Chapter 9

Olive Mill By-Products Management

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Additional information is available at the end of the chapter

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1. Introduction

Among the Mediterranean countries, Italy results to be the second after the Spain for the olive and olive oil production (FAOSTAT, 2012), with around 1.2 million of olive grove hectares, by 80% displaced in the Italian southern regions (ISTAT, 2010). In the olive oil industry, the oil extraction is carried out in oil mills, which are classified in pressure mills, and in continuous “two” or “three” phases way mills. In all milling typologies, only not over the 20% of processed olives constitute the oil production, while the milling by-products, wastewater and pomace, represents up to 120% of processed olives. These wastes could constitute a problem for their sustainable disposal as well as a resource for soil C stabilization and sequestration, energy generation or production of value-add compounds for the food, pharmaceutical or cosmetic industries.

A great part of husks derived by pressure and three phases mills is still destined to the industry for the extraction of residual oil through solvents (n-exane: $CH_3(CH_2)_4CH_3$). The residual defatted pomace is used as fuel in cogenerative processes (heat and electric power generation) or, as well as the two phases mill husks (fluid pomace) and olive mill wastewaters, disposed on soil as amendments, both raw and after composting. In the Mediterranean countries, where soils have frequently problems of organic matter lack, and active desertification processes, the recycle of the olive wastes as amendments should be better and more important to protect the environment being a valid alternative and a useful solution to the problems both of sustainable utilization of byproducts and soil fertility conservation.

In many experimental trials carried out in many sites, the utilization of olive industry byproducts as organic amendments, raw or stabilized through the aerobic fermentation, frequently showed good agronomic efficiency, in terms of fertility and chemical, physic and microbiological characteristics of the soils as well as crops productivity; generally pointing out some negative effects of fermentable organic matter and better findings using stabilized wastes.

Althought in literature can be found numerous findings on the influence of raw and composted organic materials on soil fertility and crops growth, only few published studies are focused on influences of waste waters and pomace compost on the soil-plant system, for a sustainable crops production.

In this chapter on report the state of the art of the by-products composting, and results of some application of raw and composted olive industry by-products on soil and crops.

2. Olive mill wastes

The olive mill byproducts are classified, according to the different systems of olive oil extraction, as: Olive mill Waste Waters (WW); Virgin Olive Pomace (OP), by pressure mills (OPP), with around 30% moisture; by centrifugal "three phases" mills (OP3), with around 50% moisture; or by centrifugal "two phases" mills (OP2), with moisture more than 60%. The Solid Defatted Pomace (SDP), is the byproduct of the pomace industry, after the extraction with solvents of the residual oil from virgin pomace.

2.1. Waste waters characteristics and treatments

The waste waters constitute the liquid fraction of the olive mill byproducts and are composed by the olives water content and by the waters used in the milling (olives and equipments washing waters and the waters of dilution process in the three phases centrifugal systems). As reported in Table 1, the different extraction systems produce, from 100 kg of processed olives, around 10 liters of waste waters for the two phases system, around 55 liters for the pressure crushers, and more than 100 litres for the continuous three phases system, that they reduce to only 35 litres in case of recycle of water.

Milling technology	H_2O added (%)	Pomace (kg/100 kg olive)	Pomace moisture (%)	Waste waters (kg/100 kg olive)
3 phase continuous	50	55-57	48-54	80-110
Pressure	0-10	30-35	25-30	56-58
2 phase	0-10	75-80	60-70	10
3 phase with water recycle	0-20	56-60	50-52	33-35

Table 1. Mass balance in the olive oil extraction

The main characteristic of WW is the presence of organic compounds such as organic acids, lipids, alcohols and polyphenols that turn it into phytotoxic materials, that might have unfavourable impact on plants (Capasso et al., 1992; Kavdir & Killi, 2008). It also represents a great environmental hazard if not properly managed. However, WW contain valuable resources, such as a high organic matter concentration and some nutrients, especially potassium, that could be usefully used to improve the physic-chemical and biological properties and then soil fertility and productivity; representing a valid option to close the residue-resource cycle (Roig et al., 2006). In Table 2 are reported the averages of main chemical WW characteristics, given by several Authors (Aktas et al., 2001; Filidei et al., 2003; Moreno et al., 1987; Paredes et al., 1999; Piperidou et al., 2000; Saviozzi et al., 1991; Vlyssides et al., 1996; Vlyssides et al., 2004 – as cited in Roig et al., 2006).

Dry matter (%)	6.75
pH	4.84
EC (dS/m)	8.36
O.M. (g l^{-1})	55.80
TOC (g l^{-1})	37.00
TN (g l^{-1})	0.97
P_2O_5 (g l^{-1})	0.56
K_2O (g l^{-1})	4.82
Na (g l^{-1})	0.25
Ca (g l^{-1})	0.35
Mg (mg l^{-1})	121.25
Fe (mg l^{-1})	81.70
Cu (mg l^{-1})	3.15
Mn (mg l^{-1})	6.13
Zn (mg l^{-1})	6.13
d (g $cm^{3\ -1}$)	1.04
Lipids (g l^{-1})	6.38
Poliphenols (g l^{-1})	4.98
Carbohydrates (g l^{-1})	7.16
COD (g l^{-1})	124.67
BOD_5 (g l^{-1})	65.00

Table 2. Average composition of olive mill waste waters.

About the microbiological characterization, the results of different analyses performed on different kind of WW, have individualized 130 species of lipolytic microorganisms (56 Fungi, 22 Yeasts, and 52 Bacteria), cellulolytic Bacteria and pectinolytic Fungi, while not are resulting the nitrificants nor the actinomycetes (Pacifico, 1989; Ramos-Cormenzana, 1986).

For the waste waters treatment have been proposed both physic-chemical and biological processes (Amirante & Di Rienzo, 1993; McNamara et al., 2008; Rozzi & Malpei, 1996; Vigo et al., 1990; Vitolo et al., 1999).

Among the first ones, finalized to the volumes reduction, and to the mineralization of organic compounds, they are:

- distillation, filtering or flocculation and disposal in the water bodies;
- evaporation and agronomic utilization of concentrated material;
- raw application on the soil;

- adoption of two phases mills, and management of the fluid pomaces.

The biological treatments of purification include both aerobic and anaerobic processes. The aerobic biological treatments are based on the microbic degradative activity that transform the decomposable organic matter in not pollutants mineral elements and humus-like substances.

The anaerobic processes are characterized by microbial pools that works in absence of oxygen, converting the organic polluting substances in biogas (methane) and carbon dioxide or in hydrogenated volatile substances (fatty acids and alcohols), (Filidei et al., 2003). Three main physiological groups of microorganisms are involved: fermenting bacteria, organic acid oxidizing bacteria, and methanogenic archaea. Microorganisms degrade organic matter with a sequence of biochemical conversions to methane and carbon dioxide. Syntrophic relationships between hydrogen producers (acetogens) and hydrogen scavengers (homoacetogens, hydrogenotrophic methanogens, etc.) are critical to the process. A wide variety of process applications for biomethanation of wastewaters, slurries, and solid waste have been developed. They vary from the simple WW open-air storage to the treatment in Completely Stirred Tank Reactor (CSTR) through co-digestion with others organic matrixes, up to treatments in special digesters, as UASB reactors (Up-flow Anaerobic Sludge Blanket) and with different process conditions (retention times, loading rates, temperatures, etc.) to maximize the biogas production (Angelidaki et al., 2011).

Even if these treatments are able to demolish the WW polluting power, in the practice they are often not economically sustainable. The seasonality of WW production and the characteristics of biological toxicity, make difficult the management of their treatment in the purification installations of the urban waters. Conversely, the relative low quantity produced by single milling plants do not make economic WW purification in specific installations.

The WW open-air storage is the simplest and economic system of storage and treatment. During the open-air storage by the action of aerobes and anaerobes microorganisms, it will be partially purified and stabilized. However, the WW open-air storage require ample surfaces away from inhabited centers, for the stink development, and exposes to risks of soil and subsoil water contamination, if the basins are not correctly waterproofed (Catalano et al., 1985).

In fact, these wastes can constitute a "secondary raw materials", to be consider as a resource, being of a vegetable origin, which have not undergone chemical manipulations nor received additives, and therefore without pathogenic microorganisms and viruses, as well as pollutants or toxic products. The optimal operative option results therefore to be the agronomic utilization of the WW that, when correctly managed, allows to exploit its fertilizing characteristics with low costs of management, reducing the risks of environmental pollution.

Many studies have been conducted on soil application both on olive orchard and herbaceous crops, studying differing time and doses of WW application. The results showed both the agronomic benefits and the limitations of raw WW disposal. When correctly managed, the WW application on soil generally results increasing the organic matter, phosphorus and potassium content; improving both physical and hydraulic soil properties as well as the crop yield (Alianiello et al., 1998; Andrich et al., 1992; A.R.S.S.A., 2001; Ben Rouina et al., 1999; Bonari et al., 1993; Catalano et al., 1985; Di Giovacchino & Seghetti, 1990; Di Giovacchino et al., 2001; Levi-Minzi et al., 1992; Montemurro et al., 2007, 2011; Saviozzi et al., 1991; Tamburino et al., 1999; Tomati & Galli, 1992).

