Sustainability Analyses for the Exploitation of Olive Tree Cultivation Residues

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ABSTRACT

The olive tree cultivation's cycle includes various activities. The results of this cycle are olive oil and edible olives as main products, olive kernel and olive wood as basic by-products, and several wastes, most of them not exploited, but on the contrary causing significant environmental problems. Among them are the "Olive Tree Prunings (OTP)", i.e., all small and large branches and leaves from the olive tree produced from its pruning, as well as "Olive Mill Wastewater (OMW)" produced from the three-phases' olive mills. Whereas there are plenty of research, methods, and pilot demonstration for OMW & OTP treatment, there are no wide known and applicable methods for their feasible and sustainable exploitation. Moreover, the farmers consider OTP as wastes trying to find ways to get rid of them. The most common way of elimination of OTP is their burning during or soon after the harvesting period. By means of a Life Cycle Analysis (LCA) of the olive oil production it can easily be deduced that the lop burning and the arbitrary disposal of OMW poses the most serious environmental threats. In Greece, it is common practice that all these amounts of OTP are just burnt by the farmers in open lumps, unexploited, polluting seriously the atmosphere and contributing thus harmfully to climate change. This burning causes significant gas emissions, mostly greenhouse gases, such as CO_2 and methane, and other constituents especially harmful for the human health, such as CO, NO_x, and micro-particles. The main reasons for the above situation are twofold. Firstly, the multi-dispersed character of these residues which raises significant difficulties in their logistics, and secondly the unknown market for exploitation of potential OMW & OTP derivatives. A significant improvement on this existing practice can be motivated by the possibility of their successful exploitation, and this is the main objective of the present work, together with the presentation of feasible ways of collection & management.

Keywords: olive trees, composting, sustainability, waste

1. INTRODUCTION

The Olive tree (Olea europaeaL.) is of major agricultural and economic importance as the source of olives, and the basis for production of associated agro-industrial products such as olive oil and soap. Its growth is beginning to spread globally, especially during the past two decades, due to health benefits attributed to olive oil consumption. The health promoting properties are associated with the presence of monounsaturated fatty acids (MUFA), and functional bioactive compounds like tocopherols, carotenoids, phospholipids and phenolics (Benavente-Garcıa et al., 2000; Ghanbari et al., 2012). In 2013, production of olive oil accounted for 2.67 million tons, with human consumption being its main purpose (Romero-García et al., 2014). The production for 2014 was estimated at 3.01 million tons (Rodrigues et al., 2015). Olive trees are of particular importance in Mediterranean countries, which are responsible for about 98% of the annual worldwide production of olive oil (Roig et al., 2006). In this area Spain, Italy, Greece, Portugal, Tunisia, Turkey and Syria are the main producers, with the first four alone representing about 75% of the world production (Baeta-Hall et al., 2005). It is worth noting that the European Union's (EU) olive sector was calculated to have about 2.5 million producers, which made up approximately one-third of all EU farmers (Niaounakis and Halvadakis, 2006). Despite the obvious economic importance of this food product, the olive oil industry causes diverse environmental impacts in terms of resource depletion, land degradation, air emissions and waste generation. Waste is mainly in the form of Olive Mill Wastewater (OMW) and Olive Tree Prunings (OTP) however, the amounts generated vary greatly from one country to another (Salomone and Loppolo, 2012).

The amounts of Olive Tree Prunnings (OTP) produced annually in Greece are considerable, with estimates ranging from 1.4 to 3 million tons (Khayer et. al., 2013; Manios, 2004). As most farms are small enterprises, they lack the capability and/or knowhow of treating these wastes in an environmentally friendly manner. Current practice means that OTP are either disposed of in landfills (resulting in rapid exhaustion of landfill capacity) or burned immediately after the harvest of the olive fruits and the tree pruning operations (from November to March), resulting in the loss of large amounts of energy and material recovery, and the simultaneous emission of considerable amounts of Green House Gases (GHGs). The importance of this issue comes into sharp focus when considering that the uncontrolled burning of OTP releases about 2.7 million tons CO_2 annually. As the calorific value of OTP is 8MJ/kg, these amounts could produce 6.67 TWh of thermal energy or equivalently 2.33 TWh electricity, sufficient to cover, at the best case, 4.8% of the total country's energy consumption (Charisiou, et al., 2015). Moreover, the European Landfill Directive (EU 1999/31) requires the phased reduction of landfill disposal of such biodegradable organic materials. Therefore, recycling of biodegradable agro industrial residues and the organic fraction of municipal solid waste (after source separation) could also reduce the problems relating to the increasing production of wastes and the difficulties of locating new landfill sites. Arguably, the absence of an economically feasible waste management plan is vital to long term viability of the agro-economic sector.

