Chapter 9

# The Solid Wastes of Coffee Production and of Olive Oil Extraction: Management Perspectives in Rural Areas

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.69427

**Abstract**

There are two problematic solid residues from agriculture and agro-industry, produced in vast amounts in rural areas: those from coffee bean production and processing and those deriving from the extraction process of olive oil. Notwithstanding these residues originating in different geographical areas, they have striking similarities. They both derive from traditional, conventional and organic agriculture; they have a high content in lignins, celluloses and (poly)phenols; they are produced in million tonnes annually; they pose relevant environmental problems for disposal; they contain bioactive compounds; and the approach for their re-use is often similar, sometimes overlapping. The most promising re-uses in rural areas are for agriculture, as animal feed and for energy production. There are also minor uses, suitable for the production of added-value commodities. The re-use will be dependent on a variety of factors according to the diversity of (a) pedoclimatic areas that include altitude and latitude, soil texture and organic matter content, water regime and availability, (b) level of expertise of the small farmers, (c) social environment that includes training opportunities and availability to create associative forms among producers, (d) access to trade and communication networks and (e) easy access to community-level processing installations. The perspectives of agronomic management and valorization are compatible with the objectives of a regenerative, sustainable agriculture.

**Keywords:** rural areas, coffee solid waste, olive oil extraction solid waste, re-use of agricultural waste, rural areas, regenerative agriculture, valorization of solid residues

## 1. Introduction

The rural areas where coffee is cultivated are located mainly in the equatorial and sub-equatorial zone in Africa, Asia and South America. The top ten producing countries are Guatemala

(224,871 tonnes/year), Mexico (257,940), Uganda (314,489), Honduras (380,296), India (385,786), Ethiopia (423,287), Indonesia (814,629), Colombia (892,871), Vietnam (1,818,811) and Brazil (2,859,502) [1]. Coffee production and processing, the latter step often taking place in locations distant from the beans production sites, generate yearly over 20 million tonnes of liquid and solid waste to be disposed of by farmers and processing plants. Although the farms in these areas range in size from 0.5 to 6 hectares (ha), typically they are 1–2 ha and coffee is generally grown along with other cash and food crops, such as maize, as well as cattle. An example is provided by coffee farmers in Uganda [2] having larger-than-average farm plots, while farmers growing coffee and maize tend to have larger plots than coffee farmers without maize (2.69 ha compared to 1.86 ha, respectively). Thus, coffee and maize production is a key determinant for household incomes and poverty, and some land is dedicated to traditional staple food with low-added value. Indeed coffee and maize producers have significantly lower poverty rates compared to coffee farmers that do not grow maize. In general, we can assume that coffee farm economics is dependent upon a wide variety of factors, including productivity, quality, costs of production and waste disposal, price premiums, the latter to achieve quality or sustainability standards. The options for the valorization of the coffee residues, not focusing on waste management in rural areas, have been recently reviewed [1, 3–6].

The rural areas where olive trees are cultivated are located mainly in the Mediterranean basin, where in the northern side over 82.5% of the world production of olive oil (i.e. 2.34 out of 2.84 million tonnes) takes places (Spain, Italy, Greece, Portugal, France, Cyprus, Slovenia and Malta) [7]. This figure rises up to 94.1% of the world olive oil production, i.e. 2.63 million tonnes, if the countries of the southern side of the Mediterranean basin are included (Morocco, Algeria, Tunisia, Lybia, Egypt, Jordan, Israel, Lebanon, Syria and Turkey). Olive trees cultivation and olive oil processing, the latter step often taking place in locations distant from the olive production sites, generate every year in the northern side of the Mediterranean basin 6.01 million $m^3$ of liquid waste (**Figure 1**) and 8.06 million tonnes of solid waste (**Figure 2**) as an average. This amount rises up to 30 million $m^3$ of olive mill wastewater and 20 million tonnes of solid waste, called wet husks [6] if the southern side of the Mediterranean basin is

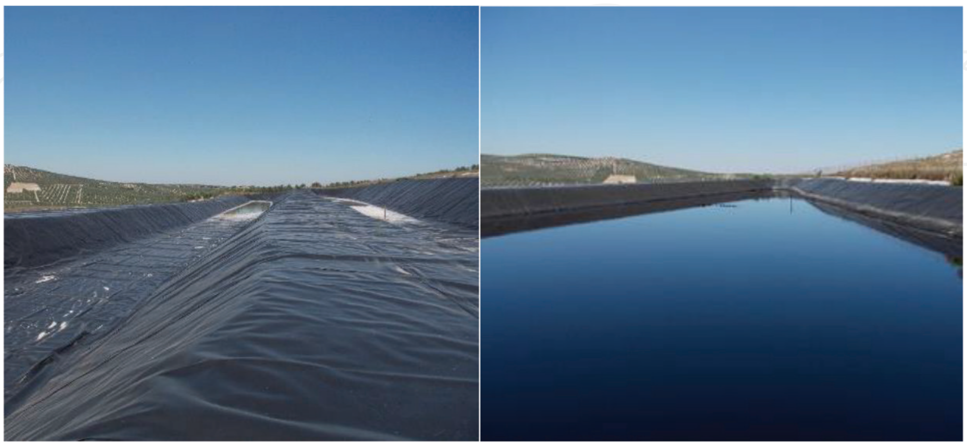

**Figure 1.** Ponds for the confinement of the wastewater (left = before filling, right = after filling) from the extraction of olive oil at the facility of Coop. Sor Ángela de la Cruz, Estepa (Sevilla, Spain). Due to the environmental toxicity of the liquid phase, the large amounts produced from intensive olive tree cultivation in that area need to be stored separately before further processing, e.g. for biogas production (Source: Marco Nuti).