Another option concerns WW composting through biological processes of aerobic stabilization, on supporting matrixes with adequate physical and mechanical properties (porosity, structure, texture), to allow the reactions of bio-oxidation in the solid phase. In this way it is possible to obtain a not phytotoxic organic material, humus-like partially transformed, that could be used in fertilization plans to restore or maintain soil fertility on partial or total substitution of mineral fertilizers (Benitez et al., 1997; Filippi et al., 2002; Galli et al., 1997; Paredes et al., 2002; Tomati et al., 1995; Vallini et al., 2001).

2.1.1. Waste Waters agronomical value

The WW contain appreciable amount of mineral elements and organic substances, and can be considered as liquid amendments by vegetal origin. WW application to the soil could realize the double purpose to allow a natural chemical and biological degradation and to enrich the soil in organic matter and in mineral elements. This means that the agronomical use of these waters represents one of the most effective systems to decrease their BOD_5. For this reason, the elevated values of WW BOD_5 and COD that make extremely risky WW disposal in surface or ground water bodies, would come to lose importance in the case of soil distribution. The WW poliphenols, held substances of elevated polluting power in the case of disposal in the surface and ground water bodies, do not represent a pollution factor for the soil, being instead precursory in the synthesis of humic substances that represent the most active fractions of soil organic matter with important role in soil organic fertility and protection from synthetic organic contaminating, as pesticides and heavy metals.

For this, the most effective option appears to be the use of WW as liquid organic amendment or fertigant, and the WW recycle in soil could be a valid alternative to other depurative treatments. In fact, WW affect positively crop performances, of olive, grapevine and cereals, when distributed in dates and doses selected through rigorous agronomical criteria.

On the contrary, an incorrect WW management, may cause temporary immobilisation of soil mineral nitrogen and, consequently, crop yield reduction, due to the deficiency of N uptake by the plants; also increasing environmental pollution risks. To avoid these effects, the maximum amount of waste water that can be applied is restricted by the Italian law to 50 and 80 $m^3\ ha^{-1}\ yr^{-1}$, for the pressure and continuous milling systems, respectively.

Phytotoxic effects can also be avoided applying simple and few expensive WW pretreatment before the application to the soil, using biological or mineral catalysts, or submitting them to suitable composting processes, mixed with other organic by-products.

The stabilization of WW through composting on effect with repeated saturation of supporting materials with suitable physical-mechanics characteristics (porosity, structure, texture) as straws, leaves, sawdust, rapiers, or pomace, to maintain a moisture level useful to the bioxidative reactions (Benitez et al., 1997; Garcia-Gomez et al., 2003; Paredes et al., 2000; Tomati et al., 1995; Vallini et al., 2001).

In this way, on allow on the WW the bioxidative reactions in solid phase, handling to a final product, without phytotoxic effects, useful in the agricultural soils as organic amendment.

2.1.2. Waste Water effects on the herbaceous crops

The effects of the WW distribution on soils destined to herbaceous crops, vary according to the WW composition, the quantity, the distribution dates in relationship to seeding or crop phenologic stage, the rainfall after the WW supply.

The olive mill WW do not generally affect the productivity of the spring-summer crops, when the shedding is effected with an adequate interval time before the seeding. It is also possible to distribute the WW with crop in action, i.e. on autumn-winters cereals, in the full growth phase, limiting the WW doses to not over 40 m^3 ha^{-1} (Bonari et al., 1993; Di Giovacchino & Seghetti, 1990; Di Giovacchino et al., 2001; Marsilio et al., 1990; Montemurro et al., 2007, 2011*a*; Roig et al., 2006).

Negative effects on grass crops are due to the elevated values of electrical conductivity, that can induce salinity damages, flocculation of soil clay fraction, the phytotoxicity of poliphenols (Della Monica et al., 1978, 1979).

In the last years, because of environmental protection policy, new technologies that minimize these risks were developed. In this framework, the raw olive waste water was differently treated to improve the percentage of recycle of these materials. In particular, different studies indicate that the application of mineral catalyser (MnO_x) on WW reduces the level of poliphenols and other pollutants. As a consequence, this treatment decreases both phytotoxicity and temporary immobilization of soil mineral N, thus making the treated WW able to sustain good levels of crops yield and products quality (Montemurro et al., 2007; Vigo et al, 1990).

2.1.3. Waste Water effects on the olive crop

Many experiences have confirmed the possibility to distribute the WW on the olive grove more than over 400 m^3 ha^{-1} without significant variations of vital parameters as the photosynthetic activity, transpiration, stomatic conductance, leaves carbohydrates and chlorophylls content. Conversely, improvements of the productivity on treated plants was frequently observed. A decrease of the vegetative development has been recorded only on young plants raised in pots and treated with higher WW doses (Proietti et al., 1988).

The organic matter content in WW treated soil always results greater in comparison to the untreated control, with greater nitrogen contents and more elevated C/N ratio.

In the soils treated with WW a greater presence of the total microflora was found (Fungi and other microbial groups), as well as an increase of respiratory and enzymatic activities. These findings showed the absence of toxicity of the WW towards the microorganisms, and the improvement of soil fertility. Moreover, the findings of different researches indicate the increase in organic matter and nutrient contents, an improvement in the aggregate stability and, as a consequence, a better physical soil properties.

In order to the possible ground water pollution, other results have shown that also up to 500 m^3 ha^{-1} of WW application do not represent a pollution danger of the surface water in the clay soils. (Andrich et al., 1992; Ben Rouina et al., 1999; Briccoli-Bati & Lombardo, 1990; Lombardo et al., 1995; Palliotti & Proietti, 1992).

2.2. Pomace characteristics and treatments

The olive pomace is composed of fruit matter (olive skins, flesh, seeds and stone fragments), and of different amount of vegetation and process water which contains the water-soluble constituents of the fruits, in order to the extraction system used.

The OPP and OP3 are usually destined to the pomace industry, for the extraction of residual oil by solvents; and then used as fuel, also in cogenerative processes (Molinari & Bonfà, 2005). These by-products could also be used as animal food, or in biodegradative processes to produce ethanol (Ballesteros et al., 2002), or compost for agricultural utilization. Nevertheless the olive pomace, being constituted by vegetable not fermented organic matter, does not contain heavy metals, toxic pollutants or pathogens, and can be considered as a vegetable amendment (Table 3), (Alburquerque, et al. 2004). Therefore, it can be used in the agricultural soils without any treatment, as allowed by the current normative (Law 574/1996).

Parameters	**Range**
Humidity %	55 - 75
pH (H_2O)	4.8 – 6.5
EC (dS m^{-1})	0.9 – 4.7
Ash (g kg^{-1})	24 - 151
TOC (g kg^{-1})	495 - 539
C/N ratio	28 - 73
Total N (g kg^{-1})	7 - 18
P(g kg^{-1})	0.7 – 2.2
K(g kg^{-1})	7.7 – 29.7
Ca(g kg^{-1})	1.7 – 9.2
Mg(g kg^{-1})	0.7 – 3.8
Na(g kg^{-1})	0.5 – 1.6
Fe (mg kg^{-1})	78 - 1462
Cu(mg kg^{-1})	12 - 29
Mn(mg kg^{-1})	5 - 39
Zn(mg kg^{-1})	10 - 37

Table 3. Main characteristics of the olive pomace (dry weight)

2.2.1. Pomace agronomical value

On the contrary to the WW, no many experiences was carried out on the OP application, because both OP3 and OPP represent a better incoming value when destined to the pomace industry and energetic production. The results of OP application both in olive orchard and herbaceous crop, was different, depending both from doses applied and crop. Against to a remarkable improvement in chemical-physics characteristics of olive orchard soil up to two years after the pomace supply, has no given significant differences in vegetative and productive parameters of treated olive trees. In herbaceous crop a phytotoxic effect was observed on plant growth with highest doses applied, showing that the fresh organic matter distributed in soil will be degraded producing intermediate metabolites which are not compatible with normal plant growth and nutrients availability, with in some cases an increase in the fungal disease (Bing et al., 1994; Bonanomi et al., 2006; Brunetti et al., 2005; Di Giovacchino et al., 2004; Diacono & Montemurro, 2010; Tejada & Gonzales, 2003, 2004).

In the practice, the benefits of olive pomaces recycling in soil occur only if were applied according to best agronomical practices, as taking into account suitable time and specific plan of fertilization, needs of the soil-plant system and the climatic conditions.

Nevertheless, the application of raw olive pomace involves a more difficult management of these biomasses and, also for possible negative aspects, a better management solution is to compost the pomace, as we can see later in this paper.

2.3. Olive mill wastes legislation

According to their nature, the extraction methods and the different phases of management, the olive mill by products have to follow different laws concerning storage, treatment, transport, application to the soil, or other destinations.

2.3.1. Waste waters legislation

The WW legislation is based on their two possible different destinations: agronomic or landfill. In case of agronomic use without any preventive treatment, the reference is the Law n. 574/1996. As established by the Decree of the Ministry of the environment, on the "Individuation of non dangerous wastes submitted to the simplified recovery procedures to the senses of the articles 31 and 33 of the Legislative Decree 05.02.1997 n. 22", the WW can also be recovered through the "Production of fluid fertilizers, as by the Law n. 748 of 19.10.1984: "New norms for the fertilizers discipline".

