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From the Soil into the Soil - A Closed Cycle of Olive Oil Residues. Future Scenarios and Perspectives

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ABSTRACT

Olive cultivation plays a key role in southern Europe and in Mediterranean areas in terms of economy and culture. Currently, the potential profit from olive cultivation and olive oil production is increasing. This is particularly true in countries where production is characterized by modern, high-density, specialized cultivation, such as in those of the southern Mediterranean. However, one of the factors that hinders the development and profitability of the olive sector is the huge amount of waste produced every year by small and medium-sized olive mills. Olive wastes have been widely viewed as pollutants due to the presence of antimicrobial and phytotoxic compounds, mainly polyphenols. However, it has been proved that the composting process can provide bioremediation of such wastes, avoiding the harmful effects on the soil that can be caused by the spreading of untreated wastes. Composting has been proved to be an effective way to transform olive wastes into valuable, high-quality agricultural amendments and fertilizers particularly suitable for organic farming systems. Composting has also proved to be highly-adaptable so as to suit various countries and their respective, widely-varying production conditions. Moreover, the closed-cycle of composted olive oil residues has been shown to be an environmentally and economically-sustainable process, which could represent a low cost solution for the management and the recycling of olive waste and an additional form of income. Thus, olive waste composting could contribute to increase the competitiveness and the profit of the olive oil industry, and especially for small and medium sized olive farms and mills which are the most affected by the global market competition.

Keywords: composting, treatment of olive residues, OMW management, olive wastes

CONTENTS

INTRODUCTION - ISSUES IN THE OLIVE SECTOR

The olive sector (cultivation and olive oil production), one of the most important agri-food industries, represents part of the heritage of the Mediterranean Basin. It is still of primary importance for rural economies, local traditions and for the environment in many countries on both the northern and southern shores.

Mediterranean countries produce the great majority (around 98%) of the world's olive oil (IOOC 2010) with a remarkably high percentage of agricultural land dedicated to olive groves. Despite the surprising figures, the Mediterranean olive sector is characterized by the substantial presence (especially in Italy, Greece, Turkey, Portugal, France, Tunisia and Syria) of old, scattered, traditional plantations covering an average surface area of 1 ha. These are characterized by low yields, marked alternation in production and very high production costs, which are mainly related to manual pruning and harvesting operations. In addition, 90% of olive mills are small and medium-sized enterprises (SMEs) and are family-owned with less than 10 workers. They tend to have low productivity, limited storage capacity

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and poor profitability and are dotted throughout the territory. The olive sector plays a crucial economic and social role since these olive-growing and processing SMEs are largely located in underdeveloped regions and relatively deprived areas in terms of gross domestic production, purchasing power and employment. During the winter, olive production provides employment on olive farms, in olive mills and in the processing industry.

The Common Agricultural Policy reform and increasing market globalization impose increasing international competition on the olive sector both within the traditional Mediterranean countries and in emerging olive-producing countries. These emerging producers, such as Argentina and Australia, have successfully been able to adopt high-yield methods due mainly to the nature of the territory and to specific development policies. As a result, in some countries (Italy and France, for example) the market retail price of olive oil is steadily falling.

The development policies and strategies, which have been successfully applied by various traditional, Mediterranean, olive-producing countries (including Spain, Morocco, Algeria, Libya, Syria and Jordan) and by a number of emerging countries (such as Australia, Chile and Argentina), have led to a substantial reduction in costs and to greater international competitiveness. This has been done by introducing intensive and super-intensive agriculture practices, by mechanization of pruning and harvesting operations and by the introduction of high-productivity olive mills and storage plants (Alfano *et al*. 2009a).

This type of production is not easy to introduce given the historical and cultural precedents, the nature of large parts of the Mediterranean area and the existing structure of the olive industry. Intensive production facilities and large milling plants still represent only a small fraction of overall production.