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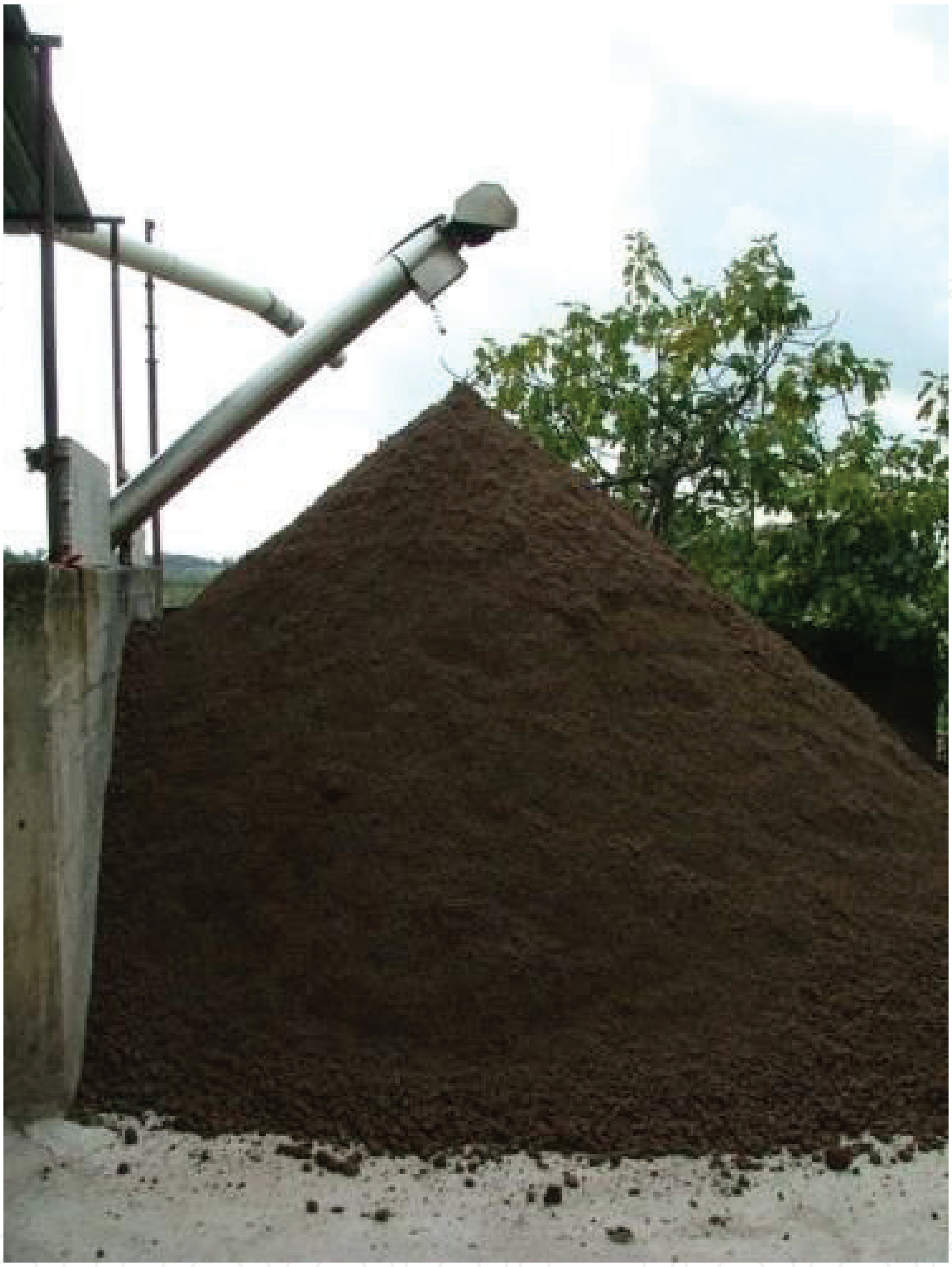

**Figure 2.** Olive pomace (wet husks) from the two-phase decanter centrifugation olive oil extraction. The wet husks have an initial relative humidity of 65–70% (Source: Marco Nuti).

included. The farming system in the Mediterranean area consists of a majority of small farms (e.g. in Italy 60% of olive farms are <2 ha, and less than 10% are >10 ha), and olive trees are generally grown along with other cash and food crops, infrequently with livestock. Overall farm economics is dependent upon a wide variety of factors, including productivity, quality, and costs of production and waste disposal. To achieve quality and sustainability standards, the costs are on the premises of the farmers, while premiums are limited to larger agro-industrial installations transforming the waste into energy, i.e. electricity (**Figure 3**). The options for the valorization of the olive oil extraction solid residues, not focusing on waste management in rural areas, have been recently reviewed [8, 9].

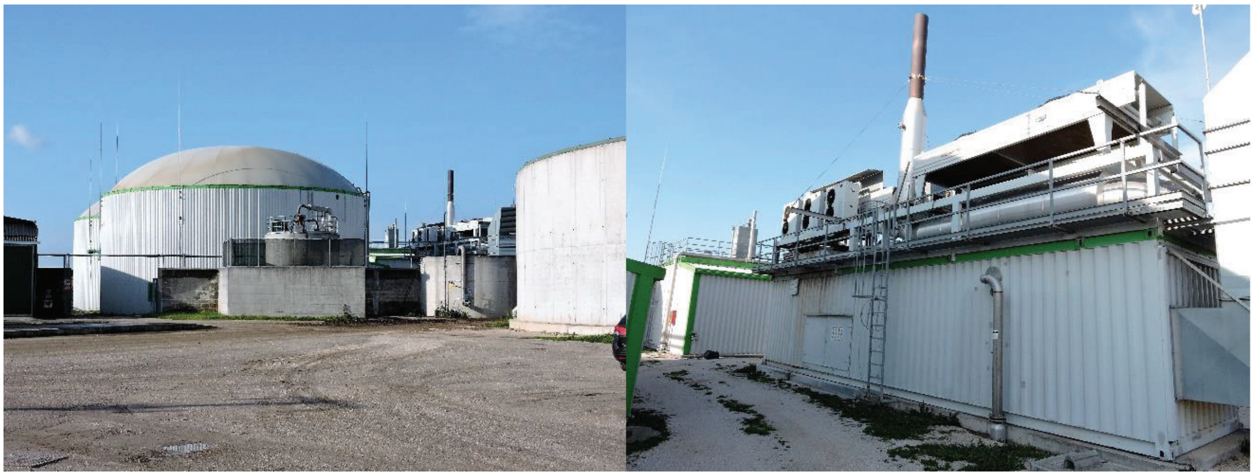

**Figure 3.** Power generation plant (1 Mw) fed with wet olive husks and wastewaters from the olive oil extraction. Biogas is generated in the digestor (right) and stored (left), then converted into electricity. Installation Friel Ionica Srl - BTM Srl spinoff of the University of Pisa, located in Manduria (Taranto, Italy) (Source: Marco Nuti).

There are many similarities between the chemical composition and end-of-use of the solid residues of the two production chains, besides their vast amounts available yearly. Both solid residues (i.e. coffee husks, defective coffee beans and spent coffee grounds on one side, and olive wet husks, olive stones on the other side) are problematic in terms of disposal, having similar environmental impacts, decontamination needs, similar possible re-uses and similar chemical nature of the components, i.e. a high content in ligno-cellulosic materials, low content of fat and protein, presence of (poly)phenols recalcitrant to degradation. The main end-of-uses in the poorer and less accessible rural areas are the production of heat and recycling into agriculture after modest composting. Production of heat for household heaters, electricity, recycling into agriculture after modest composting and minor uses for the production of commodities with high added-value (e.g. cosmetics, mushrooms, fodder) characterize the end-of-use of the solid residues in areas with more intensive agriculture.

In this chapter, the two types of solid wastes are critically reviewed separately and assessed for their valorization in the rural areas for production of coffee and olive oil, respectively.