If the WW cannot be used in agronomical purposes, it is necessary to apply preventive treatment. The products, resulting from the purification process, can be schematized as follows:

- for the liquid phase, the reference is the Law n. 319, 10.05.1976 (Merli law) with his modifications and integrations, and the Legislative Decree n. 22/1997 (Ronchi Decree) and his modifications and integrations, in which the limits of acceptability are established also for the discharge in surface and ground water, on the soils, or in the subsoils (L.D. 389 of 8.11.1997).

- for the solid phase, the reference, related both to the treatment and discharge phases, is constituted by the Legislative Decree 27.01.1992, n. 99, "Realization of the directive 86/278/CEE regarding the environment protection, particularly of the soil, in the use of the solid phase purification in agriculture", and the Law 19.01.1984, n. 748 with his modifications and integrations "New norms for the discipline of the fertilizers." The art. 8, par. 1, letter "d" of the "Ronchi Decree" establishes that WW are excluded by application, because disciplined by specific dispositions of law "the activities of byproducts treatment that give origin to the fertilizers, selected in reference to the typology and the mode of utilization as by Law 19.10.1984, n. 748 with his modifications and integrations".

Another possible destination of the WW is the agronomic use after an a intermediary phase for production of liquid fertilizers, conforming to the Law 748 19.10.1984, "New norms for the discipline of the fertilizers", according to the norms of the D.M. 05.02.1998 of the Ministry of the environment. As a consequence, WW must be recovered according to the point R3 of the Annex C of Legislative Decree n. 22/1997, article 6, paragraph 1, letter h, ("Recycle/recover of the organic substances not used as solvents, included the composting operations and other biological transformations").

2.3.2. Pomace legislation

The OP storage is disciplined by the Legislative Decree n. 22/1997 with his modifications and integrations, according to which it should be considered as not dangerous special wastes that (ex D.M. 05.02.1998 of the Ministry of the environment) can be submitted to the simplified recovery procedures according to the articles 31 and 33 of the Legislative Decree n. 22/1997 with his modifications and integrations.

About the treatments, in case of distribution on the soil, also the OP2 can be considered as OP ex Law n. 574/1996, for which is not provide any preventive treatment for the agronomic use, because: "To the goals of the application of the present law, the OP2 coming from the olives milling and constituted by the waters and the fibrous part of fruit and the core fragments, can be used as amendments in derogates to the characteristics established by the Law 19.10.1984, n. 748 and modifications". As D.M. 05.02.1998 of the Ministry of the environment, (non dangerous wastes that can be submitted to the simplified recovery procedures as the articles 31 and 33 of the Legislative Decree n. 22/1997 with his modifications and integrations) the pomace could be submitted to processes of anaerobic biostabilization, with production of biogas. This material could also be submitted to the aerobic processes, for the compost production in conformity with the annex to the Law 19.10.1984, n. 748 with modifications.

Other destinations of the OP, with exclusion of the OP2 for elevated moisture, is the conferment to the pomace industry for the extraction with solvents of the residual oil. The defatted pomace that resulted as byproduct of this process, are used as fuel, or as organic amendments after aerobic co-composting.

3. Biological treatments

With this definition, are indicated the processes and the activities on organic materials that, degraded and transformed by various decomposers microorganisms, allow its stabilization in terms of mineralization of the mostly degradable components, and the hygienization of the biomass by pasteurization.

The biological treatment of byproducts can be realized with different technologies and processes, referable to three following typologies:

- composting of quality, on selected biomasses, for the production of amendments of high agronomic value, according to the parameters defined by the Law 748/84 on the fertilizers;
- biostabilization of organic matrixes of low quality (as organic fractions from mechanical separation of the undiversified wastes residues, sludges with heavy metals, etc.);
- anaerobic digestion for production of biogas, both on high quality organic matrixes for a successive agronomic utilization, and on lower quality or contaminated organic residuals. The byproduct (digestate) can be afterward used as fuel, aerobically stabilized, or arranged as sludge according to the Legislative Decree 99/1992 on the sludge usage in agriculture.

4. Composting

The composting is a controlled process, based on the control of the natural bioxidative process on organic substances (Figure 1) transformed by aerobes microorganisms naturally present in the environment and in the matrixes, in a stabilized and sanitized organic substance, defined compost (Casacchia et al., 2011; Insam & De Bertoldi, 2007).

The composting is classified by the law (Legislative Decree 22/97) as a recovery operation of byproducts, among the actions of "The recycle and/or retrieve of the organic substances not used as solvents"; being an interesting alternative in recycling large amounts of a wide range of the residues produced in Mediterranean areas, resulting in an organic fertilizer suitable to agricultural purposes, in improvement of o. m. content of soils, and reduction of fertilization costs.

The composting process is usually divided in two phases: Active Composting Time (ACT), and Curing.

During the ACT, there is an intense develop of degradative processes on to more easily fermentescible organic components. In this thermophylic phase the biomass reaches temperatures up to 65 °C, that also allow its hygienization. The ACT can develop, according to the characteristics of the matrix, in piles, with or without overturn and with or without forced airing, or in more complex systems (bioreactors), and varying from 21-28 days in the first case or 14-16 days in the second one.

During the curing phase, the degradative phenomena will be completed, and the synthesis of the humic-like substances occurred. This process, which has a duration of more than 45 days, need a smaller oxygen and drain of heat.

The main parameters of the composting process, that ensure an optimal development of microorganism able to transform the organic matrices, are synthetically reported in Table 4.

pH	Should be between 5.5 - 8, to assure the activity of useful microbes.
Humidity %	Range variable from 50-60% in the first weeks (ACT); to go down to 30-35% to the end of process, depending on the biomass characteristics and the processing typology.
Temperature	Range to develop microorganism: 40-45 °C (3 days over 55 °C for the Italian legislation, to kill pathogens)
C/N ratio	Nutrient balance: between 25 and 35 to avoid nitrogen losses for volatilization (< 25) or decrease speed of metabolic reactions (> 35)
Porosity	To ensure aerobic process; depending on particle size. The better air-filled pore space: 25-50%
Particle size	Surface air for microbial growth
O_2 concentration	Assured by forced airing and/or overturns. Optimal range for degradative process: 15-20%

Table 4. Controllable composting parameters.

During the composting, the organic substance evolves both quantitatively, reducing weight and volume, and qualitatively, with deep modifications of its chemical and structural characteristics. The parameters that defines the composted materials are:

- stability, that characterize a specific stage of decomposition or state of organic matter during composting, which is related to the type of residual organic compounds and the resultant biological activity in the material. The specific stage of organic matter represents the exhaustion of degradative processes due to the biological metabolic activity (low static and/or dynamic respiration index).
- maturity, is the degree of composting completeness and concerns improved qualities resulting from "ageing" or "curing" of a composted matter. Usually the level of maturity is detected by the phytotoxicity, verifiable with the homonym test.
- humification, or the endowment of humic-like molecules originated from reactions on the less fermentescible organic components. (Boulter et al., 2000; De Nobili & Petrussi, 1988; Franz et al., 2005; IPLA, 1992; Zucconi et al., 1981).

In order to the duration of the fermentative process, two typologies of compost can be obtained, based on their degree of maturation:

- the ready-to-use compost, of greater fertilizing efficiency, that is obtained in 3-4 months, at ACT end, that can be used for vegetable crops, gardens and in full field, on preseed and before the transplantation;
- the mature compost, more stabile and humified, that is obtained after 5-6 or more months of curing; usable as amendment in full field, or as substrate in the greenhouse nursery.

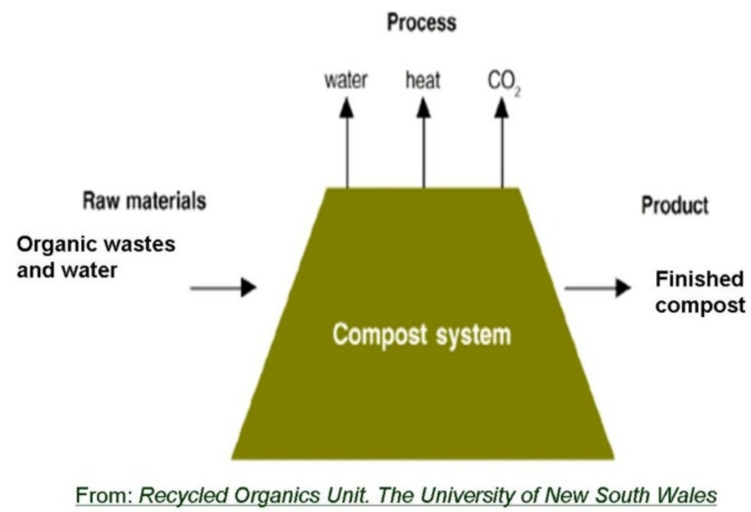

Figure 1. Composting process flow.

The composting of the agro industrial by-products and agricultural residual biomasses can be carried out according to two typologies:

- composting of crop residuals and animal manure by farmers; in this case the farmer that compost in situ produced biomasses, is not subject to any restriction, provided that the compost is used in the same firm;
- composting of extra farm biomasses; this kind of activity is not considered as normal agricultural practice, but solid wastes recycling. According to the prevailing interpretation, the extra-farm solid wastes included in the compostable materials list of the D.M. 05.02.1998, are subjected to the "simplified procedure", as from artts. 31 and 33 of the Legislative Decree 22/97 ("Ronchi" decree).