In the face of increasing competitiveness and falling retail prices, the path taken by a number of olive farmers and millers is the valorisation of olive-groves, which is only possible in certain geographical production areas. They produce high-quality oils, associated with the area of production which are of greater market value. Quality marks and production indications (Protected Denomination of Origin - PDO and Protected Geographical Indication - PGI) have been created to protect high-quality olive oil produced on a small scale and closely associated to its production area. For example, in Italy there are more than 500 different olive cultivars and more than 40 Protected Denominations of Origin (PDO) and one Protected Geographical Indication (PGI) extra-virgin olive oils (IOOC 2010).

However, the quality marks cited above apparently have some limitations. Extra-virgin olive oil labels have a little information about the chemical composition and nutritional value of the olive oil, but no indication of positive effects on human health that may be conveyed by the bioactive phenol content. The extra-virgin olive oil class is too general and does not currently permit distinction of qualitative differences between different extra-virgin olive oils. Some authors (Servili 2011) have suggested putting not only information on quality parameters such as free fatty acids, peroxides and alkyl-esters into the labels, but also parameters related to positive influences on health, such as α-tocopherol bioactive phenol content. This would allow consumers to distinguish between similar products on the market and could ensure greater competitiveness for the producers of high-quality, extra-virgin olive oils.

THE IMPACT OF OLIVE WASTE

In small–scale production, olive milling is a subscription service offered to farmers and has a cost per unit of olives processed. The cost of milling derives from overheads such as building maintenance costs, facilities, equipment, labor, energy and management of solid and liquid olive waste. A survey at local level in Italy has revealed that the management of olive waste, where the disposal of olive mill waste is regulated by specific laws, is estimated to account for 10-15% of the total milling cost; As an example we estimate that the average cost for processing one ton of olives in 2010 was around €150.00, of which from €15.00 to €22.00 may be attributed to the disposal of olive wastes.

In competitive economic conditions, it, therefore, becomes essential to reduce the costs associated with the management of olive-groves and olive-milling plants. Treatment and disposal of olive mill by-products (especially olive mill wastewater) represents an economic burden and an environmental problem especially for the smaller olive-growing and olive-milling SMEs which constitute the majority of the Mediterranean olive production sector.

A reduction in processing costs could be achieved by sensible management through reuse, recycling and distribution of these olive wastes on fields, with savings on both waste management and fertilizer costs. Therefore, direct, rational management of olive waste would provide a double advantage – a reduction in milling costs and agronomic valorization of olive waste with the return of organic matter to the soils which generated them. This is even more important considering that the EU subsidies system for olive growing and oil production is due to end in 2013.

In the current economic climate, and without financial assistance from the EU, the survival of the olive industry can only be achieved by rationalization of the production processes, leading to reduction in costs and the solution of environmental problems. The reduced availability of EU subsidies and the reduction in prices is forcing olive farmers and millers to find low-cost solutions for the management of olive waste and fertilization of olive groves.

The extraction of olive oil generates huge quantities of waste – up to 30 million m^3 of olive mill wastewater and 20 million tons of olive husks are estimated to be produced per year by Mediterranean countries (Bas Jimenez *et al*. 2000; Boubaker and Ridha 2007). Such wastes have consistently been reported to have a substantial impact on land and water environments. Several studies have proved the negative effect of these wastes on microbial soil populations (Paredes *et al*. 1987; Sidari *et al*. 2010), on aquatic ecosystems (Della Greca *et al*. 2001) and even in the air (Rana *et al*. 2003). The direct application of liquid and solid olive mill wastes to the soil has been seen to have a detrimental effect on the soil's structural stability (Tejada *et al*. 1997). Moreover, olive mill wastes and by-products may also negatively affect seed germination, plant growth and microbial activity. This is mainly due to the phytotoxic and antimicrobial effects of phenols, and organic and fatty acid content (González *et al*. 1990; Riffaldi *et al*. 1993; Ciafardini and Zullo 2003; Alburquerque *et al*. 2004; Roig *et al*. 2006).

