region, the demographics and the location of the plant. […]

Depending on the water content in the digester and the way of feeding the digester, the anaerobic digestion process can be classified into wet (< 12 % solid matter) and dry fermentation (> 30 % solid matter) and continuous and discontinuous fermentation." (Serna 2009)

a) Upstream Anaerobic Sludge Blanket Reactors

Azbar et al. (2004) consider "*Upstream Anaerobic Sludge Blanket Reactors (UASB)"* most effective and summarized different set ups for anaerobic treatment increasing the stability of the process. The first option was the mixing and dilution of OMW with sewage sludge and subsequent treatment in an UASB. A contribution of 34 percent of OMW to the inflow material resulted in a COD removal of 65 percent after treatment. Higher OMW concentrations rendered the process unstable again. Further dilution and subsequent reduction of the solid OMW content increased the treatment efficiency and showed COD removals of up to 85.4 to 93.4 percent. During another set up OMW was diluted with fresh water (ratio 1:8 – 1:5) showing COD removals of 70-75 percent for COD loads of 12-18 kg per m^3 and day. Other authors mentioned UASBs suitable for high loading rates up to 5 to 15 kg COD per m^3 and day and stated COD removal as high as 80 percent. However, they also stated great necessary dilution (ca. 1:8) rising costs (Tsagaraki et al., 2007). Subuh (1999) applied an UASB and achieved a COD reduction of 76 percent but recommended further post treatment using aerobic decomposition. Khatib et al. (2009) used an UASB and faced several problems such as the long-term start-up period and the instability of the biological activity due to toxic phenols, tannins and increasing pH levels. The authors installed an UASB near Hebron City with a volume capacity of 4 m^3 (Figure 17). During the start-up the reactor was fed with diluted OMW showing COD levels of about 2000-5000 mg per liter. The pH of the inflow material was adjusted to 6.8 to 7 and an anti-foam agent was added in order to prevent foam formation on top of the reactor. The applied flow rate increased from 980 to 1,200 l per day within one week resulting in a hydraulic retention time of 5 to 3.5 days depending on the reactor performance. The process resulted in a COD removal of about 84 percent and methane could be collected.

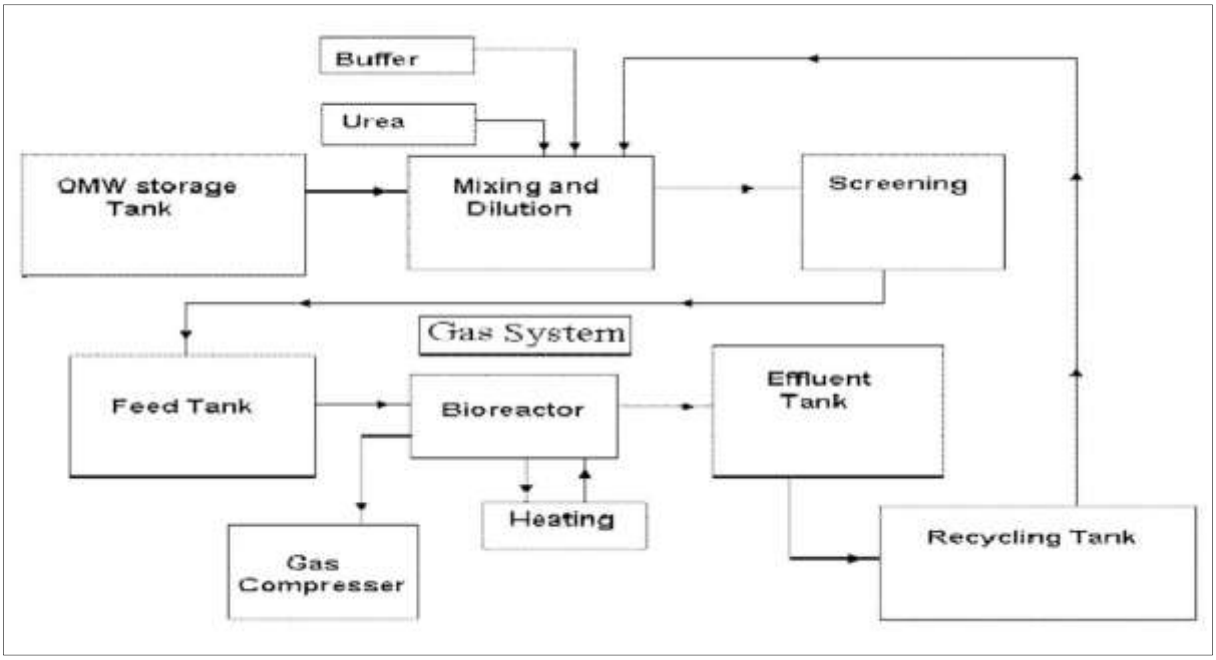


Figure 17: *Flow scheme diagram for the constructed UASB Plant in Hebron (Khatib et al., 2009)*

Li et al. (2013) sought a low-cost-treatment option for olive mills in areas showing limited access to resources and infrastructure and where centralized, high-tech treatment is not possible. They set up a plant separating dry and solid olive mill waste (Figure 18). The solid waste was mixed with saw dust pellets and composted in barrels, whereas the liquid waste was mixed and diluted with slurry and treated in circulating ponds and trickling filter systems. This method resulted in the formation of significant amounts of nutritious compost and BOD and COD removals up to 90 percent.