## 2. The management of residues of coffee production and transformation in rural areas

Over 90% of the coffee production (*Coffea arabica, Coffea canephora* and the Ethiopia's natural *C. arabica* cultivar Harrar) takes place in developing countries. In these countries, economy depends to a large extent on agriculture, coffee being one of the most important crops. In fact, countries like Vietnam, India, Kenya, Nicaragua, Ecuador and Mexico encouraged the cultivation of coffee in rural areas as a national economy strategy. About 70% of the world coffee production is cultivated in rural areas on small farms less than 6 ha [10]. The implemented policies, subsidies and incentive programs which promoted the conversion for land to intensive, technified mono-crop coffee cultivation resulted in a catastrophic impact to the environment. Coffee farms are located indeed in some of the biologically most diverse, and most threatened, environments in the world [11].

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The isolated rural areas where the best coffee is grown are extreme poverty zones (**Figure 4**). They have limited or no basic services (**Figure 5**), access roads are in poor condition and farmers have little or any basic education. For coffee growers in many countries, coffee provides their sole source of cash income and it is a family activity. Farmers have relatively weak trade positions and, in spite of it, they have to hold the same high productions standards as the large-scale producers who have additional resources to invest and access technological tools. To join the forces and improve the marketing of coffee, marginalized farmers created small communities called 'cooperatives' or 'beneficios' that are collection centres where they gather the crops and process the fruit until obtaining the coffee beans. The process of separation of the commercial product (beans) from coffee cherries generates enormous volumes of waste material in the form of pulp, residual water and parchment. Almost all these waste are disposed in the natural environment, causing bad odours, bad aspect, pathogenic insects' attraction, and pollution of soils and water bodies. In fact, they represent the major source of river pollution in Ethiopia and northern Latin America [12, 13]. The appropriate use of coffee by-products would help circumventing these problems, and valorization of the residues would represent a value addition from the point of view of environment protection [14]. The main chemical traits of the coffee processing residues at farm level, relevant for their valorization,

**Figure 4.** The small 'coffee farms' in the Amazonas very often look like an orchard exhibiting great plant biodiversity (Source: Marco Nuti).

**Figure 5.** Coffee beans are air-dried by small farmers in the western Amazonian forest at 1200 m of altitude (facility of the 'Asociación de cultivadores y comercializadores de café organico Bosque Nublado Río Golondrinas ', Parroquia Jijon y Caamano, Carchi, Ecuador) (Source: Cristina Echeverria).

are summarized in **Table 1**. The degradation process, occurring in natural conditions, is extremely slow and incomplete despite a favourable C/N mass ratio of 40, due to the recalcitrance of (poly-)phenols and complex glucides, thus giving rise to toxicity problems.

Various attempts have been made to circumvent these environmental problems and minimize the toxicity levels, e.g. improving production systems, reducing the volume of wastewater or recycling wastes to obtain value-added compounds such as enzymes and caffeine [1]. Out of the alternatives, only a few have been implemented in rural areas because of the costs and unavailability of the technology in these small communities. The valorization of coffee residues in agriculture, as animal feed and for energy production is still the most attractive application to solve in part the problems of people in these areas.

During the years 2000–2004, many farmers started a transition to organic coffee production, encouraged by the growth of certified coffee markets and development projects. This transition involved the use of new forms of fertilization [11, 15]. From this point of view, large quantities of coffee pulp are available for those organic farmers. Approximately three-quarters of the nutrients extracted to obtain the coffee beans are found in the pulp. Co-composting the solid waste with animal manure is the most used alternative to minimize the environmental impact of the residue. However, in most cases the compost is not obtained under controlled conditions to ensure its stabilization and sanitization. Pulp is typically left to degrade in piles without any treatment, thus resulting in an organic material incorrectly named 'compost'. Introducing a non-stabilized organic matter into the soil has caused a negative effect on crops

| Component | Spent coffee grounds | Coffee pulp | Coffee husk |
|---|---|---|---|
| | g × 100 g$^{-1}$ d.w. | g × 100 g$^{-1}$ d.w. | g × 100 g$^{-1}$ d.w. |
| Proteins | 6.7–13.6 | 10.1 | 5.2–11 |
| Total lignin | 33.6 | – | – |
| Cellulose | 8.6–13.8 | – | 16.0–43.0 |
| Carbohydrates | – | 63.2 | 35.0–85.0 |
| Reduced sugars | – | 12.4 | 0.71 |
| Ash | 0.43–1.6 | 8.3 | 0.7–6.2 |
| Fat | 6.3–28.3 | – | 0.3–3.0 |
| Tannins | 1–9 | 1.80–8.56 | |
| Caffeín | 1–2 | 1.3 | 1.0–1.3 |
| Organic carbon | – | – | 50.8 |
| N | – | – | 1.27 |
| Polyphenols | – | – | 1.22 |

Data collated from different authors ([65–67] and references cited therein), showing a fairly wide range of values, possibly due to the diversity of tested materials, i.e. Arabica or Robusta variety, not specified by Aa. The ligno-cellulose component and tannins are the most recalcitrant components to degradation.

**Table 1.** Main chemical components of the solid coffee residues (spent coffee grounds, coffee pulp, and coffee husk) relevant for their valorization at small farm level.

production [16]. Vermicomposting is an alternative widely used in Colombia and Ethiopia showing better results in terms of organic fertilization [17].

Small projects to obtain bioethanol and biogas have been also implemented in some key areas of Africa and Central America [18–20]. The production of energy from coffee wastes partially meets the energy needs in rural areas. Furthermore, the technology needs further improvement in order to be applied in the most remote or marginalized places.

The use of pulp as an animal feed has had limited use due to the high content of caffeine which affects ruminants. In Ethiopia, it has been used as a nutrient supplement to sheep feeding [21, 22].

In conclusion, there is still a lot of pollution because of the lack of knowledge and government policies. There is a vital need to counterpart this production with an appropriate utilization of coffee by-products. The valorization of the liquid and solid residues should be regarded as a value addition from an environmental point of view. However, it is essential that coffee production and processing take into account environmental needs to ensure sustainability, reasonable living standards for the populations involved with coffee, and ensure the maintenance of quality. Such an effort is one of the objectives of the International Coffee Agreement 2007, i.e. to encourage members to develop a sustainable coffee sector in economic, social and environmental terms [23].

## 3. The management of residues of olive oil extraction process in rural areas

The olive tree cultivation in the Mediterranean countries of EU (ca. 400 cultivars in Italy, 150 in Spain, 40 in Greece) takes place in 4.8 million ha, and the olive oil extraction process is carried out in about 12,000 olive-mills, most of which are small and medium enterprises (SMEs), involving 800,000 jobs [6, 24]. Olive oil is obtained essentially *via* traditional pressing (TP), two-phase decanter process (2-PDP) and three-phase decanter process (3-PDP) [25], each of them generating different amounts of wastes (**Table 2**). There is an uneven distribution of the type of extraction process in southern Europe: in Spain 99% of the adopted technology is 2-PDP, while in Italy 55% is 3-PDP, 15% is 2-PDP and 15% is TP. In Greece, 82% of the olive mills have adopted 3-PDP and 18% 2-PDP. However, there is an increasing interest in these last two countries for the two-phase system, possibly coupled with the de-pitting of the olive wet husks (synonyms: crude cake or pomace). In this way the stones can be separated and used for heating purposes, particularly at small community level and for household heaters.