A number of basic and applied studies have provided ambiguous and conflicting results on the use of olive mill wastes in agriculture. Often the different experimental conditions adopted have led to inconsistency in results and to difficulty in making comparisons. This may also be due to environmental factors (rain and temperature, for example), the origin of the raw material (olive cultivar), the olive oil production process (press, two- or three-phase continuous systems), agronomic practices such as fertilization and phytosanitary treatments and OW treatment processes (lagooning, evaporation, etc.).

It has been reported that OW contains a high organic load, substantial amounts of plant nutrients and is a low cost source of water (Cegarra *et al*. 1996; Paredes *et al*. 1999; Niaounakis and Halvadakis 2004) which make its use as a fertilizer or organic amendment significant for the poor soils that are frequently found in the countries where it originates (Nunes *et al*. 2001). Furthermore, beneficial effects on soil have been related to the high nutrient content, especially K, and to the potential for mobilizing soil ions (Roig *et al*. 2006).

Germination tests carried out by Riffaldi *et al*. (1993) revealed that after about twenty days even soil amended with the highest dose of sludge obtained from OW no longer displayed toxicity. Saadi *et al*. (2007) reported some direct short-term effects of OMW application on soil phytotoxicity, but the soil had partly or completely recovered between successive applications. No phytotoxicity was observed three months after OW application. Microbial activity in soil has been reported to be stimulated by controlled OMW application. In general, the spreading of OW caused slightly positive modifications to the microbial biomass and activity in the soil. This was probably related to the consumption of readily available C sources in these wastes. These modifications were temporary and disappeared as early as a few months after the treatment (Gamba *et al.* 2005; Saadi *et al.* 2007).

Several studies suggest that the problem of the negative impact of olive mill wastes should be reconsidered and approached from a slightly different perspective.

The phytotoxicity of olive waste has been mainly studied and reported on with regard to seed germination and early plant growth of different species, including barley, tomato, lettuce and wheat (Pérez *et al.* 1986; Niaounakis and Halvadakis 2004; Komilis *et al.* 2005; Bonanomi *et al.* 2006). Even the germination index proposed by Zucconi *et al.* (1981), to evaluate compost maturity considers the germination of seeds of *Lepidium sativum*. In terms of phytotoxic risk, it would be necessary, therefore, to take into account the nature (woody or herbaceous) and type (cultivar) of the crops subjected to OW application. In fact, the phytotoxic risk to woody plants appears to be limited. No harmful effect on olive trees (Ben Rouina *et al.* 1999; Ouzounidou *et al.* 2010), or on olive grove growth or yield (Altieri *et al.* 2008) have been reported. However, the distribution of high doses (6-8 liters per pot) of OW caused the death of young olive plants (Ben Rouina *et al.* 1999).

The controlled distribution of OW into olive groves, and especially into highly-intensive, specialized olive groves not associated with other crops (barley or grapes) could represent a valid solution for the management and exploitation of such wastes. Since olive wastes are of pure vegetable origin, recycling them into agricultural ecosystems seems to be reasonable environmentally and feasible financially (Ouzounidou *et al.* 2010).

Irrigation of fields with raw OW is a relatively inexpensive disposal technique (Cegarra *et al.* 1996; Niaounakis and Halvadakis 2004) that could be implemented by small-sized, three-phase, centrifugal olive mills. Moreover, it could convey significant advantages to the soil, such as the enhancement of soil fertility and the improvement of the physical and chemical properties of the soil, the improvement of organic matter in the soil and nutrient content (mainly K, but also N, P and Mg) and the enhancement of microbial activity (Klammer *et al.* 2005). It would also represent a valuable, low-cost source of water, taking into account the increasing scarcity of water resources for irrigation (Tomati and Galli 1992; Niaounakis and Halvadakis 2004). This is particularly true for certain Mediterranean olive oil producing regions, where there is a significant water shortage during the dry season. Further, high-tech techniques to treat OW, as are occasionally cited in the literature, are not usually feasible for olive mill owners to adopt (Komilis *et al.* 2005). Hence, our proposal, for the distribution of the olive waste to the olive groves for re-use within the olive farm so as to close the cycle residue-resource, could be adopted as a two-fold solution - the controlled distribution of untreated olive wastes and microbiological stabilization through the composting of olive wastes.