Various attempts have been carried out in order to better exploit OTP's, amongst them: (i) the use of OTP's as animal feed (Molina and Nefzaoui, 1996), (ii) the valorization of Olive Tree Leaves (OTL's) for the extraction of oleuropein, tyrosol, hydroxi-tyrosol and other components (Japon et al., 2006), (iii) the production of energy from OTP pellets (Carone et al., 2011) or through the gasification process (Skoulou et al., 2008), and (iv) the composting of OTL's and OTP's. In regards to composting, efforts have concentrated on the exploitation of OMW (Paraskeva et al., 2007; Plaza et al. 2007). Additionally, several studies assessed the compost quality that was produced by different olive processing residues, such as olive kernel, olive leaves and olive prunings (Konstantakou et al., 2010; Konstantakou and Papadakis, 2010; Manios, 2004). Moreover, researchers in Greece have focused on materials such as olive tree leaves and branches, olive press cake, vine branches, pressed grape skins, pig manure, sewage sludge and the organic fraction of municipal solid wastes for their behaviour during composting, their compatibility in mixtures and the quality of the end product (Manios, 2004; Bustamante et al., 2008). The composting of olive tree residues has also been extensively studied in Spain. Indicatively, Garcia-Gomez et al. (2003) composted the flocculated solid fraction of OMW, obtained from two different olive oil extraction systems, with olive leaves as the bulking agent in a static pile system. Furthermore, the same group studied the dynamics of Organic Matter (OM) degradation and its relationship with the basal respiration and fluorescein diacetate hydrolytic activity, as indicators of biological activity. In Italy, biological indexes were used in order to assess the compost's stability produced by organic greens (Baffi et al., 2007). Composts were obtained from the organic fraction of municipal solid wastes, chicken manure and paper. The results suggested that the integrated use of biological, chemical and thermoanalytical methods could represent a useful tool in differentiating stabilized composts from non-stabilized ones. In Israel, chemical parameters were examined of composts from three types of source materials (municipal solid waste, separated cow manure, and biosolids), using different procedures and facilities (Zmora-Nahum et al., 2005).

Coping with the environmental issues created by wastes from olive mills presents large difficulties, mainly due to the high cost of the treatment of residual waters using the various systems proposed so far. In recent years, only in Italy more than 100 companies have proposed relevant systems, but none of them constitutes a practical and low-priced solution to the problem. As the fixed cost for installing such systems seems not decreasing, a profit from possible useful by-products could contribute significantly to the problem solution. The management of OMW has been extensively investigated and some extensive and detailed reviews, which focus mainly on its management, have been published (Niaounakis and Halvadakis, 2004; Azbar, et al., 2004). Provided that the fixed cost for the installation of OMW treatment systems seems to be in-elastic, operational cost reduction may be attained through the exploitation of the waste by-products. Various separation techniques (prefiltration, ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO)) of the OMW treatment using membranes filtration have been proposed by a number of researchers (Gigliotti, et. al., 2012; Zaglis et. al., 2013).

Thus, regarding OTP, the main objective of this work is to demonstrate ways of exploitation of olive tree lopping instead of burning them in–situ, converting them to innovative and high-added value products, following a logic chain of exploitation:

- Removal of olive leaves for extraction of useful constituents (for pharmaceutical purposes or for cosmetics) or for animal feeding
- Composting of small branches to create an organic fertilizer
- Conversion of the remaining quantities to pellets for energy production.

2. TECHNO-ECONOMICAL ANALYSES

2.1 OTP collection & exploitation

The main objective of the present work is to perform a techno-economical study, for the design and implementation of a pilot plant for an integrated management of OTP in the Municipal Department (Elika, Municipality of Monemvassia, Laconia, Greece). This area counts approximately 300,000 olive trees producing 2100 t/yr of olives that when milled produce approximately 420 t/yr olive oil. The quantity of OTP produced from the harvesting and pruning is estimated at 6000 t/yr on average; this is the designed capacity for the unit under consideration. Three final products are envisaged:

a) separate olive leaves for disposal to pharmaceutical or cosmetics industry,
b) compost for agriculture and soil enhancement and
c) pellets for energy applications.