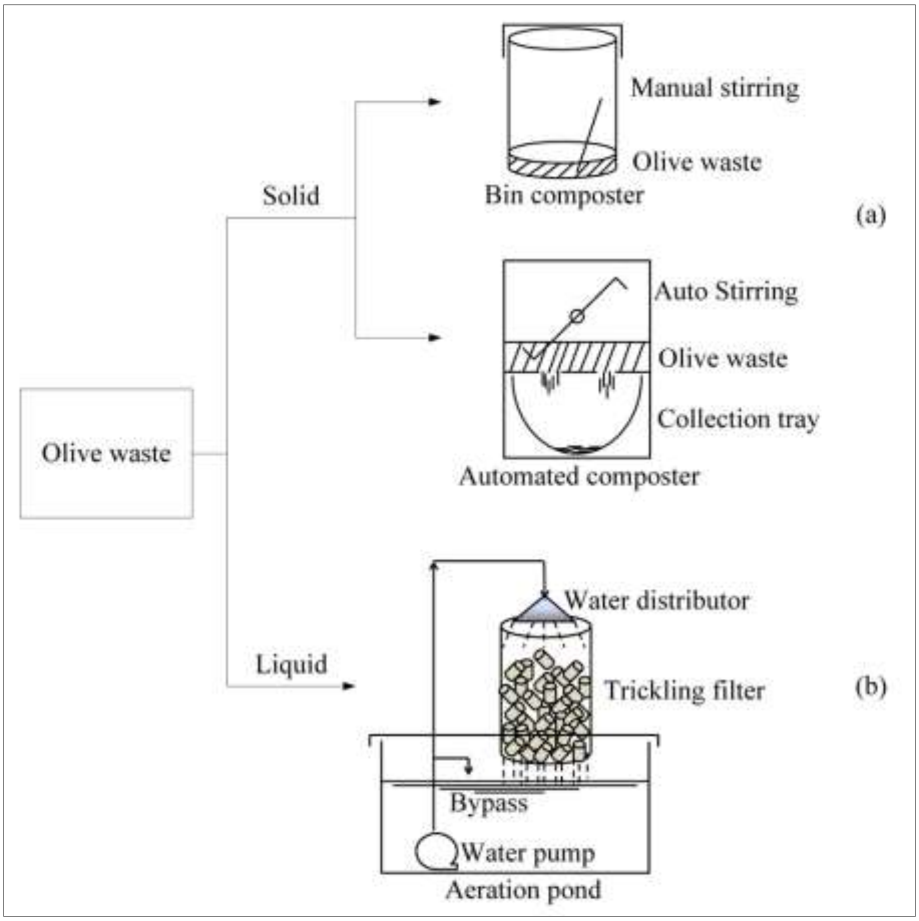


Figure 18: *(a) Composting for OMW solids; (b) Pond/trickling filter for OMW liquid (Li et al., 2013)*

b) Other Anaerobic Treatment Options

Even though methanogenic microorganisms are also present under more acidic conditions they are most efficient under pH levels of about 6.5-7.6. For that reason, some anaerobic systems are based on the separation of acidogenesis and methanogenesis. At this, the OMW can be treated with alkaline substances such as lime, sodium hydroxide, sodium carbonate or bicarbonate separately after the acidogenesis (Azbar et al., 2004).

Besides the UASBs, anaerobic filters have been reported to be suitable to deal with high volumetric pollution loads of 5 to 15 kg COD per m^3 and day. The process requires little control and monitoring and resulted in phenol reduction of about 75 percent during a test. However, COD removal has shown to be only between 60 and 65 percent. Further, the OMW feed needs to be diluted (1:5) rising costs.