A CLOSED CYCLE OF OLIVE OIL RESIDUES

The ripe olives, if not harvested, would normally fall from the tree and into the soil. They would be subjected to microbial degradation phenomena that would provide organic matter and nutritive substances to the soil and soil microorganisms, restoring and perpetuating soil fertility over time. Olive oil production, but in a broader sense all agricultural production, results in the removal and loss of organic matter (in this case the olives) from the originating soil. In order to restore fertility and organic content to the agricultural soils, modern agriculture makes heavy use of synthetic chemical fertilizers from non-renewable energy sources (petrol and oil) which are produced, in most cases, a long way from the place of final use. This worsens further when intensive agricultural techniques are adopted. The gradual expansion of high and very high- density olive farming systems both in some traditional production countries of the Mediterranean Basin, such as Spain, Morocco and some southern regions in Italy, as well as in some emerging producers, such as Australia and the USA, causes massive loss of organic matter (the olives) from the originating soils and at the same time leads to a high concentration of organic matter in limited areas adjacent to the olive mills. After oil extraction, the remaining parts of the olives (the husks, wastewater, leaves and twigs) are generally not returned to the soil from which they originated. In the majority of cases, especially for smaller olive mills, they are improperly or wastefully disposed of, spread, or treated, causing further risks to the environment.

These habits lead to a "distortion" in soil fertility, which must be restored and maintained by consistent use of chemical fertilizers. Environmental sustainability is also brought into question due to the great reliance on chemical fertilizers, which are derived from non-renewable energy sources. Similarly, the potential pollutant effect of phytotoxic and antimicrobial activity when olive wastes are improperly distributed can temporarily cause critical imbalances in soil conditions.

As a result there is an increase in management costs for the whole olive production chain. Olive farmers must manage and protect soil fertility and oil producers are responsible for the management of the high levels of olive waste that remains after processing.

Many different methods have been proposed to treat solid, semi-solid and liquid olive residues (Kalderis and Diamadopoulos 2010). These include - lagoons (Niaounakis and Halvadakis 2004), flocculation-clarification (Zouari 1998; Roig *et al.* 2006), ultrafiltration/reverse osmosis (Niaounakis and Halvadakis 2004), thermal concentration and evaporation (Netty and Wlassics 1995; Vitolo *et al.* 1999), incineration and combustion (Vitolo *et al.* 1999; Roig *et al.* 2006), combustion and gasification (Caputo *et al.* 2003; Roig *et al.* 2006), anaerobic digestion (Hamdi 1996; Rozzi and Malpei 1996; Marques 2001; Filidei *et al.* 2003; Roig *et al.* 2006; McNamara *et al.* 2008), extraction of valuable compounds including phenolic compounds, squalene and tocopherols, triterpenes, pectins and oligosaccharides, mannitol, polymerin (Fernández-Bolaños *et al.* 2006; De Leonardis *et al.* 2008), bioconversion to high added-value products including vitamins (Fernández-Bolaños *et al.* 2006), exopolisaccharides (Ruíz-Bravo *et al.* 2001), enzymes (Ramachandran *et al.* 2004; Fernández-Bolaños *et al.* 2006; Morillo *et al.* 2009), biopolymers (Dionisi *et al.* 2005; Fernández-Bolaños *et al.* 2006; Morillo *et al.* 2009), biofuels (Fernández-Bolaños *et al.* 2006; Roig *et al.* 2006; McNamara *et al.* 2008; Morillo *et al.* 2009). Unfortunately all these suggested methods have proved unable to completely resolve the problem because of the need for disposal of sludge deriving from the processes themselves (Paredes *et al.* 2002). High costs also make these methods uneconomical for the small-scale olive mills which constitute the majority of the olive industry in the Mediterranean Basin.