As far as the residues from the olive trees cultivation are concerned, in the rural areas of southern Europe, two main components of biomass burning are the incineration of wood as household fuel, and the combustion of crop residues (i.e. prunings and leaves of olive trees) in open fields. At the same time, as the population continues to rise in the African side of the Mediterranean basin, the contribution from these two types of biomass burning tends to

| Extraction process | Input | Amount of input | Output |
|---|---|---|---|
| Traditional pressing | Olives | 1 tonne | Oil |
| | Washing water | 0.1–0.12 $m^3$ | Solid waste (*ca*..25% water + 6% oil) |
| | Energy | 40–63 kWh | Waste water (*ca.* 88% water) |
| 3-Phase decanter (3-PDP) | Olives | 1 tonne | Oil |
| | Washing water | 0.1–0.12 $m^3$ | Solid waste (*ca.* 50% water + 4% oil) |
| | Fresh water | 0.5–1 $m^3$ | |
| | Water to wash the impure oil | 10 kg | Waste water (*ca.*94% water + 1% oil) |
| | Energy | 40–63 kWh | |
| 2-Phase decanter (2-PDP) | Olives | 1 tonne | Oil |
| | Washing water | 0.1–0.12 $m^3$ | Solid waste (*ca.* 60% water + 3% oil) |
| | Energy | <90–117 kWh | |

**Table 2.** Solid and liquid waste generated using different olive extraction technology. The solid waste contains olive pits [25].

increase. In the northern side of the Mediterranean basin burning olive branches and leaves in open fields is allowed (**Figure 6**) under an increasingly stringent legislation as they can contribute to greenhouse gas emissions (GHG). These burnings can be avoided once the agro-residues are employed for sustainable, cost-effective and environment-friendly options such as composting and subsequent ploughing of the compost. A quantitative description of the spatial distribution of biofuel and open-field burning has been attempted to assess the impact of this burning on the budgets of trace gases [26], but no real attempts to discourage burnings are currently made on the basis of continuous educational programs for small olive farmers. Therefore, open-field burning of olive crop residues is still the most traditionally adopted end-of-use in rural areas. From a purely agronomic standpoint, the delivery of ashes in cropped agriculture would be meaningful for fertilization purposes only when the content of soil organic matter and organic nitrogen at plough depth is high, which seldom occurs in both northern and southern side of the Mediterranean basin [27–29].

The use of in-house pressing (i.e. with large stone wheels or stone cones) of the olives in small farms has almost disappeared, and this type of extraction is often confined to demonstration farms for teaching or museum purposes. The traditional pressing is also decreasing in favour of the decanter-centrifugation systems, either two- (olive oil and wet husks) or three-phases (olive oil, husks and wastewater). The small olive mills in rural areas work preferably with 3-PDP, but the availability on the market of 2-PDP decanter extractors with reduced energy consumption is gradually offering new opportunities. On the contrary, in agriculture-intensive areas, the preferred technology is 2-PDP with large working capacity (**Figure 7**) or the last-generation decanter extractors combining the modern extraction technology without the addition of water with batch processing, thanks to the bowl discharging device (**Figure 8**). Using the latter system, the waste is represented by a dehydrated husk similar to the one coming from the three-phase decanter, along with the pulp from the husk, the so-called 'pâté', i.e. wet husks without any trace of kernel directly inside the bowl. This pâté can be used for various purposes, including agronomic use, animal feeding, or can be mixed with other biomass for biogas production.

The biochemical and physical-chemical traits of the solid waste 'wet husks' are reported in **Table 3**, where for convenience they are compared with the traits of the wet husks after micro-

**Figure 6.** Burning olive leaves and prunings in the open field in controlled (left) and uncontrolled (right) conditions. In the olive oil producing EU countries burning is submitted to stringent legislation (Source: https://i2.wp.com/www.quiantella.it/wp-content/uploads/2016/06/a.jpg?fit=533%2C348&resize=350%2C200).

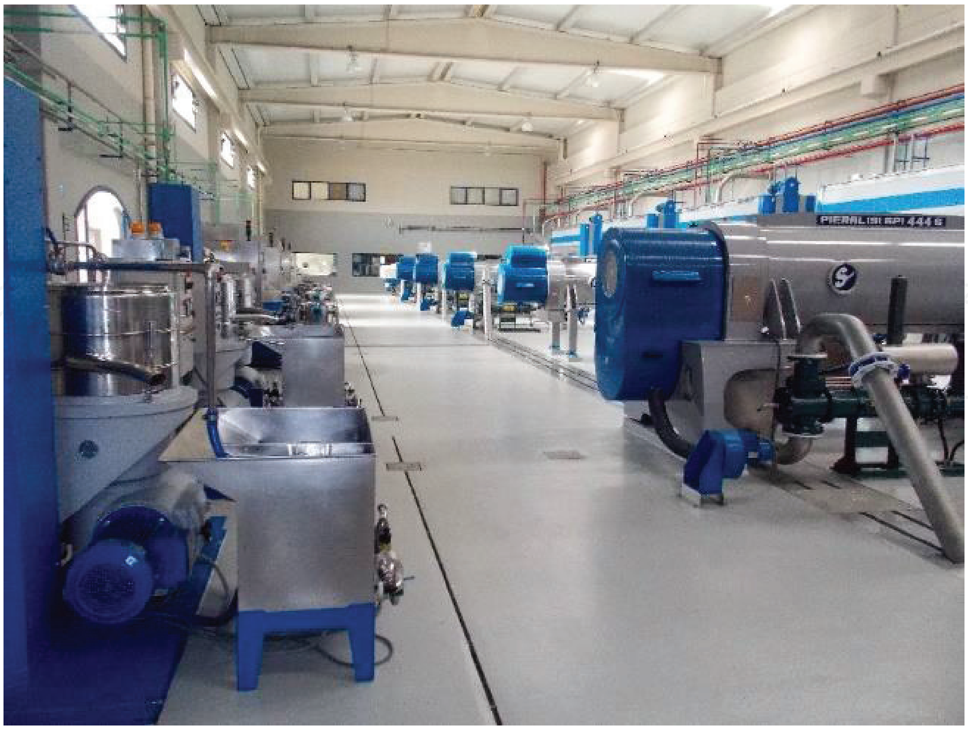

**Figure 7.** Two-phase decanters in series in an olive mill for the extraction of olive oil (Picualia, Proyecto de traslado y perfeccionamento de almazaras por fusiòn de Cooperativas 'Agricola de Bailén virgen de Zocueca', Jaen, Spain) (Source: Marco Nuti).