The on-farm composting does not require particular technologies, while the necessary machineries (carver, shovel loader, wagon mixer) are often already present in farm.

The biomasses to be composted, mixed with opportune percentages of appropriate structural and absorbent fractions (lignocelluloses bulking), are typically placed in pile on paved stage, preferably covered, and periodically overturned up to stabilization.

The shape and the dimensions of the pile will depend from the quantity and the quality of the material to be treated. The forms are of triangular, parabolic or trapezoidal section, of 1.5 - 1.8 m height, while width and length depending from the quantity of material or from the available space, and also in base to the machinery used for the overturns (hauled or self moving over-turner, shovel loader).

During the composting, must be constantly monitored temperature and moisture of the pile, taking care of maintain the porosity, to allow the aeration and thermic dispersion of biomass.

According to the moisture and granulometry of biomass, the overturns will have to take place to intervals of 2-3 days, in case of high moisture or low percentage of structural fraction (bulking); while greater intervals (up to 10-15 days) can be applied on more porous or coarse matrixes, and in the curing phase of compost.

The composting practices contemplate several operative options, in relationship to the different typologies of biomasses to be treated, and to the different managerial and environmental situations: from the simplest systems of aerobic stabilization on natural conditions, up to the industrial plants with the complete control of the process conditions (Alfano et al., 2008; Amirante & Montel, 1999; Baeta-Hall et al., 2005; Calvet et al., 1985; De Bertoldi et al., 1983; Diaz et al., 2007; Madejon et al., 1998; Montemurro et al., 2009; Tomati et al., 1996; Veronesi & Zampighi, 1997).

Although the OP is characterized from inadequate physical characteristics, in particular the OP2, that makes difficult the aerobic degradation, this by-product can be easily composted by using complementary residues such as pruning residues or cereal straw as bulking agents; also mixed with other agricultural wastes as animal manures or horticultural residues. During the process, the potentially dangerous organic substances in the olive wastes are degraded, allowing the safe and useful use of the obtained compost in agricultural fields; and valorizing these byproducts as a resource.

4.1. Composting normative

The composting sector is disciplined by the two following normatives: the wastes normative, that defines the conditions of production of the compost from wastes or selected fractions, and the fertilizers one that establish the marketing conditions of the compost.

- Wastes Normative: Legislative Decree n. 22, 05.02.1997 with modifications, and Technical Normative of realization of the Legislative Decree 22/97, and the D.M. 05.02.1998: Individuation of non-dangerous wastes submitted to the simplified retrieving procedures to the senses of the artts. 31 and 33 of the Legislative Decree 22/97.
- Fertilizers Normative: Law 748/84 (Annex 1C) and modifications and integrations.

The Legislative Decree 22/97, which follows the CEE/91/156 wastes directive, classifies the composting among the recovery operations of wastes (Annex "C", R3: Recycle/recovery of the organic substances not used as solvents, included the composting operations and other biological transformations).

With the Technical Normative, the D. M. 05.02.1998, have been defined the technical aspects tied up to the compost production, even if limited to the activities of recovery in simplified regime, with a reference to the Law 748/84 "Norms for the fertilizers discipline", that in the enclosure 1C, as modified by the D.M. 27.03.1998, defines the marketing characteristics for the compost, indicating the following four types of final products:

- Simple not composted vegetable amendment: not fermented product composed of barks and/or other vegetable residues as pomace, chaffs, peels, with exclusion of algae and other marine plants (it is a product that, for definition, cannot considered as raw material for composts);

- Green composted amendment: obtained through a controlled process of transformation and stabilization of organic wastes constituted by urban green residues, crops residuals, other residues of vegetable origin, with exclusion of algae and other marine plants;
- Mixed composted amendment: obtained through a controlled process of transformation and stabilization of organic residues that can be constituted by the organic selected fraction of the urban wastes, from animal slurry, included the animal sewages, from agro industrial residues, and from the wood and textile untreated throughput as well as from the matrixes of the Green composted Amendment;
- Peaty composted amendment: obtained by mixture of peat with Green composted amendment or Mixed composted amendment.

For the realization and the management of the composting installation can be followed:

- the simplified procedure (as artts. 31 and 33 of the Legislative Decree 22/97) when the installation, the first and the final products are entirely conforming to the prescriptions of the D.M. 05.02.1998, particularly for the selection of the organic materials. Furthermore, the characteristics of the final products should be conforming to the requisite in the enclosure 1C to the L. 748/84 (as modified by the D.M. 27.03.98). This procedure lay down a preventive communication of start of the recovery activity together with a technical explanatory document, in the respect of the discipline contained in the DPR 203/88, for the releases in atmosphere, and of that reported in the Legislative Decree 152/99, for landfill.
- the ordinary procedure (as artts. 27 and 28 of the Legislative Decree 22/97), that require a specific authorization, released from the local administrations.

4.2. Composting procedures

The compost should to have an adequate degree of stabilization (maturity); and qualified amendments and nutritional properties.

The quality of the compost is function of the following factors:

- the composition of the mixture (raw materials), as percentage among different components;
- the management of the composting process, particularly the duration, the moisture and the oxygenation of mixture;
- the final conditioning (refinement, addition of other products).

The composting of selected organic substances has to be considered as a recovery system for the production of high quality organic amendments to use for the agricultural purpose able to replace, even though partially, the manure in the extensive agriculture, the chemical fertilizers in the intensive crops and the peat in nursery.

The ACT phase, in relationship to the characteristics of the treated mixture, can happen in piles on open air, or confined in more complex systems (bioreactors) with forced airing, with or without overturns. During this phase must be checked the temperature, moisture, pH and oxygen. The duration of this phase should be enough to guarantee the attainment of an adequate Respiration Index (I.R.) of biomass, to be test with the IPLA (Institute of Plants, Wood and Environment) method (IPLA, 1992). This duration corresponds to about 21 days of treatment, in the case of stabilization in overturned piles and about 14-16 days in the case of bioreactors.

The curing phase is always carried out in piles and require a lower amount of oxygen and overturn in comparison to the ACT phase.

The biomasses to be composted must be previously grinded and mixed to optimize the characteristics of the matrix (C/N ratio, porosity, moisture, pH). A good starting matrix for the production of a Quality Composted Amendment (ACQ), has to have a moisture among 45 and 65%, C/N among 20 and 30, with at least a 30% in weight of lignocelluloses material. The ACQ can be commercialized to the senses of the Law 748/84, also in mix with other fertilizers, according to the same law prescriptions, as reported in Table 5. This material could be used in the agricultural activities or similar (maintenance of the public or private green, biofilters, etc.).

Parameter	Green Composted Amendment	Mixed Composted Amendment	Peaty Composted Amendment
pH	6.0-8.5	6.0-8.5	-
Humidity (%)	<50	<50	-
TOC (% d.m.)	>30	>25	>30
Organic Nitrogen (%)	>80	>80	>80
C/N ratio	<50	<25	<50
Humic and fulvic acids (% d.m.)	>2.5	>7	>7
Peat (%)	-	-	>50
Cd (mg kg^{-1})	<1.5	<1.5	<1.5
Cu (mg kg^{-1})	<150	<150	<150
Hg (mg kg^{-1})	<1.5	<1.5	<1.5
Ni (mg kg^{-1})	<50	<50	<50
Pb (mg kg^{-1})	<140	<140	<140
Zn (mg kg^{-1})	<500	<500	<500
Cr VI (mg kg^{-1})	<0.5	<0.5	<0.5
Inert (>10 mm) (%)	none	none	none
Salmonelle (on 25g sample)	none	none	none
Enterobacteriacee (CFU g^{-1})	< 100	< 100	< 100
Fecal Streptococcus (MPN g^{-1})	< 1000	< 1000	< 1000
Nematodes (on 50g sample)	none	none	none
Trematodes (on 50g sample)	none	none	none
Cestodes (on 50g sample)	none	none	none

Table 5. Limits of acceptability for the Quality Composted Amendment (ACQ), conforming to Annex 1C of the Law 748/84, as modified by the D.M. of 27.03.1998.

The composting process can also carried out with low-tech approaches and extreme operational simplification, excluding the forced airing and effecting the biomass overturns using machineries already in endowment to the farm (choppers, shovel loader, wagon mixers).

4.3. Technological systems: classification and description

The bioxidative processes are carried out in different operative systems, classified as (Amirante & Montel, 1999; Clodoveo et al., 2000; Goldstein, 1980; Willson et al., 1980):

- intensive or extensive systems, according to both the technological complexity and the energetic needs;
- closed or open systems, according to be confined or not by the open air;
- static or dynamic systems, according to whether the mass has moved;
- aired or not aired systems, in presence or absence of forced airing.

The intensive systems are destined to high fermentability biomasses. They are generally closed, dynamic and aired, and works through a first active phase (ACT), with control of process parameters, and a second phase (curing) with lower-level of technological complexity, similar to the extensive systems. The processing times vary between 25-30 and 120 days (in average 90 days). The energetic needs are around 40-60 kwh ton^{-1} for the machinery power (overturners, ventilation systems, grinders, sieves). The need areas are around 0.7-1.5 $m^2 ton^{-1}$ of annual biomass to process.