Further, so called contact reactors can process very high OMW feed concentrations up to 60 g COD per liter but only low loading rates of less than 5 kg COD per m^3 and day. (Tsagaraki et al., 2007)

6.4.2. Aerobic Treatment

(Vlyssides et al., 1996) studied an interesting demonstration plant for the aerobic co-composting of olive oil processing water and solid residues. The aerobic bioreactor had a length of 18 m, a width of 6 m, a height of 2.2 m and a volume of 195 m^3. Sufficient air supply for oxygen and cooling was secured by an aeration system consisting of three fans and nine diffusion pipes installed over the bottom of the bioreactor. Nutrient supply was guaranteed through a nutrient preparation and dosing unit and traveling bridge ensured sufficient agitation. Additional information regarding the general set-up can be obtained from Figure 19 and Figure **20**.

During the process certain critical parameters had to be maintained such as a moisture content at around 40 to 60 percent, a temperature between 45 to 65°C (optimum: 60°C) and a C/N ratio below 30:1. During the start-up solid OMW was used as bulking material and the system was fed with 91.5 tons of solid residue, 119 tons of liquid OMW and 1.6 tons of urea (1.34 kg per m^3 liquid OMW) as a nitrogen source. Due to oxygen depletion, nitrogen uptake, heat development and evaporation the digester had to be supplied with air and additional liquid OMW (enriched with urea). The amount of daily inflow was highly dependent on the temperature of the bioreactor in order to maintain best microbial conditions. Following equation was applied: Inflow (m^3/h) = 2.228 - 0.034 x Temperature (°C). The thermophilic aerobic digestion developed and continued until the 23rd day after the start-up resulting in the processing of 236 m^3 of olive waste. After the thermophilic stage the waste material was transferred and piled up outside the bioreactor entering the mesophilic stage. Here it was stabilized for another three months until it reached ambient temperature. Finally, the treatment resulted in significant depletion of organic matter, an increase of pH levels from 4.5 to more than 8 and in stabilization of the compost material. However, the authors mentioned that the air and inflow cooling system lacked of efficiency resulting in very high process temperatures. Further, the high final pH might be a consequence of excess urea supply. Thus the process and its treatment outcome could be improved.

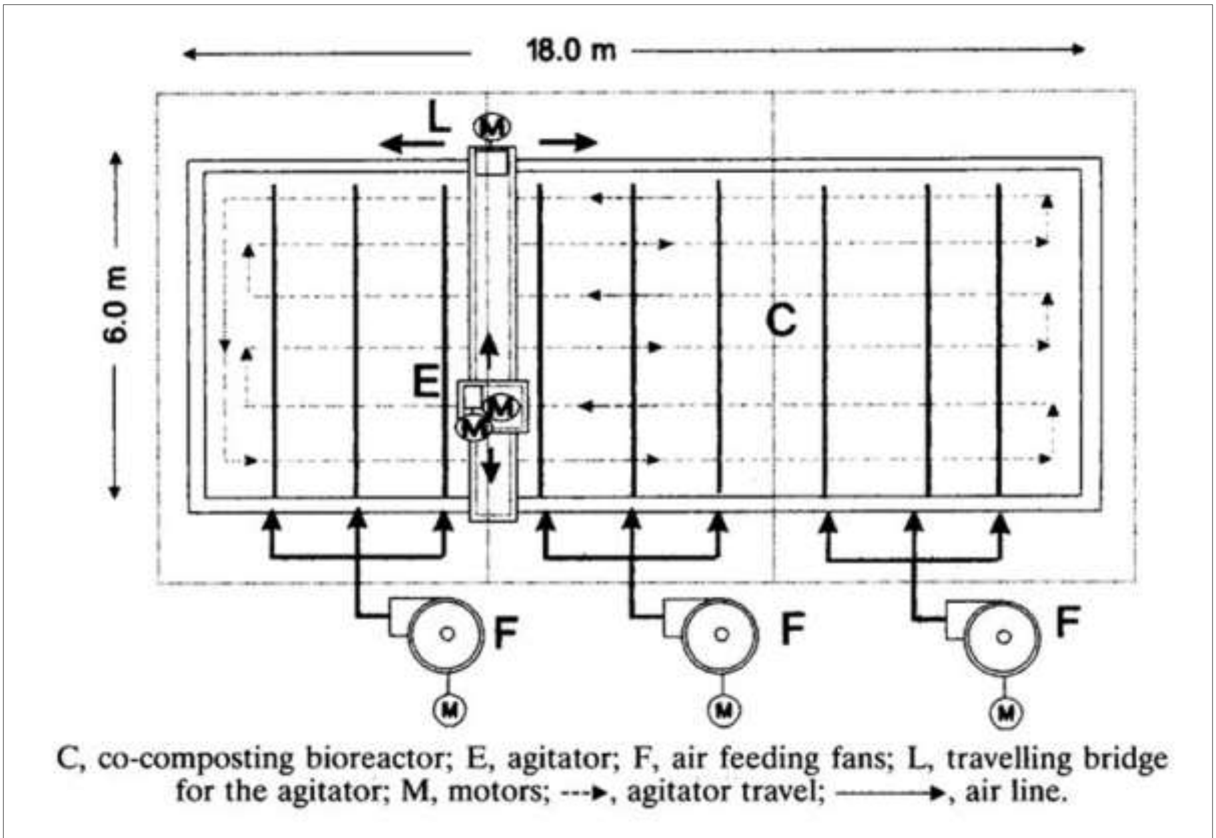
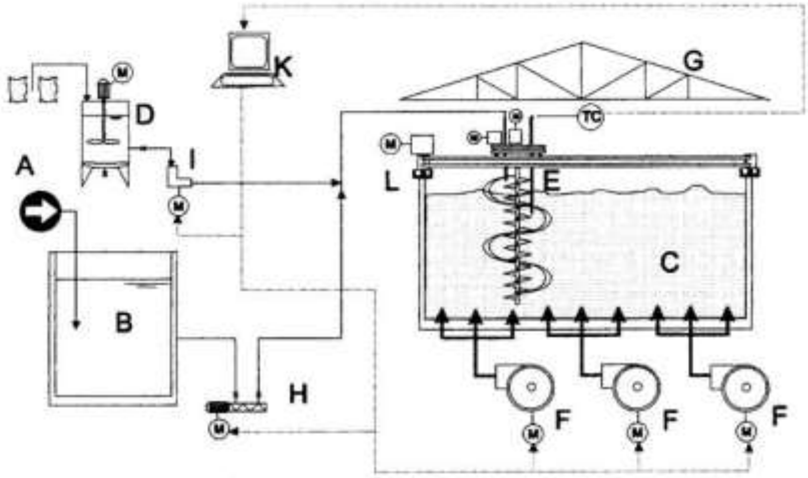