Therefore, until now, the preferred method for the disposal of olive waste has been field application, which can have a negative environmental impact and, moreover, does not allow for the energetic and economic valorization which could be derived from the proper management of olive waste. It is well known that olive waste contains valuable resources, including a large proportion of organic matter, a wide range of nutrients and high, added-value antioxidants, which could all be utilised.

The extensive research carried out on the composting of olive waste in the last 20 years clearly suggests and emphasizes the composting approach as one of the most promising.

It would be feasible to use composting for the treatment and valorization of all olive wastes (Baeta-Hall *et al*. 2005; Roig *et al*. 2006; Alfano *et al*. 2009a, 2009b). The composting of olive waste has been proved to be compatible ecologically and economically sustainable, combining the recovery of valuable resources with environmental protection. The various technological solutions already proposed to regulate temperature control, air supply and for mixing and turning, as well as the time required for composting (Paredes *et al*. 2002; Principi *et al*. 2003; Baeta Hall *et al*. 2005; Cayuela *et al*. 2006; Alfano *et al*. 2008, 2009a, 2009b) have enabled satisfactory performance in terms of plant management, ease of use and manageability of equipment, in addition to generating the appropriate quality of cured composts. Clearly, in terms of parity of results, the difference between the technological solutions proposed is shown by the relative costs of building and management of the relevant facilities. The type of plant and technological composting solutions which have already been developed would permit adaptation of this process to the most diverse environmental, technological and economic conditions (Ahmad *et al*. 2007). As a result, given its versatility, olive-waste composting has been proved to be easily adoptable in, and adaptable to, agricultural and olive milling SMEs, which often do not have significant labor and economic resources, and for which it may represent an additional form of income (Cayuela *et al*. 2006; Alfano *et al.* 2008, 2009a). Especially as far as the small and medium-sized olive farms and milling plants that constitute the majority of the Mediterranean olive industry are concerned, composting may be a suitable, low-cost strategy for the recycling of olive mill wastes within agricultural SMEs (Cayuela *et al.* 2006; Alfano *et al*. 2008).

Composting of solid, semi-solid and liquid olive residues permits nutrients to be returned to land used for crops, while avoiding the negative effects which may be caused by wastes when directly applied to soils (Baeta-Hall *et al.* 2005). The high purity of olive mill wastes (lacking in recalcitrant toxic substances and hazardous microorganisms) ensures the quality and competitiveness of composts made from the biological transformation of these residues (Roig *et al*. 2006).

Moreover, the majority of olive oil producing countries in the Mediterranean area are exposed to desertification processes, so the application of organic matter would be beneficial in improving soil fertility and controlling erosive processes. Furthermore, the use of these by-products could represent an important source of nutrients in organic agriculture, closing the residue-resource cycle. Therefore, the use of olive mill wastes as soil conditioners or fertilizers can play a fundamental role in the maintenance of the olive tree ecosystem and in sustainable agriculture (Roig *et al.* 2006).

QUALITY STANDARDS FOR OLIVE MILL WASTE COMPOST

Almost every country has its own legislation and or regulations for compost quality standard and marketability that often vary greatly with consequent non-uniform application of generally accepted guidelines (Alfano *et al*. 2009). Quality standards of European countries refer to compost produced from organic substrates from different origin, including sewage sludge, municipal solid waste, industrial, agricultural and zootechnical waste. In this sense, European countries regulations consider several quality parameters for different types of compost and among these the most important is the heavy metals content. Unfortunately, the heavy metals content limit largely differ from country to another (Centemero and Perelli 2011).