In this techno-economical analysis the dependence of the rate of the return on investment (ROI) on various important characteristics was estimated, suggesting the minimum percentage of leaves required for break-even point (7% of the total OTP), and also indicating the sensitivity on raw material value and on fixed cost value, see Figures 1 & 2.

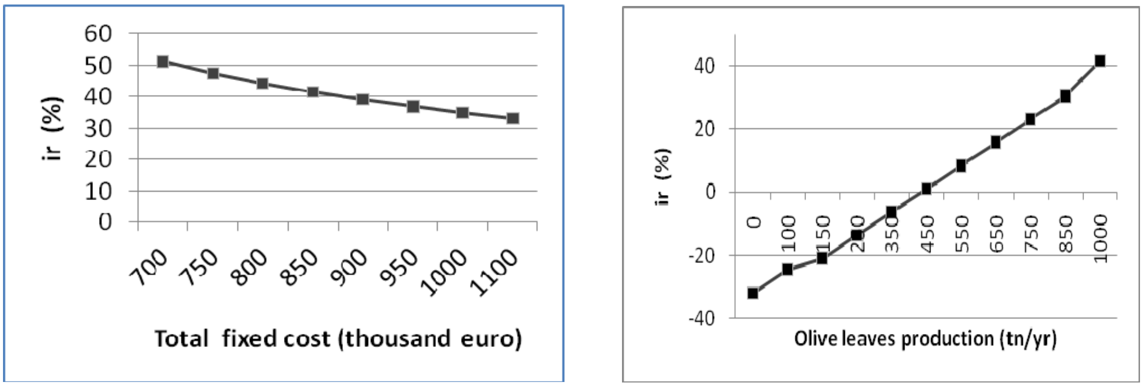

Figure 1. Dependence of the rate of return on investment, i_r, on the raw material value (left) and on the olive leaves' production (right).

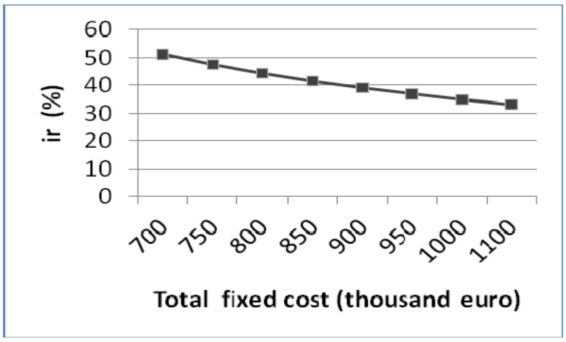

Figure 2. Dependence of the rate of return on investment, i_r, on the fixed cost value.

2.2. OMW management and exploitation

The management of produced OMW constitutes a long-term and particularly difficult problem, because of their high organic load, their particular physicochemical composition, the potentially toxic attributes, the intense of short time interval of production and the high cost investment requirements (Komilis and Tziouvaras, 2009). The present work presents brief results of a techno-economic analysis of the OMW treatment using membrane filtration. The idea of using membrane technology – fraction separation- is presented by some of the authors in a previous work (Paraskeva, et al., 2006) in which a new cost-effective system for complete exploitation of OMW was suggested, that offered a viable solution to the problem of OMW disposal. Laboratory research was performed and a pilot plant was designed, constructed and installed in a typical olive mill, where OMW quantities were treated at larger volumes. The efficiency of the proposed method for separation and exploitation of the OMW useful constituents was demonstrated. In recent works, feasibility and sustainability studies of the proposed method at a regional level were performed, indicating very positive financial results for a future exploitation (Arvaniti, et al., 2012, Zagklis et al., 2013).

Series of laboratory experiments, based on the technology of membrane filtration (Ultrafiltration and Nanofiltration and/or Reverse Osmosis), have been carried out for the fractionation of olive mill wastewaters into fractions with nutritive value, phytotoxic action and pure water. Based on these results, pilot plant membranes of larger volume were installed at an olive mill enterprise for an entire harvesting period and appropriate experiments were performed. The study showed that a fraction of pure water up to 80% can be recovered and fractions that contained concentrate nutritious and separate polyphenol content can be isolated and further exploited in order to reduce the, indeed, high cost of the suggested treatment process. A detailed techno-economic analysis for the implementation of the suggested method for the Region of Western Greece was performed.