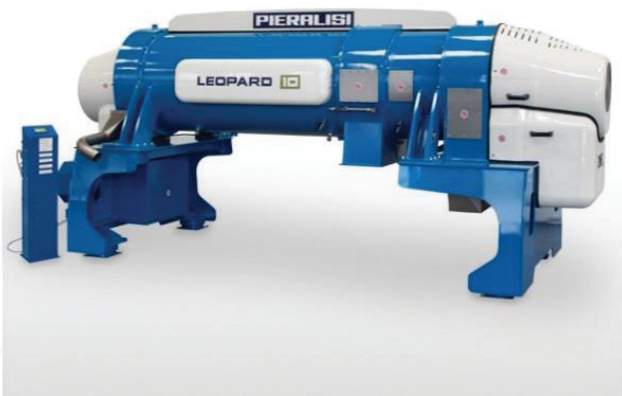


**Figure 8.** Last generation decanter extractors of olive oil, which combines the two-phase extraction technology without the addition of water with batch processing, thanks to the bowl discharging device. The installed power ranges from 7.5 Kw (more adapted to small quantities of olives to be extracted, i.e. process capacity of 0.5 tonnes/hour) to 45 Kw (for very large quantities of olives to be extracted, i.e. process capacity of 9 tonnes/hour) (Source: courtesy of Pieralisi SpA, Ancona, Italy).

bially enhanced composting in mechanically turned static piles. The re-uses at small farm level include (i) further oil extraction as the wet husk still contain 2–4% oil, (ii) delivery by soil treatment into the legally allowed soil acreage, (iii) sale to larger companies, (iv) re-use as fodder for animals, which requires pre-treatment with appropriate enzymes and process, (v) delivery into soil after composting, as a green (i.e. only plant materials) or mixed (i.e. plant

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| Parameter | Time (days) | |
|---|---|---|
| | 0 | 60 |
| pH | 6.4aA | 8.1bB |
| EC (dS $m^{-1}$) | 1.28aA | 0.79bA |
| TN (UoW) | 2.05aB | 1.88bB |
| TOC (UoW) | 46.8aA | 31.9bA |
| C/N | 22.8aB | 16.9bB |
| HA (UoW) | 15.6aA | 41.6bB |
| FA (UoW) | 14.3aA | 19.5bA |
| HA/FA | 1.10aA | 2.14bB |
| HI | 1.1aA | 0.1bB |
| HD | 48aA | 94.5bB |
| HR | 6.4aB | 19.2bB |
| Ash (%) | 8.3aA | 11.6bB |
| Fats (UoW) | 21.5aA | 2.9bB |
| Lignin (UoW) | 47.7 | 27.8 |
| Phenols (UoW) | 14.0bA | 1.6 bB |
| Respiration ($CO_2$–C)mg g-1) | 1087.8aB | 678.3bA |

UoW = units of weight. The microbially enhanced composting (static piles with mechanical turning) was carried out with the use of selected microbial starters [60]. Different letters indicate statistically significant differences ($P < 0.05$). Low case letters, comparison between sampling times within each treatment. Capital letters,comparison between treatments within each sampling time.

**Table 3.** Chemical-physical properties of the initial olive wet husks ($t$ = 0) and of the stabilized compost after 60 days of composting ($t$ = 60) in controlled conditions.

material plus manure) fertilizer. None of the first three options is considered really profitable by small farmers, because pomace oil has a low price with very marginal profit, direct delivery into soil requires a lot of bureaucracy and intoxicates the soil and selling the husks as a fuel is poorly profitable and needs transportation of a material with 70% humidity. If air-dried before transportation, the volatile phenolics can cause air pollution. The fourth option would be feasible, provided that the technology is available to the farmer. The last option is probably the most feasible in-house, provided the farm has a tractor for the mechanical turning of the piles.

## 4. Agronomic and legislative aspects

Agricultural utilization of residues as organic amendments and fertilizers has been shown to be a sound alternative for both residue recycling and soil fertility improvement [16]. The latter goal can be achieved in the frame of a modern agronomic management such as the conservative and regenerative agricultural practices. Regenerative agriculture stands on the three pillars of the conservative agriculture (use of crop rotation, reduction in tillage, retention of adequate levels of crop residues and soil surface cover) plus the maintenance of soil carbon sink. All these management practices can lead to a significant increase of carbon content in soil [30]. In turn, the increase of organic matter and humic fractions in soil determine the increase of soil richness and diversity of microbiota [31]. Therefore the utilization of residues of both coffee and olive cultivation, along with the utilization of the residues of the first step of processing (i.e. those feasible at small farm level in rural areas) cannot be merely identified with their disposal. On the contrary, the utilization of these residues is advisable, particularly because advantages to crops and soil are expected, either in the short- or in medium-term.

More specifically, the good agronomic practices (GAP) adopted for coffee cultivation by both top and low-producing countries, e.g. [32–34], define the criteria leading to a product conforming quality and safety criteria in regimes of both conventional and organic agriculture, and include the use of organic fertilizers and their quality. Though the aims are the same, the rules and recommendations can vary, reflecting the different pedo-climatic characteristics of the cultivation area. The density and productivity of coffee plants per hectare for small holders coffee farms can range from 1332 plants of Arabica, with a very low productivity of about 400 kg in the traditional organic coffee orchards of the Galapagos Islands (Ecuador) [35] to 1100 plants producing up to 3.5 tonnes per ha in Vietnam with Robusta variety grown with high farm inputs [36], or high yields in intensified monocultures with a density of 10,000 plants [37].

Maximizing the small coffee farms seems to be linked nowadays more to the quality of the beans rather than to the yields per ha. In this sense, enhancing the bean quality by minimizing or avoiding chemical inputs and maximizing the re-use of correctly composted residues could help in achieving the task. On the contrary, in intensive coffee cropping systems where the predominant criterion is the harvesting cost, the trend is to have much higher plantation density since it costs almost as much to harvest a low-yield as a high-yield field. But in this case, additional costs could emerge for shading management systems (arborization), for more irrigation inputs, and more plant protection products usage. For the legislative framework of organic fertilizers, biostimulants and microbial-based amendements in coffee-producing countries, most of them have installed recent rules for the safe use, production or import. As an example see the rules in Brazil [38], Vietnam [39] and Colombia [40] among the top producers, and Ecuador [41] among the smaller coffee-producing countries.