Figure 19: *Aerobic co-composting plant: top-view (Vlyssides et al., 1996)*



A, wastewater feed; B, feed storage tank; C, co-composting bioreactor; D, urea feed system; E, agitator; F, air feeding fans; G, roof to prevent access of rainwater; H, monopump for wastewater dosing; I, proportional pump feeding urea solution; K, computer for controlling and data collection; L, travelling bridge for the agitator; M, motors; TC, temperature controller.

Figure 20: *Aerobic co-composting plant: cross section (Vlyssides et al., 1996)*

Another interesting study on aerobic digestion has been published by Laor & Raviv (2010). The authors focus on OMW treatment in Israel and stated that in the Western Galilee nine olive mills are equipped with pre-treatment floatation devices. The COD removal achieved by these treatment plants is up to 80 to 90 percent. However, the remaining COD of the treated OMW is still as high as 15,000 to 30,000 mg/l, which is far above the 2,000 mg/l usually required by municipal sewage treatment plants. Nevertheless, due to the lack of appropriate treatment alternatives treated effluent is often discarded to domestic treatment plants as soon as COD removals of 70 percent can be approved. In order to improve the pre-treatment results the authors suggest aerobic co-composting. At this, co-composting shows much better pollutant destruction and economic feasibility than single OMW treatment for different reasons. First of all, the aerobic decomposition is much more stable if the content of microtoxic phenols is diluted through the mixing with other organic wastes. Further, OMW is much to liquid for single treatment and needs to be solidified anyway (pure OMW contains only ¼ of solids needed for the process). Instead of discarding or evaporating parts of the liquid fraction, other solid organic materials can be used. Finally, the economic problems caused by the short olive season and the lack of waste material during the rest of the year can be balanced by the use of other more steadily available materials.

6.4.3. Combined Treatment

In order to limit investment and operating costs, the mutual treatment of OMW with domestic sewage has been suggested. However, as mentioned in chapter 4 this treatment option is very limited and might only be conducted when OMW is very much diluted declining organic and phenolic contents. The effluent might than be used for irrigation. If N-fixing bacteria are applied using OMW as a carbon source the remaining fertilizer could be enriched by main plant nutrients and exopolysaccharides (forming stable aggregates), auxins and cytokinins (plant growth promoting).

However, due to the variety of pollutants present in OMW various treatment steps might be necessary for a complete depletion of all pollutants (Shaheen & Karim, 2007). For this reason, the treatment results are likely to be better when pre and post treatment is applied. Following exemplary pretreatment options have been reported: (Tsagaraki et al., 2007)

- dilution of OMW
- gravity settling
- sand filtration
- centrifugation
- adsorption
- membrane processes
- physicochemical treatments (pH neutralization, etc.)
- aerobic degradation

6.4.4. Improvement of Oil Extraction Method

As described in chapter 3 the amount and properties of formed OMW are directly linked to the method used for the oil extraction. This is why Shaheen & Karim (2007) suggest to improve the extraction techniques throughout the West Bank additionally to the treatment of the formed waste. The authors recommend the exchange of old three-phase decanters by more modern two-phase decanters in order to reduce the amount of formed liquid waste. Further, they suggest the step wise allocation of regionally scattered small-scale mills to the benefit of more centralized extraction sites. This measure would help simplifying the collection of OMW for subsequent treatment.