This analysis took into account the fixed and the operational costs of the equipment, the costs for the infrastructure and land, the costs for the maintenance, etc., considering the treatment of 50,000 tons per harvesting period in the Region of Western Greece. The study showed that the establishment of one central treatment manufacture could reduce the uncontrolled disposal of OMW and their final discharging in the aqueous receptors. The exploitation of the nutritious content of the fractions as manure in fertilizers together with the polyphenol content that can be used as components of ecological herbicides can depreciate the total cost in a very short period of about 3 years.

The rate of return on the investment is high enough (about 30%), much higher than the current bank interest, which makes the investment vital. Moreover, the mean payout period can be considered as satisfactory, taking into account that the whole equipment of the investment is new, and the total cost of the investment has been considered, thus in the net profit the depreciations have been added. This is a very encouraging result, taking into account that a rather low value for the toxic fraction was also considered. The above result is characterized as positive and indicates to undertake the investment.

3. PROCESS SUSTAINABILITY

Sustainability issues regarding OMW management are presented in details elsewhere (Zagklis et al., 2013). An ongoing research is being carried out for elucidating sustainability issues for OTP exploitation (Charisiou, et al. 2015). In this chapter, the sustainability results for OTP exploitation as compost are presented.

The GHG emissions that may be produced by composting include: (i) methane (CH_4) generated by anaerobic decomposition, (ii) carbon dioxide (CO_2) generated by aerobic decomposition, (iii) nitrous oxide (N_2O) produced by materials' initial nitrogen content, and (iv) the non-biogenic CO_2 emissions caused by the shipping of collected organic wastes to composting facilities and mechanical turning of the compost piles. Composting is an aerobic biological treatment method and if perfectly carried out, CH_4 is generally not generated. The CH_4 produced at the center of the compost pile, most likely oxidizes when it reaches the oxygen-rich surface of the pile, where it is converted to CO_2 or may be emitted due to unintentional leakages during process disturbances. As the adding of organic matter to the soil through compost increases the soil's C level, this helps make up for the reduction in C content caused by an increase in crop yields or other soil activities. Stable C compounds created by the composting process include an increase in humic substances and aggregates allowing C to be stored for long periods of time in the soil. The C storage potential created by the compost was therefore also taken into consideration in the present study.

CO_2 accounts for over 99% by mass of total gaseous biogenic emissions from aerobic composting, excluding water vapor. Emission measurements and LCA studies quantifying the C emissions from the aerobic composting of various types of feedstock have been performed by many researchers. The summary data from five of these studies is presented in Table 1. The other principal emissions to air from aerobic composting are CH_4, volatile organic compounds of various kinds, ammonia (NH_3) and nitrous oxide (N_2O) (Colón et al., 2010; Martino-Blanco et al., 2009). CH_4 emissions may arise from anaerobic pockets within unturned windrow piles, but where forced aeration is accompanied by periodic windrow turning any methane will be oxidized, resulting in minimal residual emissions. A study of municipal waste composting by Martino-Blanco et al. (2009) reported CH_4 emissions equivalent to 4 g/tone of wet organic waste. By contrast, Colón et al. (2010) reported CH_4 emissions from home composting in the region of 3000 g/tone wet waste, which may be partly a function of home composting in containers with little or no aeration.

Table 1: Comparison of literature data on carbon and nitrogen emissions for home composting per kg carbon input assuming short-term carbon storage in compost

Study	Feedstock type	Feedstock volume	Composting process	Total processing period	Emissions (CO_2 kg/tone)
Jackson & Line, 1997	Pulp & paper mill sludges, urea, ammonium sulfate ammonium nitrate	75m^3 windrows	Wind rowing	21 weeks	191
Jakobsen, 1994	Garden organics, food organics, sewage sludge, pig & cattle manure	Information not available from study	*Not stated*	*Not stated*	182
Komilis & Tziouvaras, 2006	Yard wastes –grass clippings & leaves	Simulated composting using 25l airtight stainless-steel digesters	*Not stated*	*Not stated*	217
Martino-Blanco et al, 2009	Organic MSW & pruning wastes(1:1)	*Not stated*	Forced aeration & wind rowing	10 weeks	165
Riffaldi et al, 1986	Paper processing, sludge, straw	11.25m^3 static pile	Forced aeration & wind rowing	60 days composting, 80 days maturation	193

4. CONCLUSIONS

It was clearly observed from the sensitivity results of the techno-economical analysis that the proposed investment on OTP complete exploitation is very sensitive on the production and disposal of olive leaves. A minimum level of 7% of olive leaves production from all OTP is required in order to ensure viability. The other parameters presented herein have the expected influence on ROI; the higher the raw materials price and the higher the fixed cost value, the lower the ROI observed, with a more significant dependence from the raw material price. In general, however, it could be stated with certainty that the criteria of ROI, payout period and net present value (NPV), by taking into consideration the above sensitivity results, the presented OTP exploitation is suggested to be undertaken. Additionally, composting process indicates that OTP is an excellent raw material for composting producing high quality compost with rather low GHG emissions, if perfectly carried out. The present work, as a general concept, contributes to opening up a paved road showing a feasible solution of the problem of OTP management. The proposed solution could be further extended to any agricultural residue offering multiple environmental and economical benefits.