The extensive systems are dedicate to biomasses of low fermentability and are open, or also confined, static and not aired (aired for diffusion and natural convection), and do not differentiate the operative phases, but they adopt an only lower technological step. Typically they consist in macropiles open air, without or very time deferred overturns. The process times varying around 6 months up to over 1 year. The energetic needs are low (10-20 kwh ton^{-1}), for the grinding, the optional overturn with generic machines (mechanical shovels) and the sifting. They need surfaces around 1.5 - 2 $m^2 ton^{-1}$ of annual biomass to process.

4.3.1. Systems "closed" or "open"

In the closed systems the process is carried out in confined spaces (bioreactors) or in covered areas (sheds), for biomasses that require greater control of the fermentative parameters (high moisture, stinking as well as selected for high quality compost). Conversely, the open systems are destined to biomasses of low fermentability, high percentage (i.e. 70%) of lignocelluloses bulking, or for curing phases of biomasses already submitted to ACT.

4.3.2. Systems "static" and "dynamic"

These systems differ for the periodic or continuous biomass moving (dynamic) or for immobility (static). The base idea of the static systems is not to disturb the growth and the action of the fungi and of the microbial population, maintaining a microecological environment. This situation is important to create in the biomass good growth conditions with the purpose to facilitate the stabilization processes. This systems can work with matrixes well structured and homogeneous, with at least 40 - 50% in weight of lignocelluloses bulking, to avoid the compaction of the mass, and moisture less than 65%.

In the dynamic systems can be processed very moisture matrixes (> 65%) and with less than 30% in weight of lignocelluloses bulking.

4.3.3. Systems "aired" and "not aired"

The forced airing of the biomass is an important factor of optimization of the process particularly for the treatment of low consistence and higher fermentability biomasses. For the optimization of the forced airing it is necessary to calculate and monitoring:

- the specific air flow, generally expressed in Normal cubic meters for hour and of weight biomass unit (NCM h^{-1} ton^{-1}). Generally, the airing needs for the drain are higher also of a dimensional order, in comparison to those of oxygen in stechiometric demand for the mineralization. The airing systems are therefore sized and used for the control of the temperature, while the biomass oxygenation is obtained as derived effect. This sizing involves nevertheless an excessive evaporation and drying of the biomass, with early interruption of biostabilizative processes. For this reason, in airing systems are necessary appropriate systems of control and remoisten.
- the proportion between times of airing activation and turning off. The intermittent ventilation of the biomass, besides the energetic saving, has the purpose to allow during the periods of turning off the equalization of moisture and temperature in the different zones of the biomass, while the airing in continuous can behave more sensitive stratifications of them. The proportion between times of working and turning off is established in order to the better thermal level needed for the biomass, being the optimization of the temperatures another of the essential parameters to the efficiency of composting process. To the same flow of air and of "heating power" of the biomass (dependent from moisture and fermentability), greater periods of working airing proportionally involve lesser thermometric levels of the biomass (Higgins, 1982).

The different processing systems, classified according to the installations or the operational methodology, can be associate to one or more of following categories. Typically, among the open systems are included: Aired static pile; Overturned pile; Short pile. While, among the closed systems they are: Biocontainer; Dynamic trenches; Dynamic basins; Silos.

4.3.4. Aired static pile

The aired static pile constitute a system of relative technological simplicity. It was developed in America as "Beltsville system ", with the purpose to have a simple system of the wastes biomasses bioconversion to the farmers for agronomic reuse. In his different variations, it shapes as an open, static and aired system (Willson et al., 1980). Typically it foresees the disposition of the biomass in pile, with forced airing in aspiration below the pile and dispatch of the exhausted air to a compost-made biofilter. On the pile surface a layer of mature compost is placed, with not permeable and filtering actions. As static system, it requires of a high percentage of structural lignocelluloses bulking, and of a relatively low moisture of the starting matrix. It also requires a appropriate homogenization pretreatments of biomass. In some different systems the forced airing works by inflation, while for the pile coverage are adopted cloths or semi-permeable membranes, to limit the losses of moisture.

4.3.5. Overturned piles

In this system the biomass are disposed in piles of great dimensions (3-4 m of height; width up to over 20 m). The piles are typically open, not aired and overturned with ample intervals (weeks or months), with mechanical shovels or specific overturning machines in the case of continuous systems. This system is adopted for matrixes to tall prevalence of lignocelluloses material (green residues) or in the curing of biomasses after the ACT. The piles can be managed in batch, or in continuous, with progressive translation of the biomass during the overturns, toward the unloading section. This second solution eliminates the unused spaces between piles, while is forcing to adopt a fixed overturns periodicity, that would not correspond to the real needs of process.

4.3.6. Short pile

The short pile differ from the piles for their smaller dimensions (max 2.5 m height) and can be or not endowed with the forced airing. The overturn is generally frequent (from few days up to daily intervals) and are made with specific overturners. The short piles are planned as "closed system" for the active phase of high fermentable matrixes; or as "open" where the stinking impacts do not constitute trouble, or for low fermentable material, or for the curing of end-fermented biomasses.

4.3.7. Biocontainer and biocell

Biocontainer and biocell are horizontal closed reactors, typically static and airing. The biomass is placed in beds of the maximum height of around 3 meters. The biocontainer are made with metallic or concrete, insulate, and have unitary volumes of the order of many about ten cubic meters. These systems generally adopt the recycle of the air, and survey systems to manage the parameters of process (moisture, oxygen percentage in the inside atmosphere, temperature) and feed-back regulation of the air flows and the percentages of air recycle.

4.3.8. Dynamic trenches

Conversely to the biocontainer, in this system the reactor is divided in trenches served by one or more lines of forced airing, with modulation of the air flows in the different sections correspondents to the different times of process. The trenches race binary for the translation of self-moving overturners that also effect the progressive transfer of biomass (continuous system). The trenches are typically used for the management of the active phases of biomasses to elevated fermentability, in closed environments. As dynamic system, can effectively process also biomasses with high moisture content.

4.3.9. Dynamic basins

In this installation typology, typically closed, aired and dynamic, the composting biomass is placed in basins, and moved with special self-moving overturners. It is generally used for the active phase of higher fermentability biomasses or also for whole process (ACT and Curing, without discontinuity). This system result to be economically competitive for processing over 100 tons day^{-1} of biomasses.

4.3.10. Silos

The silos are vertical reactors, to one or multi step, closed and airing, with continuous or discontinuous loading and unloading of the biomass. The system can be static (for batch processes) or semi-dynamic (top loading of composting matrix and bottom unloading of stabilized biomass).

5. Composting experiences and results

Several experimental trials were carried out using different olive mill typology wastes (two phase mill fluid pomace; three phase mill pomace and waste water), mixed with others agricultural or agroindustrial byproducts, with the aim to evaluate both the composting process efficiency, and the amendment and nutritional efficiency of obtained composts on: i) maintain or improving soil properties and soil fertility; ii) growth and yield performance of herbaceous crops; iii) growth and yield performance of olive orchards (Albuquerque et al., 2007; Alfano et al, 2008; Baeta-Hall et al., 2005; Boulter et al., 2000; Calvet et al., 1985; Casacchia et al., 2012; Diacono & Montemurro, 2010; Hoitink et al., 1997; Montemurro et al., 2004, 2006, 2010, 2011*b*; Tejada et al., 2006, 2009; Toscano et al., 2009 *b*).

5.1. Results on olive orchards

In some experimental trials, the assessment of the composting process in natural conditions was studied on two different typology of matrices, respectively composed by olive mill wastes and other crop by-products as structural biomass: i) wet pomace by two phases mill with olive leaves and cereals straw; ii) pomace and waste water by three phases mill with carved pruning residuals. All materials were placed on a beaten-soil platform, and remixed to homogenize the matrices. The evolution of bioxidation was monitored controlling the temperature and humidity of matrices, and assuring oxygenation and thermal drain by weekly blending with mechanical shovel on tractor front loader. At the end of the fermentation period, both biomass microbial pools and chemical parameters were analyzed to evaluate the characteristics of obtained composts. Results of composting parameters trend and microbiological analysis, indicate a correct way of aerobic process; and the compost analyses confirmed that a “mixed composted amendments” was obtained (Law 748/1984).

To evaluate amendment and nutritional efficiency, the composts were spread at doses of approx. 150 kg tree^{-1} (60 tons ha^{-1}) on 6 x 4 scaled olive orchard, and buried with a light disk arrow tillage. At the following year’s harvesting time, was compared the differences between treated and untreated soil characteristics, and yield responses of 15 treated vs. 15 untreated olive trees of a 15 years old “Nocellara messinese” cultivar for OP2 compost, and 20 years old “Leccino” cultivar for OP3 compost.

The amendment and nutritional efficiency of these kinds of composts was confirmed both by soil organic matter increment (+ 38.6%; + 40.6% for two phase and three phase compost, respectively), and trees productive responses at the following year harvesting time (+ 10.5% and + 15.1% oil yield increase on respective treated trees).