The olive tree is considered as one of the cultivated trees with the lowest demand for soil nutrients. This is the main reason why the tree can survive and be productive even in poor, rocky areas with soils mostly derived from hard limestone, e.g. in Greece, Italy and Spain, or in sandy soils in the southern side of the Mediterranean basin, e.g. Tunisia and Morocco. A significant portion of the olive groves can be found, in the small farms of the EU countries, on steep hill and mountain slopes which have been terraced with stone walls to hold the soil. For the olive chain residues, the amount of residues at farm level will be strongly dependent on the density of olive tree plantations. In the actual agronomic management of olive groves in the Mediterranean basin, the density of olive trees plantations ranges from 10 to 15 trees per ha of Tunisian or 40–50 trees per ha of Puglia's (Italy) small farms (due to low water availability) and soil often maintained without cover, to more than 1500 trees per ha in the intensive new cultivation areas of Spain and Italy. The inter-row space, in the intensive cultivation areas, is often left without cover in Andalusia, while many small farmers in Italy have continued to adopt the traditional intercropping of olive groves with vineyards and arable crops (**Figure 9**). In northern and central Greece, farmers have historically combined olive production with arable crops in the same plot. This practice is reputed to be appropriate to ensure a steady economic return year-after-year, irrespective of the weather conditions. The positive contribution of agroforestry mixed with olive groves include continued olive production along with benefits in terms of animal health, appropriate control of manure usage and the creation of wildlife habitats. In a recently started project in the province of Chalkidiki (Crete, Greece), the olive production that takes into consideration both biodiversity maintenance and wildlife habitats showed high performances, whereas the main negative effects included extra costs of management, administrative overburden, the complexity of the planning and field work and aspects related to mechanization [42]. Small farmers in Greece and Italy have identified that intercropping is probably only appropriate where the principal product is represented by the olives for olive oil production, rather than the edible olives which require a relevant use of pesticides. The presence of some understory species in the cropped area is thought to enhance both quality and flavour of the olive oil.

For the residues from olive cultivation and olive oil extraction, in the Mediterranean basin there is an increasing trend to frame the soil application with unprocessed residues into a more stringent legislation. At EU level the matter is regulated by the Waste Framework Directive 2008/98/EC [43], the Directive on Industrial Emission of 2010 [44] implemented by the European Commission in 2012 [45]. For landfill disposal during the whole life-cycle of the landfill, the relevant rules to prevent or reduce the pollution of surface water, groundwater, soil and air, and the resulting risks to human health, are provided by the Landfill Directive 99/31/EC [46]. The EU legislation on this issue has been critically reviewed [47]. At national level, in Spain the disposal of olive chain wastes is regulated [48]. In Italy, the disposal of olive wastes is regulated by the national Law n. 574 of 1996 [49]. In Greece, the disposal of olive wastes is regulated by the national Laws n. 1650/86 and 3010/2002. The present legislative status in Greece does not allow the application of untreated olive mill wastes to soil surface [47].

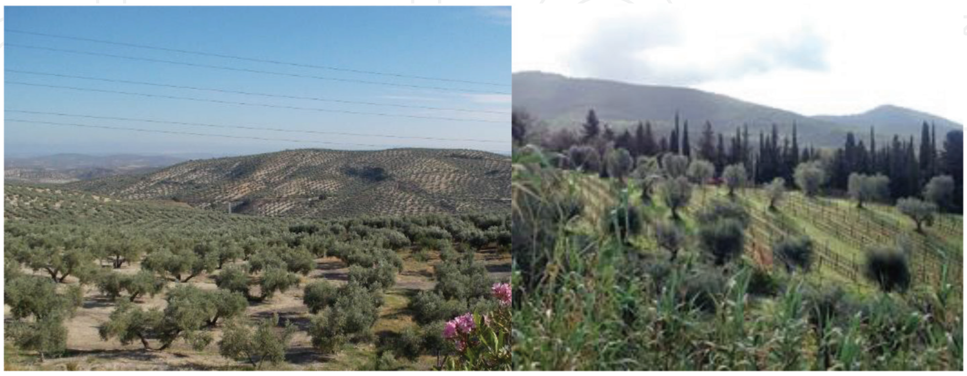

**Figure 9.** Extensive olive tree (var. Picual) cultivation (left) along the 'Carretera de los olivares' between Jaen and Sevilla (Spain). In the province of Jaen there are over 40 million olive trees. The olive cultivars (cv.) mostly grown in Andalucia are Hojablanca, Picual, Lechin, Picudo, Verdial, Cornicabra, Empeltre, Arbequina. In Tuscany (Italy) the small farms often grow olive trees (cv. Leccino, Moraiolo, Frantoio, Pendolino, Leccio del corno, Maurino) intercropped with vines (right) (Source: Marco Nuti).

| | Process and essential components | Minimum content/useful substances | Obligatory to be declared | Notes |
|---|---|---|---|---|
| Green composted amendment | Product obtained through a transformation and stabilization process, in controlled conditions, of organic residues. These can be prunings, olive husks, crop residues, other residues of plant origin. | Max humidity: 50% | Humidity | The content of other forms of N, total P and total K can be declared. |
| | | pH 6–8.5 | pH | Plastics, glass and metals cannot be higher than 2% |
| | | Minimum organic carbon: 20% | Organic C | Stony inerts (diameter ≥ 5 mm) cannot be higher than 5%. |
| | | Humic and fulvic carbon: min 2.5% | Humic and fulvic C | *Salmonella*: absent in 25 g of the sample w.w. (where $n = 5$, $c = 0$, $m = 0$, $M = 0$) |
| | | Organic N ≥ 80% of total N | Organic N | *Escherichia coli* lower than 1.000 cfu (where $n = 5$, $c = 1$, $m = 1000$ cfu/g, $M = 5000$ cfu/g) |
| | | Max C/N: 50 | C/N | Germination index (diluted 30%) ≥ 60%. |
| | | | Salinity | Algae and aquatic plants are allowed, such as Posidonia left on the shores, after separation from sand of the organic fraction. Their content must be lower than 20% of the initial mix. |
| | | | Na content | Thallium must be lower than 2 mg $kg^{-1}$ (only in amendments containing algae). |
| Mixed composted amendment | Product obtained through a transformation and stabilization process, in controlled conditions, of organic residues. These can be by the organic fraction of USR from differentiated recycling of animal waste including liquid waste, residues of untreated wood processing and of the untreated textile industry, organic residues from effluents and muds, and all residues allowed for green composts. | Max humidity: 50% | Humidity | The muds (defined according the Legislative Decree 27 January 1992 n.99, cannot represent more than 35% (w/w) of the initial mix. The content of other forms of N, total P and total K can be declared. Plastics, glass and metals cannot be higher than 2% |
| | | pH 6–8.5 | pH | Stony inerts (diameter ≥ 5 mm) cannot be higher than 5%. |
| | | Minimum organic carbon: 20% | Organic C | *Salmonella*: absent in 25 g of the sample w.w. (where $n = 5$, $c = 0$, $m = 0$, $M = 0$) |
| | | Humic and fulvic carbon: min 7% | Humic and fulvic C | *E. coli* lower than 1.000 cfu (where $n = 5$, $c = 1$, $m = 1000$ cfu/g, $M = 5000$ cfu/g). |
| | | Organic N ≥ 80% of total N | Organic N | .Germination index (diluted 30%) ≥ 60%. |
| | | Max C/N: 25 | C/N | Algae and aquatic plants are allowed, such as Posidonia left on the shores, after separation from sand of the organic fraction. Their content must be lower than 20% of the initial mix. |
| | | | Salinity | Thallium must be lower than 2 mg $kg^{-1}$ (only in amendments containing algae). |

All requirements are expressed in dry weight. The category 'Amendments' includes also manure, artificial manure, green non-composted amendment, composted turf, acid turf, neutral turf, humified turf, leonardite, vermicompost from manure, lignite. Cultivation substrates are in Annex 4, and the products with specific action on plants (e.g. mycorrhizal inoculants) are in Annex 6 of the same Legislative Decree [52].