Olive wastes from milling and farming activities do not contain heavymetals, toxic pollutants, potential human pathogens and is entirely constituted by "clean" plant residues, which do not cause risks for the environment or human health. Thus, composted olive waste is particularly suitable to be used as agricultural fertilizer or amendment (Aviani *et al*. 2010). Beside the conventional biological, microbiological, chemical and physical parameters used to assess the quality of the composts, many authors propose several useful parameters to improve the determination of the quality of OW composts, including enzymatic activities (β-glucosidase, arylsulphatase, acid-phosphatase, alkaline-phosphatase, urease and fluorescein diacetate hydrolysis) (Cayeula *et al*. 2008; Fourti *et al*. 2008), electrical conductivity and saline content (Hachicha *et al*. 2008).

Table 1 Cost of olive waste composting (%).

Piles preparation	4-10
OW transport	2-5
Labour	2-5
Turning machine	40-60
Turning operations	8-10
Gasoline	1-2
Labour	7-8
Emission recycling plant	15-20

COST OF OLIVE WASTE COMPOSTING

On the basis of previous experiences (Alfano *et al*. 2008) the total cost of olive waste composting is made up of several items (**Table 1**). The disaggregated costs breakdown and their percentage contribution to the total cost reveal how the turning machine and the emission recycling plant weigh heavily on the overall cost. However, on the basis of our experiences, it should be taken into account that more productive cycles would lead to the sharing of such costs. In fact, considering an allowance of 15 years depreciation for the turning machine and the emission recycling plant, the estimated cost of the cured compost would be between 0.08 and 0.10 Euro kg^{-1}, and after additional costs for packaging and selling the final estimated retail price would be around 0.12-0.20 Euro kg^{-1}.

THE BENEFITS OF COMPOSTING OLIVE WASTES

Various benefits are apparent and are listed according to their effect on the environment, agriculture, energy saving and health:

Protection of the environment

Although the direct application of olive mill wastes into the soil may be interpreted as recycling nutrients and organic matter, it can have a negative impact on existing plants (Niaounakis and Halvadakis 2006; Kavdir and Killi 2008), on microbial population, on microbial activity in the soil (Alburquerque *et al*. 2004; Komilis *et al*. 2005), on aquatic ecosystems (Della Greca *et al*. 2001) and even in the air (Rana *et al*. 2003). This is due to the phenolic, fatty acid and mineral salt content, as well as the high COD and BOD_5 (Alburquerque *et al*. 2004; Vlyssides *et al*. 2004; Roig *et al*. 2006; Boubaker and Ridha 2007; Kavdir and Killi 2008). Composting permits the return of nutrients to land used for crops, while avoiding the negative effects that can be caused by the direct application of olive wastes to soils.

Preservation of the water supply

Nitrogen compounds in composts are mainly present in organic form. They are bound and are not easily leached (Abu-Zreig and Al-Widyan 2002). The use of compost in agriculture leads to the protection of rivers, streams and aquifers from nitrate pollution deriving from nitrate fertilization of soils which can easily reach streams and groundwater supplies. The water supply is also protected as a result of the reduction in the amount of chemical fertilizers and pesticides applied to olive groves. Furthermore, the use of olive mill wastewater for fertirrigation of crops or to water compost piles permits water to be saved. This is especially significant considering the nature of the Mediterranean area, which is often characterized by scarcity of water.

Preservation of the soil

The return of composted olive waste to originating olive groves is the most highly-sustainable solution. It preserves soils, maintains soil fertility and represents closure of the residue-resource cycle. The use of olive waste compost leads to an improvement in soil structure, porosity, water-retention capacity and fertility (Baeta-Hall *et al*. 2005; Alburquerque *et al*. 2007). This is of particular importance in the Mediterranean Basin, where the majority of olive grove soils are characterized by very low levels of organic matter, and, hence, are exposed to progressive degradation processes (Alfano *et al*. 2009a, 2009b). The application of organic matter is required, therefore, to compensate for this C deficiency and to improve the properties of the soil (Abu-Zreig and Al-Widyan 2002).