Even if the condition of fermentative process (open air, natural conditions) was not optimal, the obtained compost demonstrate that the aerobic fermentation of olive mill residuals can run in a correct way also in natural conditions, producing an hygienized and partially stabilized organic amendment, that can be better spread out at the optimal time, and without the negative effects related to the raw olive mill wastes supply. At the used doses, both composts increased soil fertility, improved water retention and the availability of nutrients in amended soils, and improved plant productivity. The showed nutritional effect of these composts would allow a reduction in the use of chemical fertilizers, in agreement with the energetic and economic sustainability principles in the use of renewable resources. In common situations where industrial installations are unfeasible, the natural composting process of olive mill wastes can therefore be a interesting alternative to the raw pomace and waste-water spreading on soils; and could represent a solution of sustainable disposal problem, allowing to increase soil organic matter contents and to reduce the desertification processes (Casacchia et al., 2012; Toscano et al., 2009*b*).

5.2. Results of olive mill waste water application on herbaceous crops

As mentioned before, the national law (Law 574/1996) allows the olive mill waste water (WW) spreading on soils with appropriate characteristics for agronomical use with the maximum amount of 80 m^3 ha^{-1} yr^{-1} for the centrifuge system and of 50 m^3 ha^{-1} yr^{-1} for the pressure method.

In a research carried out in the semi-arid environment of Southern Italy, the application of two WW rates without preliminary treatments was studied. To reach this objective, the effects on cereal and leguminous crops yield, quality, N uptake and on soil characteristics were recorded.

The results obtained indicate that the WW treatments (both doses) positively affected the yield of ryegrass, while a significant yield increase was found at the highest level of WW in proteic pea. The clover crop showed a species-specific sensitiveness, but the WW applications increased the protein content compared to the untreated plots. The WW rates also increased total organic content in the soil, in respect to the unfertilized control. At the end of this three-year experiment the values of soil total extracted carbon and humified organic carbon were higher compared to the initial ones. The values of soil available P and K of the control treatment found at the end of experiment were almost the same than those recorded at the beginning of the research confirming that the increases found in WW plots were due to the WW applications.

A two-year experiment was also carried out in controlled environment (lysimeters) to study the effects of applying untreated and treated WW as soil amendments on both rye-grass growth and soil characteristics. The results of this research indicated that the untreated and treated WW application increased growth parameters, indicating the possible use of WW as an amendment to rye-grass. A significant increase of total, extracted and humified organic carbon in soil, and humification parameters (degree and not humified organic carbon) were found, whereas no accumulations of heavy metals in the soil were measured at the end of the experiment. Furthermore, N content in WW was used by rye-grass for plant growth that increases N uptake and consequently the dry matter accumulation (Montemurro et al., 2007).

5.3. Results of pomace application on herbaceous crops

As already mentioned, the composting of olive pomaces could be recycled for agricultural purposes. In addition, a specific test could be performed to assess the phytotoxicity for both the raw pomace and the stabilized composts. The phytotoxicity is one of the most important criteria for evaluating the agronomical potential of organic materials as olive pomace, and can be measured by specific test. A method can be used to assess phytotoxicity of this residues, by combining the measurements of seeds germination and roots elongation of cress (*Lepidium sativum* L.). Different experiments indicate that the olive pomace composts were not phytotoxic. According to other researches, it can be suggested that repeated compost application might preserve the soil organic carbon content and supply macronutrients to crop. Finally, among different solutions, the addition to olive pomace of manure, as a nitrogen source, and pruning wastes, as bulking-agent, may generate organic amendments suitable for the organic cultivation management of some herbaceous crops.

Several experiments on herbaceous crops indicate that the use of organic pomace fertilizer, as a partial substitution of mineral fertilizers, reached the same yield of the highest mineral fertilizer treatment, ensured also an increase of soil total organic carbon and other soil properties. Furthermore, the application of these organic composted wastes also induce a lower nitrogen mineral soil level at the end of the experimental trials, indicating the possibility to reduce pollution risks. These findings were found in maize and barley in a same experimental research (Montemurro et al., 2006).

5.4. Results on greenhouse olive nursery

On the market are available different organic (peats, manures, urban wastes, barks, sawdusts) and inorganic (sand, pumice, clay, perlite, vermiculite) materials, usable in the preparation of olive nursery substrates. All these materials have some advantages, i.e. sterilization process not necessary, and commercial fertilizers can be added. Even though the peat is the more used organic material in the preparation of the substrates, other different material have been tested with the aim to replace it, include the olive industry byproducts.

In some experimental trials has been valued the compatibility and efficiency of composts, obtained from different olive mill wastes, in the composition of growth substrates for olive nursery, with the aim of mostly valorizing these biomasses as partial or total substitution of peat. Variable proportions of peat and/or two different olive waste composts deriving from the continuous two and three phases extraction systems, were added to a basis of river sand, used as control, for a total of six treatments for each of the three cultivars under observation (Carolea, Nocellara messinese and Tondina). The self-rooted plantlets were kept for 28 months in greenhouse, making periodic measurements of linear growth (cm) and number of internodes. At the end of trial, dry weights of leaves, branches and roots were detected. The results showed a greater nutritional efficiency of the substrates containing composts derived from the three phases olive mill wastes, with highly significant differences both in the linear growths and in the number of internodes; while the compost derived from two phases olive mill wastes do not showed particular benefits, giving results similar to peat, and to sand (control), presumably due to the higher C/N ratio of this compound (Santilli et al., 2012; Toscano et al., 2009*a*).

5.5. General findings

In the experimental conditions of southern Italy, the findings of the studies on repeated applications of WW indicate that it could be possible both to sustain herbaceous crops performance and support soil fertility, valorizing these wastes as organic amendment and reducing the risks of soil degradation, giving also a useful practice to reuse purposes as EU provides.

Also the composting experiences of olive mill and olive orchard wastes carried out in natural conditions, demonstrate as relatively easy feasible and noticeable effective the production of stabilized organic amendment of elevated agronomic value to very contained costs. These materials have their natural utilization to maintain soil organic fertility, as well as substrate for olive nursery, in perspective as substitute of peat. According to the modern principles of the energetic and economic sustainability of agro industrial processes, the olive mill and olive orchard wastes composting has been confirmed as a valid alternative to the raw waste water and pomace shedding on the soil. In particular, a higher efficiency was found in stabilizing the organic matter, which works better in the restoration and in long-term maintenance of soil fertility. Furthermore must be considered that the nutritional effect of compost can allow to reduce the use of chemical fertilizers in fertilization plans, mostly raising the value of this kind of agro industrial by-products management. So could be a better solution also to fit EU prescriptions concerning wastes reuse.

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6. References

Alburquerque, J.A., Gonzalvez, J., Garcia, D. & Cegarra, J. (2004). Agrochemical characterisation of ''alperujo,'' a solid by-product of the two-phase centrifugation method for olive oil extraction. *Bioresource Technology* 91, pp. 195–200.

Alburquerque, J.A., Gonzalvez, J., Garcıa, D. & Cegarra, J. (2007). Effects of a compost made from the solid by-product (alperujo) of the two phase centrifugation system for olive oil extraction and cotton gin waste on growth and nutrient content of ryegrass (Lolium perenne L.). *Bioresource Technology*, 98, pp. 940–945.

Alfano G., Belli C., Lustrato G. & Ranalli G. (2008). Pile composting of two-phase centrifuged olive husk residues: technical solutions and quality of cured compost. *Bioresource Technology*, 99, pp. 4694-4701.

Alianiello F., Trinchera A., Dell'orco S., Pinzari F. & Benedetti A. (1998). Somministrazione al terreno delle acque di vegetazione da frantoio: effetti sulla sostanza organica e sull'attività microbiologica del suolo. *Agricoltura Ricerca*, 173, pp. 65-74.

Amirante P. & Di Rienzo G.C. (1993). Tecnologie e impianti disponibili per la depurazione delle acque di vegetazione. *Collana di Agricoltura e Agroindustria" Tecnologie e Impianti per il Trattamento dei Reflui dei Frantoi Oleari"*, Ed. Conte, Lecce, pp. 24-57.

Amirante P. & Montel G.L. (1999). Tecnologie ed impianti per il compostaggio intra ed inter aziendali. *In Il compostaggio in ambito agricolo. Promozione ed impiego del compost in agricoltura biologica. I quaderni di Biopuglia*, 5, pp. 136-141. IAMB, Bari.

Andrich G., Balzini S., Zinnai A., Silvestri S. & Fiorentini R. (1992). Effect of olive oil wastewater irrigation on olive plant products. *Agricoltura Mediterranea*, 122, pp. 97-100.

Angelidaki I., Karakashev D., Batstone D.J., Plugge C.M. & Stams A.J. (2011). Biomethanation and its potential. *Methods Enzimol.*, 494, pp. 327-351.

A.R.S.S.A. (Agenzia Regionale per lo Sviluppo e per i Servizi in Agricoltura della Calabria), (2001). Utilizzazione agronomica delle acque reflue olearie. *Pgt. POM Mis. 2 Cod. A 10: Sistemi e metodi per la valorizzazione a fini agricoli dei residui delle industrie agroalimentari nel meridione d'Italia.* Ed. Zefiro, Cosenza.

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

Ballesteros I., Oliva J. M., Negro M. J., Manzanares P. & Ballesteros M. (2002). Ethanol Production from Olive Oil Extraction Residue Pretreated with Hot Water. *Applied Biochemistry and Biotechnology*, 98-100, pp. 717-732.