**Table 4.** Specifications and requirements of the Italian Legislative Decree n. 75 of 2010 (Annex 2) for green composted amendments and mixed composted amendments.

http://dx.doi.org/10.5772/intechopen.69427

Essentially, for the three major olive oil-producing countries the disposal is prohibited or strongly restricted in quantity, land area and timing. Unfortunately, the small farms in marginalized rural areas sometimes tend to overcome the restrictions, mainly because of the small quantities produced, the transportation costs and road difficulties. Also the production and quality of amendments, including those derived from a composting process of the olive cultivation and olive oil extraction process, are regulated by national laws in the EU countries of the Mediterranean basin. In Spain, the matter is regulated by the Fertilizer Act n.7540 [50] and n.13094 [51]. In Italy, the matter is regulated by the Annex 2 to the Fertilizers Act n. 75 [52]. As an example, the requirements of the Italian law for green and mixed amendments are reported in **Table 4**. Emphasis has been given to the source of materials to be used and the transformation process, to the physical-chemical traits of the amendments with particular attention for the level of humification, and to the hygienization and safety aspects. All the different types of amendments (non-composted, green composted, mixed composted) must conform to the limits of heavy metals, namely (in mg per kg dry matter: Pb 140, Cd 1.5, Ni 100, Zn 500, Cu 230, Hg 1.5, $Cr^{6+}$ 0.5). In Greece, the matter is regulated by the Fertilizer Act n. 30(I) of 2006, and n. P.I. 118 of 2006. At EU level, the legislation on fertilizers, i.e. the Regulation (EC) No. 2003/2003 of the European Parliament and of the Council of 13 October 2003 [53], which was cantered on chemical fertilizers only, is actually being repealed by a new legislation that includes the organic fertilizers, biofertilizers and amendments. The approval of the new Regulation is expected by the end of 2017. The agronomic benefits from the use of a correctly composted amendment include a positive effect on soil structure, an increase of phytostimulatory substances, and a direct effect on crop yield. The latter is obtained through an increase of nutrient availability. In addition, as secondary effect it has been often observed that these amendments act as biosimulants or bio-effectors providing an increased biocontrol activity of soil-borne phytopathogens and a substantial soil detoxification. These traits may lead to some difficulty in placing these borderline products into an appropriate legislative framework [54]. The agronomic advantages of delivering green compost from olive waste as a fertilizer for olive groves include the possibility to run organic agriculture, to maintain and increase the soil carbon stocks and to detoxify the cropped area.

## 5. Perspectives of management practices

Different approaches are clearly needed to upgrade the residues of coffee and olive tree cultivation, as well as the processing residues. The variety of approaches is a consequence of the diversity of (a) pedoclimatic areas that include altitude and latitude, soil texture and organic matter content, water regime and availability, (b) level of expertise of the small farmers, (c) social environment that includes training opportunities and availability to create associative forms among producers, (d) access to trade and communication networks, (e) easy access to community-level processing installations.

In the case of coffee, the valorization of residues (**Figure 10**) in agriculture, as animal feed and for energy production, apart from a few minor uses, is still the most attractive application to respond to the challenges of the rapidly evolving socio-economic and poverty problems

**Figure 10.** Solid residues of coffee first step processing (i.e. up to the production of beans) in a small coffee farm in the Andean region (Ecuador). If not properly stored or quickly bio-transformed, the residue can be easily re-colonized by spoilage and pathogenic microorganisms (Source: Cristina Echeverria).

of the farmers in these areas. A minor use of plant leaves in organic coffee farms could be the production of herbal teas, whereas for the extraction of functional products for human food supplement, probably only more centralized processing installations can provide the appropriate machinery and food grade safety standards. Another minor use could be the production of edible mushrooms from (co)composted solid waste, i.e. mucilages and spent coffee grounds. This re-use has long been studied by Cenicafé in Colombia and interesting results were obtained with shiitake [55] and Pleurotus [56] as simple technology among low-income communities in the urban areas of the city of Manizales. However, sanitization and detoxification of the substrate remain the major problems and further development of substrate pre-treatment would help to obtain a mushroom production meeting food-grade safety standards.

The coffee prunings, actually mostly left *in situ* as a mulching agent or as an amendment, may retain their phytotoxity and presence of plant pathogens. Therefore their valorization *in situ* implies that they are processed via composting (or co-composting in farms where cattle manure is available). (Co-)composting will then be made by mixing prunings, leaves, coffee husk (i.e. the skin, pulps and parchment generated by pre- and post-fermentation de-hulling) and eventually manure. The residue amounts are relevant: for 1 tonne of coffee beans produced, ca. 1 tonne of husks are generated (dry coffee processing), while where wet processing is adopted, there will also be a relevant amount of wastewater from washings. The latter could be used to feed biodigesters for biogas production at community level since the process requires installations and machinery of capacity larger than the ones of a single small farm. In this case, transportation difficulties and costs should be taken into account.

The transformation of coffee plantations residues at farm level, along with the residues up to the production of the coffee beans, for agricultural end-of-uses, requires a remarkable improvement of the process as it is actually adopted in most cases by small farmers. The composting process of cultivation residues (prunings, leaves) should lead to the production on-farm of a detoxified, sanitized green composted amendment, suitable for use in organic agriculture, containing living microbial consortia. This goal can be properly achieved if these residues are bio-transformed together with the coffee processing solid waste. The actual composting process, far from being a science-based technology, needs the use of indigenous microbial starter cultures capable to degrade the recalcitrant substrates, to detoxify the phenolic toxic substances, transforming the intermediate and still toxic chemical compounds into useful phytostimulatory substances. In those farms where manure (preferably cow-dung and horse manure) is available, the process of co-composting should lead to a detoxified, sanitized mixed composted amendment. The two processes are different and require different expertises. In both cases, the use of selected starter cultures, bio-compatible among them, allows to include those microbial cultures having relevant phytostimulatory activity to the plants and also bio-control activity towards the most commonly encountered soil-borne pathogens. The use of the mature, sanitized, humified compost obtained in this way as a fertilizer could substantially contribute to strengthen the natural plant defence traits and therefore minimize the density of the soil-borne disease.

The second alternative in small farms could be the re-use of the solid residue as animal feed [57]. In different field trials, pigs and cows fed with up to 15% ensiled coffee pulp and 5% of bagasse showed no negative effects on weight compared to those fed with commercial concentrates, and the pulp used as a fodder in milking cows was shown to replace up to 20% of commercial concentrates. The advantages are that coffee husk and pulp are rich in glucides and minerals. However the presence of (poly)tannic complexes and of caffeine decreases the palatability of husk by animals. Furthermore, the caffeine has stimulatory and diuretic effects and tannins diminish the protein availability and inhibit digestive enzymes. By consequence, the removal of these two anti-physiological components would require pretreatments consisting in repeated washings and the use of commercial inoculants to enhance the fermentation (i.e. silage) process. Therefore this alternative looks less feasible economically at single farm level, and would be probably feasible at more centralized facilities level.