However, the reorganization of the extraction process would also effect the production of olive cake briquettes as burning material, as the solid waste formed by two-phase decanters contains more water and concentrated pollutants than the dry fraction formed by three-phase extraction. Further, the replacement of decanters requires sufficient financial strength which is scarce in Palestine. Forced allocation of oil mills would harm the current predominant family based business structure and cause social problems. Thus, the centralization of oil presses must be a long term process and needs economic incentives.

6.4.5. *Further Treatment Options Summarized by Karine David (ARAVA Institute Intern 2015)*

Author	Abstract	Location	Description	Advantages	Disadvantages	Efficiency/ Recommendations
"Algatec System", 2012	- OMW Recycling	Malaga, Spain	- Recycling of olive washing water - Using algae and sunlight for decontamination	- Drinking water quality achieved - pollutant amounts minimal	- Expensive	- Good treatment results - 90 % of OMW can be reused
Navarro et al., 2014	- Reclamation of anti-glycative activities of OMW - carbonyl trapping	Non specific	- Ultrafiltration & nanofiltration of OMW - Successive spray drying with maltodextrin and acacia fiber → extracting powders as antiglycative (ingredients in foods and pharmaceutics)	- Reuse of OMW - Potential future development for production of antiglycative ingredient	- Expensive	
Schievano et al., 2015	- Integrated bio refinery of OMW - supercritical CO_2 extraction and energy recovery	Non specific	- Using non-isothermal thermogravimetric analysis - Apparent activation energies required 20-140 kJ/mol (pyrolysis of OMW) depending on heating ramp rate and temperature regime	- Reuse of OMW for pharmaceutical & nutraceutical market (antioxidants, anti-cancer, anti-bacterial, fertilizer)	- Further development necessary - In-depth view on bio refinery needed to consider total energy balance & market values - Not feasible for small-scale local business	- Exhaust fume almost dry - Evident advantage for downstream
Di Lecce et al., 2014	- Integrated mebrane process - OMW fractions treatment	Italy	- 2 membrane based filtrations (microfiltration & nanofiltration)		- Further research and development necessary - Phenol depletion must be enhanced	
Laor & Raviv, 2009	- Pre-treatment flotation device	Israel	- Removal of solid particles and volatile organics (permitting discharge of OMW into municipal treatment facilities) - COD reduction by at least 70%.	- Removal of COD, organic load and fats	- Only pre-treatment - Clean up not completed (remaining pollutants)	- potentially capable of COD reduction by 80-90% - final effluents still contain COD about 15,000-30,000 mg/l (much above 2,000 mg/l allowed by sewage treatment in Israel)
Azbar et al., 2004	- Use of OMW for antioxidants production	Italy	- Several compounds in OMW are natural antibacterial agents - Might be used as rwa material for antioxidants	- High economic value - In experiment 1500-4000 mg/l antioxidant from polyphenol could be obtained	- Not feasible for small-scale local business	
Toscano & Montemurro, 2012; Paraskeva & Diamadopoulos, 2006	- Aerobic digestion of OMW	Non specific	- pilot-scale subsurface horizontal flow constructed wetland system - Aerobic treatment using activated sludge - 1:10 dilution of a physicochemically pretreated OMW	- Easy method in open air storage container - Aerobic stabilization - Feasible for small scale business - Production of fertilizer	- Remaining pollutants - Aerobic pollutant destruction not complete	- Average reduction of COD by 74.1% and of phenol by 83.4%
Toscano & Montemurro, 2012; Azbar et al., 2004; Paraskeva & Diamadopoulos, 2006	- Anaerobic biological process to treat olive oil waste water	Non specific	- Anaerobic treatment - Great variety treatment options exist (e.g. simple OMW open-air storage tanks, "Completely Stirred Tank Reactor" (CSTR) through co-digestion with others organic matrixes and UASB reactors (Up-flow Anaerobic Sludge Blanket) - Different process conditions (retention times, loading rates, temperatures, etc.).	- Effluent useful for irrigation - Considered environmentally friendly, reliable and mostly cost-effective - able to remove most organic matter and pollutants	- medium costs - still little pollutant remains - post and pre-treatment necessary for perfect results	- High-rate anaerobic processes (e.g. anaerobic filters & up-flow anaerobic sludge blanket reactors) can process OMW containing up to 10-20 g/l COD - Conventional anaerobic contact reactors applicable at higher concentrations up to 60 g/l COD (> 80% COD removal efficiency)

