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Article

Techno-economical & Sustainability Analyses for Multilateral 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.

Key words: olive tree pruning, life cycle analysis, sustainability, techno-economic evaluation, composting.

INTRODUCTION

Amongst Mediterranean countries, olive trees are a major source of agricultural residues. 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 Pruning (OTP) however, the amounts generated vary greatly from one country to another.

The amounts of OTP produced annually in Greece are considerable, with estimates ranging from 1.4 to 3 million tones (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 usually 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 tones 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. Arguably, the absence of an economically feasible waste management plan constitutes one of the most serious disadvantages in the efforts to achieve more sustainable practices in the agricultural industry.

Olive oil production is also associated with the generation of large quantities of OMW (Hytiris, et. al., 2004; Stoller, 2013; Stoller, et al., 2013) and solid wastes, whose management, treatment and safe disposal raise serious environmental concerns. The characteristic properties of OMW include its dark color, characteristic odor, acidic pH and high organic content mainly composed of classes of pollutants such as polyphenols that may exhibit antimicrobial, ecotoxic and phytotoxic properties (Ceggara, et al., 1996; Perades, et al., 1999). Due to the high organic load of OMW, it may contribute significantly to eutrophication of recipients in which fluid exchange rates are low (closed gulfs, estuaries, lakes etc) (DellaGreca, et. al., 2001; Paredes, et al., 1987; Rana, et al., 2003). An additional adverse impact of OMW on the environment is the aesthetic degradation caused by its strong odour and dark coloration. Problems arise also from the fact that olive oil production is seasonal and so the treatment process should be flexible enough to operate in a non-continuous mode, otherwise storage of the wastewater will be required (Gigliotti, et. al., 2012). Moreover, the olive mills are small enterprises, mostly family businesses, scattered around the olive production areas, making individual on-site treatment options unaffordable. Therefore, it is not surprising that OMW treatment has received enormous attention over the past several years and various decontamination technologies based on biological, advanced oxidation, chemical and separation processes have been proposed by several research groups as summarized in a review article (Niaounakis and Halvadakis, 2004).

Coping with the environmental pollution problem, 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. Thus, the present situation is more or less the same, at least in Greece, as in the past: these wastes are led to large pits or discharged into the sea, lakes, rivers, etc., causing destructive environmental implications. 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. The proposed separation techniques (prefiltration, ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO)) of the OMW treatment using membranes filtration have already presented in a previous work by some of the authors (Gigliotti, et. al., 2012; Zirehpour et. al., 2012).

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.

Olive leaves contain several phenolic compounds and derivatives such as oleuropein, tyrosol and hydroxytyrosol (3,4-dihydroxy-phenylenediamine). Nowadays, natural olive leaves and olive leaves extracts (OLE), are marketed as anti-aging, immunostimulators, and even antibiotics. Bioassays support its antibacterial, antifungal, and anti-inflammatory effects at a laboratory level. Because of their beneficent quality, the price of olive leaves can be approximately reached at 2 €/kg. Equally important may be the solution of the conversion of olive tree lops in biomass and energy exploitation. Biomass can be used as fuel for energy production via intermediate products such as bio-ethanol, biogas, methanol, pellets, etc. Emissions such as NOx, SOx and volatile organic compounds from pellet burning equipment, are, in general, very low in comparison to other forms of combustion heating, making this one of the less-polluting heating options available.

Regarding OMW, the idea of using membrane technology is revisited in the present work in which a new cost-effective system for complete exploitation of OMW is suggested, offering a viable solution to the problem of OMW disposal. Use of the proposed separation techniques produces by-products that might have high additional benefits. A pilot plant was developed in an olive mill operating in Achaia region (Patras, Greece) during an olive harvesting season. A feasibility-exploitation study was performed to estimate if the depreciation of the expensive investment may be done in a short period.

Thus, the main objectives of the paper are: (1) to present applicable ways of collection & exploitation of olive tree prunings instead of burning them in-situ, (2) converting them to innovative and high-added value products, following a logic chain of exploitation: Removal of olive leaves (OL) for trading for extraction of useful constituents or for animal feeding, composting of small branches to create organic fertilizer, and conversion of the remaining quantities to pellets for energy production, and (3) to present the most innovative techniques for high-added value products derived from OMW. Through techno-economical and sustainability analyses feasible and sustainable ways for OTP & OTW are finally elucidated.

TECHNO-ECONOMICAL ANALYSES

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.

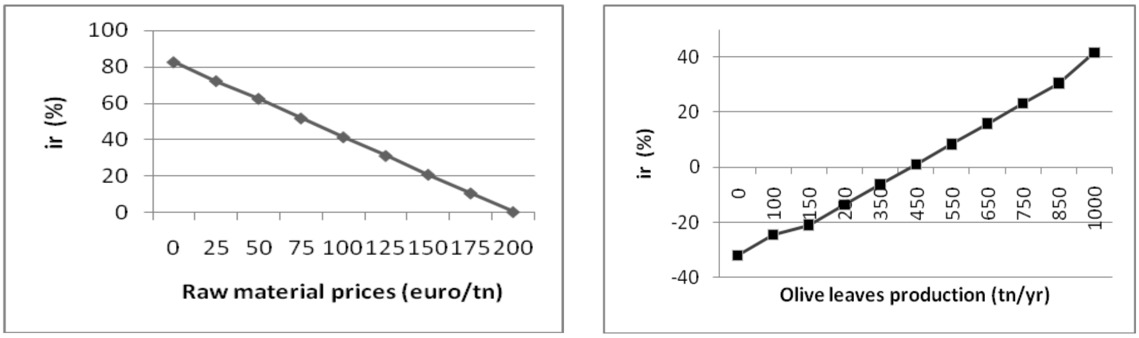

Figure 1. Dependence of the rate of return on investment, i_r, on the raw material value (left) and on the olive leaves' production (right).

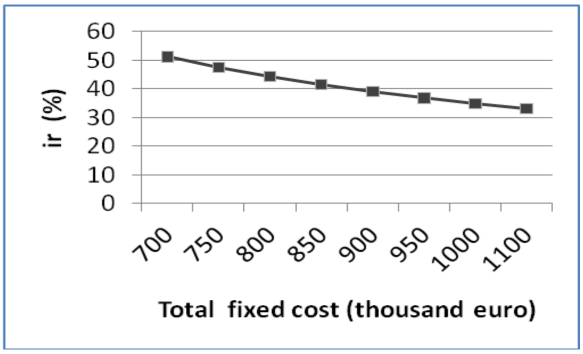

Figure 2. Dependence of the rate of return on investment, i_r, on the fixed cost value.

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 tones 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.

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. 2013). 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/tonne)
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

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.

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