The olive oil industry is very important in many Mediterranean countries, both in terms of wealth and tradition. The extraction of olive oil generates huge quantities of high organic wastewaters with toxic constituents that may have a great impact on land and water environments.

The present work suggests a cost-effective system for complete exploitation of OMW, based on membrane fractional separation, which offers a viable solution to the problem of OMW disposal. The introduction of the proposed new integrated technology reduces dramatically the environmental damage and provides a profitable alternative to the olive mills due to utilization of all by-products. As main derivatives from the suggested OMW exploitation are alternative ecological herbicides, fertilizers and other useful by-products. It is expected that these new products will be highly accepted from the farmers and will enhance the agriculture sustainability.

The successful integration of the proposed management and exploitation possibilities suggested in this work, both for OTP and OMW, establishes the basis for a complete and profitable solution of one of the most important Mediterranean environmental problems.

REFERENCES

Arvaniti, E.C., Zagklis, D.P., Papadakis, V.G., Paraskeva, C.A. 2012. High-added value materials production from OMW – A technical and economical optimization. International Journal of Chemical Engineering, *Article ID 607219, 7 pages, doi:10.1155/2012/607219.*

Azbar N, Bayram A, Filibeli A, Muezzinoglu A, Sengul F, Ozer A (2004). A review of wastes management options in olive oil production. Crit. Rev. Toxicol. 34(3): 209–247.

Benavente-Garcıa, O., Castillo, J., Lorente, J., Ortuno, A., Del Rio, J.A., 2000. Antioxidant activity of phenolics extracted from Olea europaea L. leaves. Food Chemistry, 68, 457–462.

Baeta-Hall, L., Sàagua, C.M., Bartolomeu, M.L., Anselmo, A.M., Rosa, M.F., 2005. Biodegradation of olive oil husks in composting aerated piles. Bioresource Technology, 96, 69-78.

Baffi, C., Dell Abate, M.T., Nassisi, A., Silva, S., Benedetti, A., Genevini, P.L., Adani, F., 2007. Determination of biological stability in compost: A comparison of methodologies. Soil Biology & Biochemistry, 39, 1284-1293.

Bustamante, M.A., Paredes, C., Marhuenda-Egea, F.C., Perez-Espinosa, A., Bernal, M.P., Moral, R., 2008. Co-composting of distillery wastes with animal manures: Carbon and nitrogen transformations in the evaluation of compost stability. Chemosphere, 72, 551-557.

Carone, M.T., Pantaleo, A., Pellerano, A., 2011. Influence of process parameters and biomass characteristics on the durability of pellets from the pruning residues of Olea europaea L. Biomass and Bioenergy, 35, 402-410.

Charisiou, N.D., Konstantakou, P.P., Papadakis, V.G., 2015. Exploitation of olive tree prunings as raw material for the production of high quality compost. Environmental Engineering and Management Journal, *In press*.

Colón, J., Martinez-Blanco, J., Gabarell, X., Artola, A., Sanchez, A., Rierdevall, J., Font, X. 2010. Environmental assessment of home composting. Resource Conservation and Recycling, 54, 893–904.

Garcia-Gomez, A., Roig, A., Bernal, M.P., 2003. Composting of the solid fraction of olive mill wastewater with olive leaves: organic matter degradation and biological activity. Bioresource Technology, 86, 59-64.

Ghanbari, R., Anwar, F., Alkharfy, K.M., Gilani, A.-H., Saari, N., 2012. Valuable nutrients and functional bioactives in different parts of olive (Olea europaea L.) – a review. International Journal of Molecular Sciece. 13, 3291-3340.

Gigliotti, G., Proietti, P., Said-Pullicino, D., Nasini, L., Pezzolla, D., 2012. Co-composting of olive husks with high moisture contents: Organic matter dynamics and compost quality. International Biodeterioration & Biodegradation, 67, 8-14.