Author	Abstract	Location	Description	Advantages	Disadvantages	Efficiency/ Recommendations
Laor & Raviv, 2009; Rincón et al., 2012	- Anaerobic digestion	Israel	- Anaerobic fermentation to produce biogas (MIS-TOW)	- Low energy requirements - little sludge - allows energy recovery from methane - applicable for 2-phase and 3-phase decanters	- not applied in a wide scale - process needs to be tested further	
"Biogas2PEM- FC project", 2015	- OMW as fuel for power-plants	Granada, Spain	- 1.: Anaerobic digestion of OMW - 2.: Converter converts CH_4 into CO_2 and H_2 - 3.: Heat-/ Energy production from H_2	- Electricity production - Pollutant destruction - No landfill space	- Very expensive - Not economic yet	
"Oli-PHA Project", 2012	- Production of bio-plastics from OMW	Barcelona, Spain	- OMW as raw material for PHA (bio plastic) production - Produced by photosynthetic bacteria (cyanobacteria).	- Plastics replacement - Sustainable source of organics instead of additional framing for PHAs	- Expensive - Not feasible for small scale business	
Azaizeh & Jadoun, 2010; Paraskeva & Diamadopoulos, 2006	- Anaerobic co-digestion	Non specific	- Co-composting final byproduct is toxic-free waste that can be safely disposed in landfills without concern of leaching toxins.	- Large pollutant destruction - Remaining material can serve as fertilizer or can be land-filled - Cost-effective - Co-treatment with other waste streams (no lack of waste after season; better pH, water ratio and nutritious conditions)		- 75 – 90 % COD removal depending on dilution and post treatment
Laor & Raviv, 2009	- Controlled land spreading	Israel	- OMW land spreading of up to 40-50 $m^3ha^{-1}a^{-1}$ - Every alternate year on the same plot.	- Improved nutritious conditions - Increased organic matter - Fertilizer replacement - Low pollutant loads if spreading is limited yearly	- Danger of too much spreading and pollution of ground soil and groundwater leachate	- More research needed for appropriate selection of spreading areas (minimizing risks)
Kapellakis et al., 2015	- Land application	Greece	- OMW stored in retention ponds - Applied after using irrigation and distribution system (Land treatment system) - organics did not exceed 500 kg BOD_5 $ha^{-1}day^{-1}$ - Effluent applied on fortnightly cycles (provide time for OM degradation & to avoid soil pores clogging)	- significant reduction in inorganic and organic contents of OMW - great pollutant depletion potential if limited application - soil improvement	- OMW fertilizer lacks of nitrogen - Toxic phenols might influence young plant growth - Danger of too much OMW spreading	- More research needed for appropriate selection of spreading areas (minimizing risks) - Perhaps pre-treatment declining phenols
Andiloro et al., 2009	- Planed agricultural utilization of OMW	Calabria, Italy	- Study examines interactions of OMW spreading with: soil type, soil morphology, hydrology, general pedology - Aim: development of management strategies for OMW spreading (OMW spreading model)	- Helps appropriate OMW application - Reduces pollution risks - Maximizes nutritious properties	- Neglects economic and organizational factors (actually to be considered) - More research required	

Author	Abstract	Location	Description	Advantages	Disadvantages	Efficiency/ Recommendations
Mekki et al., 2013	- Application of treated OMW to soils	Tunisia	- Irrigation of soil with treated OMW - Evaluation of biodegration, nitrogen availability and seed germination	- Improved germination index, biomass, spike number, plants growth and similar or even better dry productivity		
Aly et al., 2013	- OMW treatment through simple zeolite-based low-cost method	Saudi Arabia	- OMW treatment through 3 columns of gravel, fine sand and a mix of acidified cotton and zeolite (weight ratio of cotton : clinoptilolite of 2:1) - followed by treatment with activated charcoal (AC) and lime	- simple low-cost method - cleaned water ready for irriga-tion	- more research is needed. - Special equipment required	
Azbar et al., 2004	- Evaporation-Hydrolysis-Oxidation (EHO)	Greece	- Mutual treatment by evaporation, hydrolysis (con-trolled heat input and subsequent oxidation by air) - Sludge removal before pulp oil manufacturing and fuel production - Removal of residual fatty acids through ceramic ultrafiltration membrane - Removal of phytotoxic substances - Recovery of useful secondary materials - further treatment of residual pollutants		- very expensive (investment ca. 14 Mio € for capacity of 1,400 tons per year plus 1 Mio € operating costs)	