Benitez J., Beltran-Heredia J., Torregrosa J., Acero J.L. & Cercas V. (1997). Aerobic degradation of olive mill wastewaters. *Applied Microbiology and Biotechnology,* 47, pp. 185-188.

Ben Rouina B., Taamallah H. & Ammar E. (1999). Vegetation water used as a fertilizer on young olive plants. *Acta Horticolturae,* 474, pp. 353–355.

Bing U., Cini E., Cioni A. & Laurendi V. (1994). Smaltimento-recupero delle sanse di oliva provenienti da un "due fasi" mediante distribuzione in campo. *L'Informatore Agrario*, 47, pp. 75-78.

Bonanomi G., Giorgi V., Del Sorbo G., Neri D. & Scala F. (2006). Olive mill residues affect saprophytic growth and disease incidence of foliar and soilborne plant fungal pathogens. *Agricolture, Ecosystems and Environment*, 115, pp. 194-200.

Bonari E., Macchia M., Angelini L. G. & Ceccarini L. (1993). The Waste Water from Olive Oil Extraction: their influence on the germinative characteristics of some cultivated and weed species. *Agricoltura Mediterranea,* 123, pp. 273-280.

Boulter J.I., Boland G.J. & Trevors J.T. (2000). Compost: A study of the development process and end-product potential for suppression of turf grass disease. *World Journal of Microbiology and Biotechnology*, 16, pp. 115-134.

Briccoli Bati C. & Lombardo N. (1990). Effects of olive oil waste water irrigation on young olive plants. *Acta Horticolturae,* 286, pp. 489–491.

Brunetti G., Plaza C. & Senesi N. (2005). Olive Pomace Amendment in Mediterranean Conditions: Effect on Soil and Humic Acid Properties and Wheat (*Triticum turgidum* L.) Yield. *J. Agric. Food Chem., 53* (17), pp. 6730–6737.

Calvet C., Pagés M. & Estaún V. (1985). Composting of Olive Marc. *Acta Horticolturae, (ISHS),* 172, pp. 255-262.

Capasso R., Cristinzio G., Evidente A., & Scognamiglio F. (1992). Isolation, spectroscopy and selective phytotoxic effects of polyphenols from vegetable waste waters. *Phytochemistry*, 31, pp. 4125-4128.

Casacchia T., Toscano P., Sofo A., & Perri E. (2011). Assessment of microbial pools by an innovative microbiological technique during the co-composting of olive-mill by-products. *Agricultural Sciences*, 2, pp. 104-110.

Casacchia T., Sofo A., Zelasco S., Perri E. & Toscano P. (2012). In situ olive mill residual co-composting for soil organic fertility restoration and by-product sustainable reuse. *Italian Journal of Agronomy*, 7, pp. 35-38.

Catalano M., Gomes T., De Felice M. & De Leonardis T. (1985). Smaltimento delle acque di vegetazione dei frantoi oleari. *Inquinamento*, 2, pp. 87-90.

Clodoveo M.L., Leone A., Montel G.L. & Tamborrino A. (2000). Impianti semplificati per il compostaggio dei reflui e controllo dei parametri di processo. *Agricoltura Ricerca*, 187, pp. 135–142.

De Bertoldi M., Vallini G. & Pera A. (1983). The biology of composting: a review. *Waste Mangement & Research,* 1, pp. 157–176.

De Nobili M. & Petrussi F. (1988). Humification Index (HI) as evaluation of the stabilization degree during composting. *J. of Fermentation Technology*, 66 (5), pp. 577-583.

Decreto Legge 162 del 10/05/1995: Disposizioni in materia di riutilizzo dei residui derivanti da cicli di produzione o di consumo in un processo produttivo o in un processo di combustione, nonché in materia di smaltimento dei rifiuti.

D. Lgs. 99 del 27/01/1992: Attuazione della direttiva 86/278/CEE concernente la protezione dell'ambiente, in particolare del suolo, nell'utilizzazione dei fanghi di depurazione in agricoltura. *Suppl. ord. G.U., serie Generale*, n. 38 Feb.

D. Lgs. 22 del 5 Febbraio 1997 (Ronchi): Attuazione delle Direttive 91/156/CEE sui rifiuti, 91/689/CEE sui rifiuti pericolosi, e 94/62/CE sugli imballaggi e sui rifiuti da imballaggio. *Suppl. ord. G.U. serie Generale*, n. 38 Feb.

D. Lgs. 389 del 8 Novembre 1997: Modifiche ed integrazioni al d.lgs. 22 del 5/2/1997 (Legge Ronchi), in materia di rifiuti, rifiuti pericolosi, di imballaggi e di rifiuti da imballaggio. *G.U. serie Generale,* n. 261 Nov.

D.M. 5 Febbraio 1998 (Min. Ambiente): Individuazione dei rifiuti non pericolosi sottoposti alle procedure semplificate di recupero ai sensi degli artt. 31 e 33 del d. lgs. N. 22 del 5 febbraio 1997. *Suppl. ord. N. 72 - G.U., Serie Generale*, n. 88 Apr.

Della Monica M., Potenz D., Righetti E. & Volpicella M. (1978). Effetto inquinante delle acque reflue della lavorazione delle olive su terreno agrario. Nota 1: Evoluzione del pH, dei composti azotati e dei fosfati. *Inquinamento*, 10, pp. 81-87.

Della Monica M., Potenz D., Righetti E. & Volpicella M. (1979). Effetto inquinante delle acque reflue della lavorazione delle olive su terreno agrario. Nota 2: Evoluzione dei lipidi, dei polifenoli e delle sostanze organiche. *Inquinamento*, 1, pp. 27-30.

Diacono M. & Montemurro F. (2010). Long-term effects of organic amendments on soil fertility. A review. *Agronomy for Sustainable Development*, 30, pp. 401-422.

Diaz L.F., De Bertoldi M., Bidlingmaier W. & Stentiford E. (2007). Compost science and technology. *Elsevier Science. Waste Management Series*, Vol 8. ISBN: 9780080439600.

Di Giovacchino L. & Seghetti L. (1990). Lo smaltimento delle acque di vegetazione delle olive su terreno agrario destinato alla coltivazione di grano e mais. *L'Informatore Agrario*, 45, pp. 58-62.

Di Giovacchino L., Basti C., Costantini N., Ferrante M.L. & Surricchio G. (2001). Effects of olive vegetable water spreading on soil cultivated with maize and grapevine. *Agricoltura Mediterranea*, 131, pp. 33–41.

Di Giovacchino L., Basti C., Seghetti L., Costantini N., Surricchio G. & Ferrante M.L. (2004). Effects of olive pomace spreading on soil cultivated with maize and grapevine. *Agricoltura Mediterranea*, 134 (1), pp. 15-24.

FAOSTAT (2012). Food And Agriculture Organization Of The United Nations (http://faostat.fao.org/)

Filidei S., Masciandaro G. & Ceccanti B. (2003). Anaerobic digestion of olive oil mill effluents: evaluation of wastewater organic load and phytotoxicity reduction. *Water, Air and Soil Pollution*, 145, pp. 79–94.

Filippi C., Bedini S., Levi-Minzi R., Cardelli R. & Saviozzi A. (2002). Co-composting of olive oil mill by-products: chemical and microbiological evaluations. *Compost Science and Utilization* 10, pp. 63-71.

Franz L., Ceron A., Paradisi L., Germani F., Bergamin L. & Caravello G. (2005): Stabilità biologica: studio comparativo di due differenti metodiche per la determinazione dell'indice di respirazione nel compost. *Rifiuti Solidi,* 19 (1), pp. 22-26.

Galli E., Pasetti L., Fiorelli F. & Tomati U. (1997). Olive mill wastewater composting: microbiological aspects. *Waste Management & Research,* 15, pp. 323-330.

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, pp. 59–64.

Goldstein J. (1980). An overview of composting installation. *Compost Science and Land Utilization*, 21 (4), pp. 28-32.

Higgins A.J. (1982). Ventilation for static pile composting. *Biocycle*, 23, pp. 36-41.

Hoitink H.A.J., Stone A.G. & Han D.Y. (1997). Suppression of plant disease by compost. *Hort. Science*, 32, pp. 184-187.

Insam H. & De Bertoldi M. (2007). Microbiology of the composting process. In *Compost Science and Technology. Waste management series 8*, Elsevier Ltd., pp. 26–45, ISBN-13: 978-0-08-043960-0.

IPLA (Istituto Piante Legno Ambiente) (1992). Metodi di analisi dei compost. *Collana Ambiente, 6*. Ed. Regione Piemonte, Assessorato Ambiente, Torino.

ISTAT (2010). Agricoltura e ambiente. ISTAT, Roma (http://www.istat.it/).

Kavdir Y. & Killi D. (2008). Influence of olive oil solid waste application on soil pH, electrical conductivity, soil nitrogen transformation, carbon content and aggregate stability. *Bioresource Tecnology*, 99, pp. 2326-2332.

Legge 10 Maggio 1976, n. 319 (Merli). Norme per la tutela delle acque dall'inquinamento. Gazzetta Ufficiale n. 141 maggio, int. e modif. dalla Legge 24 dicembre 1979, n. 650. G. U. n. 352 Dic.

Legge 19 Ottobre 1984, n. 748. Nuove norme per la disciplina dei fertilizzanti. *Suppl. ord. Gazzetta Ufficiale* - n. 305 Nov.