Jackson, M.J., Line, M.A. 1997. Windrow composting of a pulp and paper mill sludge: Process performance and assessment of product quality. Compost Science and Utillization, 5, 6-14.
Jakobsen, S.T., 1994. Aerobic decomposition of organic wastes, stoichiometric calculation of air change. Resource Conservation and Recycling, 12, 165-175.
Khayer A, Chowdhury MB, Akratos CS, Vayenas DV, Pavlou S (2013). Olive mill waste composting: A review. Int. Biodeter. Biodegr. 85: 108-119.
Komilis, D.P., Tziouvaras, I.S. 2009. A statistical analysis to assess the maturity and stability of six composts. Waste ManageMENT, 29, 1504-1513.
Konstantakou, P.P., Haroutounian, S.A., Papadakis V.G., 2010. Multilateral exploitation of olive tree lop – Techno-economical analysis for leave extracts, compost and energy pellet production. *Proc. Linnaeus Eco-Tech'10, Kalmar, Sweden*.
Konstantakou, P.P., Papadakis V.G., 2010. An integrated management and exploitation of agricultural residues – Application to olive tree lop. *Proc. European Biomass Conference and Exhibition – From Research to Industry and Markets, Lyon, France*.
Manios T (2004), The composting potential of different organic solid wastes: experience from the island of Crete, Environ. Int. 29: 1079-1089.
Martino-Blanco, J., Munoz, P., Antón, A., Rierdevall, J., 2009. Life cycle assessment of the use of compost from municipal organic waste for of tomato crops. Resource Conservation and Recycling, 53, 340-51.
Molina Alcaide E., Nefzaoui A., 1996. Recycling of olive oil by-products: Possibilities of utilization in animal nutrition. International Biodeterioration & Biodegradation, 38, 227-235.
Niaounakis M, Halvadakis CP (2004). Olive-mill waste management: Literature review and patent survey, Typothito-George Dardanos Publications, Athens, ISBN 960-402-123-0.
Paraskeva, C.A., Papadakis, V.G., Tsarouhi, E., Kanellopoulou, D.G., Koutsoukos, P.G. 2006. Membrane processing for olive mill wastewater fractionation. Desalination Journal, 213, 218-229.
Paraskeva, C.A., Papadakis, V.G., Tsarouchi, E., Kanellopoulou, D.G., Koutsoukos, P.G., 2007, Membrane processing for olive mill waste water fractionation. Desalination, 213, 218-229.
Plaza, C., Senesi, N., Brunetti, G., Mondelli, D., 2007. Evolution of the fulvic acid fractions during co-composting of olive oil mill wastewater sludge and tree cuttings. Bioresource Technology, 98, 1964–1971.
Riffaldi, R., Levi-Minzi, R., Pera, A., de Bertoldi, M., 1986. Evaluation of compost maturity by means of chemical and microbial analyses. Waste Management Resources, 4, 387-396.
Rodríguez, G., Lama, A., Rodríguez, R., Jiménez, A., Guillén, R., Fernández-Bolanos, J., 2008. Olive stone an attractive source of bioactive and valuable compounds. Bioresource Technology, 99, 5261-5269.
Roig, A., Cayuela, M.L., Sánchez-Monedero, M.A., 2006. An overview on olive mill wastes and their valorisation methods. Waste Management 26, 960e969.
Romero-García, J.M., Nino, L., Martínez-Patino, C., Álvarez, C., Castro, E., Negro, M.J., 2014. Biorefinery based on olive biomass. State of the art and future trends. Bioresource Technology, 159, 421-432.
Salomone, R., Loppolo, G., 2012. Environmental impacts of olive oil production: A Life Cycle Assessment case study in the province of Messina (Sicily). Journal of Cleaner Production, 28(5), 88-100.
Skoulou V., Zabaniotou A., Stauropoulos G., Sakelaropoulos G., 2008. Syngas production from olive tree cuttings and olive kernels in a downdraft fixed-bed gasifier. International Journal of Hydrogen Energy, 33, 1185-1194.
Zagklis DP, Arvaniti EC, Papadakis VG, Paraskeva CA (2013). Sustainability analysis and benchmarking of olive mill wastewater treatment methods. J. Chem. Techn. Biotechn. 88: 742-750.

Zmora-Nahum, S., Markovitch, O., Tarchitzky, J., Chen Y., 2005. Dissolved organic carbon (DOC) as a parameter of compost maturity. Soil Biology & Biochemistry, 37, 2109–2116.