7. Recommendations for a Pilot Plant in the West Bank

7.1. Techniques and Costs

A market study conducted by Studioazue (2016) unveiled that olive oil production costs are higher in the West Bank compared to other adjacent Arabic regions due to the dependency of the Palestinian market on the expensive Israeli one. At this, the production costs of olive oil in Palestine are 10-15 percent higher than in Syria, 20-30 percent higher than in Jordan and 35-40 percent higher than in Turkey. Labor costs contribute more than 50 percent to the total costs. These differences in production costs have significant impacts on the final market prices of olive oil and influence trade patterns. Appropriate treatment or avoidance of OMW causes additional costs increasing the oil price. According to, Zereini & Jaeschke (2010) the costs for the replacement of one three-phase by a two-phase-decanter is ca. 30,000 €, whereas the web site *www.alibaba.com* states prices between $ 20,000 and $ 100,000 depending on the processing capacity. Further, (Zereini & Jaeschke, 2010) mention the price for the exchange of the entire extraction equipment to be as high as $ 200,000. In comparison, a responsible for the olive groves in Neot Smadar (Israel) assumed $ 400,000 to be necessary for the entire replacement of all oil extraction devices (Neot Smadar, 2016). Figure 21 andFigure **22** show OMW treatment and avoidance costs for different management options.

Treatment scheme*	Investment cost, €	Operating cost per cubic meter of wastewater, € m^{-3}	Total cost per cubic meter of wastewater, € m^{-3}	Calculated cost per ton of olive oil, € ton^{-1}
1. Forced mechanical evaporation + lagooning	180,700	6.82	10.43	52.1
2. Physicochemical + biological + ultrafiltration	150,600	8.68	11.69	58.4
3. Biological (both solid wastes and wastewater treatment)	180,700	6.21	9.82	49.1
4. Physicochemical + reverse osmosis	138,600	5.27	8.04	40.2
5. Physicochemical + ultrafiltration	216,900	Not known	—	—
6. Biological (anaerobic + aerobic) + reverse osmosis	180,700	Not known	—	—
7. Vacuum evaporation	96,400	3.69	5.62	28.1
8. Forced natural evaporation	42,200	0.47	1.31	1.5
9. Improved natural evaporation	30,100	0.05	0.65	3.2
10. Mechanical biological pretreatment (biogas production) + sludge management (aerobic stabilization + solar drying)	500,000–850,000	3.5–5.5	13.5–22.5	67.5–112.5
11. Commercial evaporator	850,000	1	3.95	19.7

Figure 21: *Costs of various treatment schemes; three-phase mill generating 5000 m^{3}OMW/a and 10 Years of operation time, 1:5 Oil to OMW weight ratio (Azbar et al., 2004)*

(Laor & Raviv, 2010)	(Azbar et al., 2004)	(Zereini & Jaeschke, 2010)
Central OMW-Co-Composting - Transportation costs (Truck): 10 €/m3 - Operating Costs: 4-6 €/m^3 - Total Costs: 15 €/m^3 OMW	***Evaporation-Hydrolysis-Oxidation (EHO)*** - Investment (capacity 1,400 t/a): ca. 14 Mio € - Operating Costs: 1 Mio €/a	***Drying Bed and Solar Oven*** - Equipment & Logistics: 460,000 € - Operating and Maintenance: 160,000 €/a
Decentral Pre-Treatment Floatation Device - Investment: 10,000-20,000 € (depending on state support) - Relative Investment Costs (used 10 years; 1,000-2,000 m^3 OMW/a): ca. 0.5-2 €/m^3 OMW (without operating costs)		

Figure 22: *Costs for different OMW treatment options based on different studies*

7.2. Summary of the Situation and Suggestions for OMW Treatment in the West Bank

As pointed out in chapter 2 the business structure of the Palestinian olive sector is rather small scale, regionally scattered and facing economic and financial limitations. Besides the political situation, this has a great impact on the feasibility of available treatment options.

The limited financial strength constrains possible investment in treatment technique. This is especially true since small scale mills produce only little olive waste per mill rendering treatment less efficient. Further, many olive mill owners show low understanding for the environmental concerns and for more complex treatment options staff needs to be educated appropriately. In order to improve the cost-benefit ratio of OMW treatment and to provide trained employees, centralized treatment might be an alternative. Following this solution, the waste material needs to be collected and transferred to the final treatment facility. For this either trucks could be used or pipelines could be installed. At this, the pipelines are only feasible for very liquid OMW and thus not useful for two-phase decanter Systems. However, the pipeline option is strongly limited by seasonality of the waste stream, the mountainous geomorphology, low OMW production rates per mill and weak governmental capabilities (Shaheen & Karim, 2007). After all, the lack of governmental legislation and enforcement as well as appropriate incentives states one of the major problems regarding the OMW issue in Palestine and needs to be enhanced in order to achieve widespread environmental improvements.