Reduction in the use of chemical and organic fertilizers

Currently, in order to restore soil fertility to olive groves, especially those that are intensively-cultivated, every year vast quantities of chemical and organic fertilizers and amendments are used on soils. However, the application of olive-waste compost would suitably close the residue-resource cycle and should be used both as an amendment to olive grove soil and to increase fertility (Alfano *et al.* 2009a).

Reduction in the use of pesticides

Compost, has a residual, beneficial microbial population, so could also be used as an alternative means of controlling plant pathogens (Lumsden *et al*. 1986; Noble and Coventry 2005; Hoitink and Boehm 1999). A number of scientific studies have provided evidence of the disease-suppressive effect of compost from olive mill residues on several soil-borne plant pathogens (Cayuela *et al*. 2008; Lima *et al.* 2008; Alfano *et al*. 2009a, 2009b; Alfano *et al*. 2011). For this reason composted olive by-products are highly- promising for use to control fungal pathogens of olives and other crops in both organic and integrated cultivation.

Improvement in production quality

Given it is the biosuppressiveness and biofertilization effects of olive-waste composts (Noble and Coventry 2005), their use should lead to a direct reduction in the use of chemical fertilizers and pesticides. The subsequent reduction in toxic residues in agri-food production would result in an overall increase in the quality of table olives and olive oil.

Economic savings for SMEs

The drastic reduction in disposal costs by composting wastes, together with the valorization of olive mill residues as resources (as high-quality fertilizer) would represent significant savings for SMEs. On-site valorization through use of small-scale technology is one of the most suitable solutions to close the 'olive farm-olive mill' cycle. The reuse, at zero km, of olive waste conveys significant economic benefits. These are derived from the reduction in management and transport costs, and a reduction in the need for organic and chemical fertilizers to be used. Presently-used solutions for disposal outside the olive farm or mill, result in the economic and agronomic loss of the intrinsic value of the waste and an increase in transport costs.

Reduction in the costs of fertilizers and pesticides

Olive farmers are forced to bear the high costs of chemical and organic fertilizers and amenders for the maintenance of soil fertility and for the protection of crops from plant-pathogens every year. Especially at the present time as the cost of fertilizers are increasing due to rising of costs of energy and fuel from non-renewable sources.

Current climatic changes, and, particularly, global warming, could cause the northward expansion of the areas potentially suitable for olive growing. Expansion to northern latitudes may thus become the trend for olive growing in the near future. Areas that are currently considered unsuitable for olive cultivation are likely to become so in the future. It is, therefore, quite possible that interest will develop in the use of composted olive waste on several different crops, which are traditionally present in these areas (apple, pear, etc.). Thus, composted olive waste could also be used for fertilization and biocontrol of plant pathogens in a variety of forms of organic agriculture, which are entirely separate from olive growing.

Use as a substitute for peat

Peat moss is the most widely-used horticultural growing media. It is well suited to a wide range of plant species and growing regimes, and is used in the production of ornamental plants as well as fruit and vegetable seedlings and container-grown stock (Arvanitoyannis and Kassaveti 2007; Ben Jenana *et al*. 2009). The role of peat bogs in the assimilation of atmospheric CO_2 calls for replacement of peat with other, renewable organic substrates (Yogev *et al*. 2006).

To this extent, under the Biodiversity Action Plan, the UK Government is committed to facilitating research into, and the development of, sustainable alternatives to peat and to encourage the development and marketing of peat alternatives (UKBAP 2010). The UK Department for Environment Food and Rural Affairs (DEFRA) has developed a project to phase out peat from nursery and garden media by 2020. In particular, the objective is to remove peat from public garden maintenance by 2015, from the gardening market by 2020 and from the professional market by 2030. The UK government's ACT ON CO_2 campaign is encouraging gardeners to use peat-free compost for green gardening (DEFRA 2010).

In addition, peat is especially conducive to a wide variety of soil-borne pathogens (Hoitink and Boehm 1999). Composts, unlike peat which is not a significant source of plant nutrients, not only supply substantial quantities of nutrients (Raviv *et al*. 2002), but may also suppress soil-borne pathogens (Hoitink and Boehm 1999; Raviv *et al.* 2005; Yogev *et al.* 2006).