The third alternative of valorization could be the energy production. The use of biogas would fit for heating purposes at single farm level. Some case studies on the coffee processing factories indicate that the exploitation of the residues for the production of electricity is feasible. Studies carried out in Tanzania suggest that from coffee residues it is possible to obtain high methane yields: 650 $m^3$ of methane per tonne of volatile solids for Robusta variety solid waste and 730 $m^3$ methane per tonne of Arabica variety solid waste [58]. However, this alternative is probably more easily accomplished at a centralized facility level due to the engineering and expertise needed, rather than at single small farm level.

It appears, in conclusion, that for the small coffee farms the valorization of solid wastes are in any case tightly linked to initiatives of socio-economic nature, i.e. organize formal training and 'hands-on courses' for farmers, improve the road system and accessibility of the single farms, and facilitate the formation of 'cooperatives' among farmers.

In the case of olive tree cultivation waste, i.e. prunings and leaves, when they are still in the field can be finely cut and used as mulch (**Figure 11**) or ploughed into the soil. Another valorization would be to transform these residues into a humified compost. Recently a

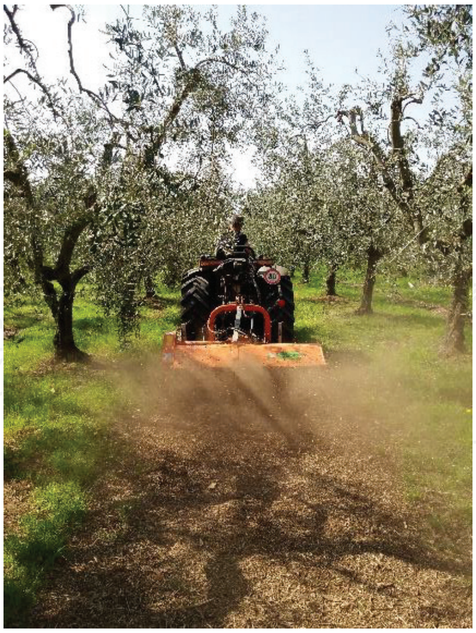

**Figure 11.** A common agronomic practice in small farms for disposal of the olive tree prunings and leaves in situ: they are first placed inter-rows, then finely cut and finally used as mulch or ploughed into the soil (facility 'Azienda La Cerreta', Castagneto Carducci, Livorno, Italy). This practice represents a step forward compared to the burning practice and is considered cost-effective for small farms (Source: Marco Nuti).

composting process of prunings and leaves enriched with phosphate rock has been described in Saudi Arabia [59]. This bio-transformation process has a duration of 8 months, presumably because of the recalcitrance of the lignocellulosic substrate to degradation. In the case of olive oil extraction solid waste (wet olive husks), the most feasible option for small farmers is the re-use in agriculture through composting. This process is a knowledge-based technology, requiring some basic training for farmers. The process has been described by Echeverria et al. [60] at industrial level and can be applied also at farm level [61, 62]. Essentially it is a solid fermentation process carried out with the help of loaders for periodical turning the piles, and is different from static piles composting with/without forced ventilation. The biochemical transformation can be enhanced through the use of starters, prepared with virgin husks enriched with selected microbial cultures. The latter approach, with respect to composting without the use of the starter, allows to achieve deeper humification (i.e. higher content of humic substances), faster deodorization (disappearance of bad smells), shorter maturation time and better detoxification of the starting material. The process duration is, on average, 60– 90 days during which the initial material undergoes profound changes of its mechanical (e.g. particle size, texture), physical-chemical (e.g. pH, humidity, phenol/lignocellulosic content, humification indexes), and biological traits (e.g. sanitization of all potential human pathogens, appearance of bioactive phytostimulatory substances, different microbiological profile). Microorganisms are the main drivers of the transformations occurring in the substrate, and their degradation activity leads to the production of carbon dioxide and minor amounts of other gases which evolve in the atmosphere, and to the production of heat (which, if let uncontrolled, can easily go to >70°C leading to pasteurization of the matrix). From a biochemical point of view, the composting of wet husks must be viewed as a respiratory process which needs oxygen (the appropriate porosity and oxygen presence in the matrix is ensured by turnings and the presence of prunings) and gives rise to carbon dioxide. One of the consequences of the degradation of the substrate components with concurrent carbon dioxide formation is the loss of weight of the substrate, as an average 30–40% expressed in dry matter. Due to heat formation and periodical turnings, the water evaporates and as an average the humidity content decreases from the initial 65–70% to ca. 40% of the compost after 90 days. Complex biochemical reaction does occur too, which involves polycondensation and polymerization reactions leading to the formation of the humic substances useful for the soil fertilization purposes. The initial fresh matrix is toxic to plants, but after composting turns into a plant growth stimulator, due to the presence of auxins and other substances synthesized during the composting process and to the concurrent degradation of phenolic plant growth-inhibitory substances, both processes being of microbial nature. The success of the composting process will ultimately depend on (a) the initial quality of the wet husks and starters and (b) the ability of the operator(s) to maintain the appropriate process conditions leading to the formation of mature compost in the time limits. The conditions will consist mainly in keeping under careful control the main process factors, i.e. oxygenation, heat and humidity. Appropriate oxygen presence and heat control will be achieved through periodical turning the piles when the temperature rises above 50°C (indicated by long-stem thermometers). The appropriate humidity will be ensured through the addition of wastewater, i.e. 60–70% (initial humidity, before composting) to obtain a compost with ca. 40 % (final humidity). The mature compost can be delivered to the farm soils as such for fertilization purposes [63]. In alternative, humidity can be further adjusted by air-drying to the desired level. Humidity below 25% will allow longer storage of the product until use. The use of such a fertilizer on-site is highly compatible with the principles of the regenerative agriculture, i.e. provides the opportunity to maintain and increase the carbon stocks in soil at farm level. This goal, if achieved until the threshold value of organic carbon reaches the minimum value of 3.5%, which allows to maintain the functional soil biodiversity [64]. If, on the contrary, the wet husks are not composted correctly, they will retain their bad odour and phytotoxicity, along with little or any humification of the initial material. In addition to the above described advantages using a correctly made compost as a fertilizer, the presence of microbial consortia, having phytostimulatory activity for the plants besides their fundamental role in the biotransformation of the initial matrix, would help substantially to strengthen the plant natural resources, minimize the attack by soil-borne phytopathogens, and by consequence would allow the use of more eco-friendly land management approaches.

## Acknowledgements

The authors wish to thank Prof. Laura Ercoli for critical reading of the manuscript. This work is part of a Research Grant (Proyecto Café) from UTN, Ibarra, Ecuador to MC Echeverria, PhD.

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