Various treatment options have been applied, but it is very difficult to determine best cost-benefit solutions. Shaheen & Karim (2007) compared different treatment options tested in Palestine in terms of their effectivity. The authors also examined the effect of the replacement of three-phase by two-phase decanters. In doing so, they consider the modernization of the oil extraction process most suitable for the reduction of environmental harm caused by OMW. As two-phase decanters require much less process water than three-phase decanters this measure would also contribute to a significant reduction of water consumption. Concerning available treatment options, they concluded forced evaporation most suitable due to relatively low environmental impacts, very low costs (compare Figure 21) and both little operational and implementation requirements (Figure 23). Forced evaporation could be conducted centralized or decentralized depending on the specific situation of the considered olive mill. At this, Zereini & Jaeschke (2010) considered such integrated approaches relatively cheap compared to other end-of-pipe options. However, on one side this treatment option declines the mobility of the waste material and thus declines the risk to ground and surface water but on the other side it produces great amounts of potentially polluting dried organic material. For this reason a more destructive treatment options might be recommended.

As stated in chapter **Error! Reference source not found.** the two-phase extraction produces a relatively dry and thus less mobile waste product. As the Palestinian territories are highly dependent on energy imports, the produced organic waste material could be dried further (natural or forced evaporation), pressed to briquettes and used as combustion material either by households or in central power plants (co-combustion due to seasonality of OMW formation). The process costs could be compensated by the final combustion material and its market price. However, this requires the wide replacement of three-phase by two-phase decanters and should be initiated by governmental incentives and international funding programs. Further, natural drying might be not feasible in autumn and winter (oil processing season) due to lower evaporation and precipitation.

Criteria Groups	OMW Treatment Options						
	Natural Evaporation	Forced Evaporation	Incineration Distillation	Membrane Processes	Biological Treatment	Chemical-Biological Treatment	Extraction Process Development
Status of development	15	9	6	4	13	8	12
Implementation requirements	9	19	17	17	14	14	25
Operation requirements	30	24	14	13	20	13	24
Environmental Impact	9	23	21	30	21	21	20
Total	**63**	**75**	**58**	**64**	**68**	**56**	**81**
Rank	**5**	**2**	**6**	**4**	**3**	**7**	**1**

Figure 23: *Evaluation Matrix for OMW treatment and reduction options in Palestine; internal evaluation system (Shaheen & Karim, 2007)*

As shown in Figure 23 the third favored option mentioned by Shaheen & Karim (2007) is biological treatment, though it is relatively expensive (Figure 21). Especially anaerobic digestion shows high potentials of pollutant destruction and mass depletion. If simple technical solutions are applied initial and operational requirements are relatively low and the process can be applied easily. However, it produces some kind of extra labor costs and thus requires either improved environmental understanding, economic incentives or legal regulations for successful implementation. At this, one incentive could be the utilization of produced biogas in order to decline energy costs. If anaerobic digestion is applied centralized, OMW should be mixed with other organic waste materials to improve the physio-chemical properties and to address the seasonal availability of olive waste.

8. Conclusion

Olive farming and olive oil production plays an important role within the Palestinian economy and both social and cultural patterns. However, the waste problem has not been considered for a long time by the Palestinian society and needs to be addressed increasingly urgent since oil production rates are planned to be extended, settlements are spreading and thus ground and surface waters are more and more endangered. At this, governance has to be improved including the adoption of appropriate legislation and enforcement as well as environmental education programs and the implementation of effective incentives for more environmentally friendly oil mill owners.

The most feasible OMW treatment method depends very much on the individual situation of each olive mill and factors such as location, size, financial capabilities and waste composition. The replacement of three-phase by more modern and effective two-phase decanters should be conducted stepwise in the long-term. At this, it might be also useful to merge remote olive mills to increase treatment efficiency, though its social impacts should be considered thoroughly.

Even though, forced evaporation, combustion and anaerobic digestion might be feasible options, more research is necessary to evaluate the cost-benefit ratio of other treatment techniques. In doing so, a comprehensive evaluation matrix should be created focusing on different factors such as pollutant destruction, costs, status of development and construction, feasibility for urban or rural areas, labor and operational requirements. Here, it might be very useful to get in contact with related engineering and construction companies that can give valuable advice concerning the realization of a potential pilot plant. Besides this, further literature research should be undertaken to unveil successfully applied treatment in the European Union in countries such as Spain and Italy.

Further, it is recommended to cooperate with the Palestinian Olive Oil Council in order to get access to more detailed market statistics. Data of registered olive mills referring to production rates and locations might be very helpful to identify suitable potential olive mills for pilot plant co-operations.

Last but not least, a survey on the perception of the environmental problem should be conducted amongst olive mill owners and local residents to find out if there is potential support for improved OMW treatment and future environmental protection measures.

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