Olive waste composts, and, more generally, all composts, have been reported as having the appropriate characteristics to replace and reduce the use of peat effectively as an organic component in gardening and nursery media (Ostos *et al*. 2008; Ben Jenana *et al*. 2009).

CONCLUSIONS AND PERSPECTIVES

Numerous solutions are already available and allow for full adaptability of the process to any environmental, structural and economic conditions. Unfortunately, both olive producers and millers are often unaware of the best solution available, due to the small size of the company they run or to the local context in which they operate. To this extent, it is necessary to educate and inform the producers and the associated institutions about the environmental and energy issues involved and to promote the rationalization of production. This must be done taking into account the technological opportunities available and the potential revenue streams that could result from different systems of production. This could be achieved through:

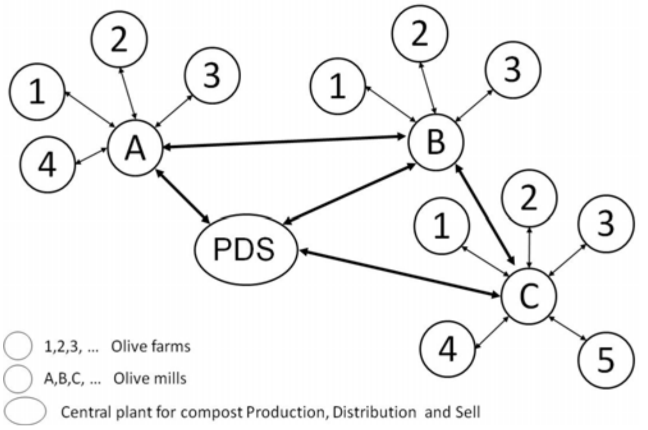

Fig. 1 Integrated olive waste management. Pattern for a local consortium processing plants for the treatment of olive mill wastes and agri-food residues (Vlyssides *et al*. 2004 modified).

Information, advice and training

Associations of olive growers and olive oil producers, in cooperation with local institutions, should play a key role in raising awareness and in providing information and training. Detailed information, suitable advice and effective training must be given to olive farmers on environmentally-beneficial practices. Currently, this only takes place on an extremely-limited scale. A promising avenue might be the establishment of farm associations which would employ their own technical adviser (usually with financial aid from the government) as already occurs under the Integrated Production Associations (API) scheme in Andalucía. By creating a much more direct link between the farmer and a specialist adviser, this system may be more effective than conventional farm advisory services or occasional training courses and information campaigns.

Creation of consortia for composting and sale of cured composts

The promotion of local associations between farmers, olive growers, olive millers and stakeholders for the valorization of organic residues produced in the area would also serve to raise the awareness of local institutions, entrepreneurs, operators in the sector and final consumers. Local consortium processing plants could be set up for the treatment of olive mill wastes and agri-food residues coming from the businesses in the area. The aim of the consortium plants would be to treat the organic residues coming from members of the association and the consortium, guaranteeing return of the composted residues to the originating producers, who would re-use them at zero km for soil fertilization, as well as to sell the compost to support the association and consortium's activities (**Fig. 1**).

Incentive policies

Through appropriate forms of financing and incentives, public institutions and local government could promote integrated, rationalized, privately-managed companies for the treatment and valorization of agricultural resources, including olive-mill wastes. This could lead to the establishment of a virtuous cycle in terms of environmental protection and economic growth with the creation of business activities and employment opportunities.

Advertising campaigns

Advertising campaigns could also make a significant contribution by increasing final consumer awareness of environmental protection, of the sustainability of agricultural production and of healthy food. It would result in the promotion of an approach to agricultural resources that would require integrated and rationalized treatment, including that of olive mill wastes.

This in turn, would also encourage the competent authorities to provide incentives and to promote policies for environmental protection and for the valorization and utilization of local agri-food wastes.

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