Legge 11 Novembre 1996, n. 574. Nuove norme in materia di utilizzazione agronomica delle acque di vegetazione e di scarichi di frantoi oleari. *Gazzetta Ufficiale, Serie generale* n. 265, Nov.

Legge 9 Dicembre 1998, n. 426: Nuovi interventi in campo ambientale. *G.U. Serie generale*, n. 291, Dic.

Levi-Minzi R., Saviozzi A., Riffaldi R. & Falzo L. (1992). Lo smaltimento in campo delle acque di vegetazione. Effetti sulle proprietà del terreno. *Olivae*, 40, pp. 20-25.

Lombardo N., Briccoli-Bati C., Marsilio V. & Di Giovacchino L. (1995). Comportamento vegeto-produttivo di un oliveto trattato con acque di vegetazione. *Atti Conv.: Tecniche, norme e qualità in olivicoltura.* Potenza 15-17 dic. 1993, pp. 93-107.

Madejon E., Galli E. & Tomati U. (1998). Composting of wastes produced by low water consuming olive mill technology. *Agrochimica*, 42, pp. 135-146.

Marsilio V., Di Giovacchino L., Solinas M., Lombardo N. & Briccoli Bati C. (1990). First Observations on the Disposal Effects of Olive Oil Mills Vegetation Water on Cultivated Soil. *Acta Horticulturae,* 286, pp. 493-496.

McNamara C.J., Anastasiou C.C., O'Flaherty V. & Mitchell R. (2008). Bioremediation of Olive mill wastewarter. Review. *Intl. Bioterioration & Biodegradation*, 61, pp. 127-134.

Molinari G. & Bonfà F. (2005). Utilizzazione di biomasse per alimentazione di gruppi cogenerativi con motori a vapore alternativi per utenze piccole e medie. *Conferenza Nazionale sulla politica energetica in Italia.* Bologna, 18-19 Aprile.

Montemurro F., Convertini G. & Ferri D. (2004). Mill wastewater and olive pomace compost as amendments for rye-grass. *Agronomie*, 24, pp. 481–486.

Montemurro F., Maiorana M., Convertini G. & Ferri D. (2006). Compost organic amendments in fodder crops: effects on yield, nitrogen utilization and soil characteristics. *Compost Science & Utilization*, 14 (2), pp. 114–123.

Montemurro F., Maiorana M., Ferri D. & Convertini G. (2007). Treated and untreated olive waste water application on rye-grass meadow: chemical soil properties and yielding responses. *Agrochimica,* 51 (2-3), pp. 148-159.

Montemurro F., Diacono M., Vitti C. & Debiase G. (2009). Biodegradation of olive husk mixed with other agricultural wastes. *Bioresource Technology*, 100, pp. 2969-2974.

Montemurro F., Charfeddine M., Maiorana M. & Convertini G. (2010). Compost use in agriculture: the fate of heavy metals in soil and fodder crop plants. *Compost Science and Utilization*, 18, pp. 47-54.

Montemurro F., Diacono M., Vitti C. & Ferri D. (2011*a*). Potential use of olive mill wastewater as amendment: crops yield and soil properties assessment. *Communications in Soil Science and Plant Analysis*, 42, pp. 2594-2603.

Montemurro F., Diacono M., Vitti C. & Ferri D. (2011*b*). Short-term agronomical effects of olive oil pomace composts on Pisum arvense L. and Trifolium subterraneum L. and impacts on soil properties. *Communications in Soil Science and Plant Analysis*, 42, pp. 2256-2264.

Pacifico A. (1989). Acque di vegetazione. *Agricoltura e Innovazione, "Dossier: Acque di vegetazione"*, Notiziario ENEA Roma, 11, pp. 33-53.

Palliotti A. & Proietti P. (1992). Ulteriori indagini sull'influenza delle acque reflue di frantoi oleari sull'olivo. *L'Informatore Agrario*, 39, pp. 72-76.

Paredes, C., Roig, A., Bernal, M.P., Sàcnchez-Monedero, M.A. & Cegarra, J. (2000). Evolution of organic matter and nitrogen during co-composting of olive mill wastewater with solid organic wastes. *Biology and Fertility of Soils*, 32, pp. 222–227.

Paredes C., Bernal M.P., Cegarra J. & Roig A. (2002). Bio-degradation of olive mill wastewater sludge by its co-composting with agricultural wastes. *Bioresource Technology*, 85, pp. 1-8.

Proietti P., Cartechini A. & Tombesi A. (1988). Influenza delle acque reflue di frantoi oleari su olivi in vaso e in campo. *L'Informatore Agrario*, 45, pp. 87-91.

Ramos-Cormenzana A. (1986). Physical, Chemical, Microbiological and Biochemical Characteristic of Vegetation Water. *In Intl. Symposium on Olive by-products valorization, Seville*. FAO, Madrid, pp. 19-40.

Roig A., Cayuela M.L. & Sánchez-Monedero M.A. (2006). An overview on olive mill wastes and their valorization methods. *Waste Management*, 26 (9), pp. 960-969.

Rozzi A. & Malpei F. (1996). Treatment and disposal of olive mill effluents. *Intl. Biodeterioration & Biodegradation*, 38, pp. 135-144.

Santilli E., Toscano P., Casacchia T., Lombardo L. & Briccoli-Bati C. (2012). Utilizzo di compost di reflui oleari nella preparazione di substrati nel vivaismo olivicolo. *II Conv. Naz. Dell'Olivo e dell'Olio*, PG 21-23 Sett., (In Press).

Saviozzi A., Levi-Minzi R., Riffaldi R. & Lupetti A. (1991). Effetti dello spandimento di acque di vegetazione su terreno agrario. *Agrochimica,* 35, pp. 135-148.

Tamburino V., Zimbone S.M. & Quattrone P. (1999). Accumulo e smaltimento sul suolo delle acque di vegetazione. *Olivae*, 76, pp. 36-45.

Tejada, M. & Gonzales, J.L. (2003). Application of a by-product of the two-steps olive mill process on rice yield. *Agrochimica* 47, pp. 94–102.

Tejada, M. & Gonzales, J.L. (2004). Effects of application of a by-product of the two-steps olive oil mill process on maize yield. *Agronomy Journal*, 96, pp. 692–699.

Tejada M., Garcia C., Gonzalez J.L. & Hernandez M.T. (2006). Organic amendment based on fresh and composted beet vinasse: influence on soil properties and wheat yield. *Soil Sci. Soc. Am. J.*, 70, pp. 900–908.

Tejada M., Hernandez M.T. & Garcia C. (2009). Soil restoration using composted plant residues: Effects on soil properties, *Soil and Tillage Res.*, 102, pp. 109–117.

Tomati U. & Galli E. (1992). The fertilizing value of waste water from the olive processing industry. *In: Humus, its structure and role in agriculture and environment. (J. Kubat ed.)* Elsevier, Barking, pp. 117–126.

Tomati U., Galli E., Pasetti L. & Volterra E. (1995). Bioremediation of olive-mill wastewaters by composting. *Waste Management & Research*, 13, pp. 509-518.

Tomati U., Galli E., Fiorelli F. & Pasetti L. (1996). Fertilizers from composting of olive mill wastewaters. *Intl. Biodeterioration & Biodegradation*, 38, pp. 155-162.

Toscano P., Turco D. & Briccoli-Bati C. (2009*a*). Utilizzo di compost di reflui oleari nella preparazione dei substrati di coltura nel vivaismo olivicolo. *Conv. Int. e finale Progetto RIOM CRA-OLI* Rende (CS), 11-12 Giu, pp. 149-152.

Toscano P., Casacchia T. & Zaffina F. (2009*b*). The "in farm" olive mill residual composting for by-products sustainable reuse in the soils organic fertility restoration. *18th Symposium Of The International Scientific Centre Of Fertilizers - More Sustainability In Agriculture: New Fertilizers And Fertilization Management*. Rome, 8 – 12 Nov., pp. 116-121.

Vallini G., Pera A. & Morelli R. (2001). Il compostaggio delle acque di vegetazione dei frantoi oleari. *Informatore Agrario*, Suppl. 1, 50, pp. 22-26.

Veronesi G. & Zampighi C. (1997). Evoluzione degli impianti di compostaggio dei residui solidi organici. *VI Convegno Nazionale di Ing. Agraria, Università degli Studi,* Ancona, 11-12 settembre.

Vigo F., Uliana C. & Traverso M. (1990). Acque di vegetazione da frantoi di olive. Trattamenti utilizzabili per una riduzione del carico inquinante. *Riv. It. Sostanze grasse*, 67 (3), pp. 131-137.

Vitolo S., Petarca L. & Bresci B. (1999). Treatment of olive oil industry wastes. *Bioresource Technology*, 67, pp. 129-137.

Willson G. B., Parr J. F., Epstein E., Marsh P. B., Chaney R. I., Colacicco D., Burge W. D., Sikora L. J., Tester C. F. & Hornick S. (1980). Manual for composting sludge by the Beltsville aerated pile method. *USDA, EPA 600/8-80 002*, Cincinnati, Ohio, USA.

Zucconi F., Forte M., Monaco A. & De Bertoldi M. (1981). Biological evaluation of compost maturity. *BioCycle*, 22, pp. 27–29.