## CHAPTER 7

# Recycling of Organic Wastes to Soil and Its Effect on Soil Organic Carbon Status

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### Chapter Outline



## INTRODUCTION

We bet that maintenance of soil organic C (SOC) has a lot to do with environmental politics, even big global politics. Let us start with this example: the Russian–Chinese friendship in the 1950s resulted in a forestry cooperation. The original climax tropical monsoon forest in the Guangdong province had been destroyed due to human overuse, resulting in severe soil erosion. The suggestion by the Russian advisors was to reclaim the land in southern China by planting highly productive *Pinus massoniana* and *Eucalyptus exserta* trees, a good idea, indeed. In a second stage, these forests were replaced by another artificially mixed forest. However, after a few years the trees ceased to grow. Initially, to supply the forest with nutrients, circular trenches were dug, and in each one domestic waste material was placed. Presumably, this waste material had been predominantly organic, and it delivered nutrients to the trees for years. In 1989 as a result of a joint European–Chinese project the immediate reason for the cessation of growth was discovered: local

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people had, for years, meticulously removed all the litter, and along with it, the carbon and nutrients (Insam, 1990). Compared to a nearby natural forest, the SOC content had dropped from 3.10% to 0.77%. Within 6 years of protection from litter removal, the organic C content recovered to 1.37% (Ding et al., 1992). This story is an example of how organic matter can be replenished by appropriate management measures, and how SOC reminds us about politics.

## Concern About Soil Organic C Loss

How far the concern about SOC loss dates back is not easy to resolve. We know, however, it is not only the nutrients that are responsible for soil fertility and plant health; let us remember the dust bowl of the 1930s that for a decennium threw farmers of the Midwest in poverty. John Steinbeck deplored in his novel *The Grapes of Wrath*: "*And then the dispossessed were drawn west- from Kansas, Oklahoma, Texas, New Mexico; from Nevada and Arkansas, families, tribes, dusted out, tractored out. Car-loads, caravans, homeless and hungry; twenty thousand and fifty thousand and a hundred thousand and two hundred thousand… Like ants scurrying for work, for food, and most of all for land*." Then, in the early decades of excessive mineral fertilization it was realized that organic matter might have some irreplaceable value for maintaining soil fertility. That time, agricultural policy seems to have failed and we should have learned from it. However, having a look at a recent book published by the International Fertilizer Association (Reetz, 2016), which devotes a meager 3 of more than 100 pages to organic fertilizers, shows a certain bias by the industry toward mineral fertilizers. Legal difficulties for marketing novel fertilizers based on organic sources proliferate, and these difficulties may be due, in fact, to extensive lobbying by those incentivized to sell mineral fertilizers. For this reason, the authors attempt some lobbying themselves for organic fertilizers and soil conditioners.

## Carbon Sequestration

SOC can reach soil through two main pathways, directly through plant input (primary production) and through external inputs like products from organic waste (secondary production, if the wastes are not agricultural ones). In addition, some input may be expected from atmospheric deposition (Fig. 7.1). SOC models like the CENTURY (Parton et al., 1987) and the Rothamsted Carbon Model (RothC) (Coleman and Jenkinson, 1996) allow for estimating C balances in soils. The RothC is a model for the

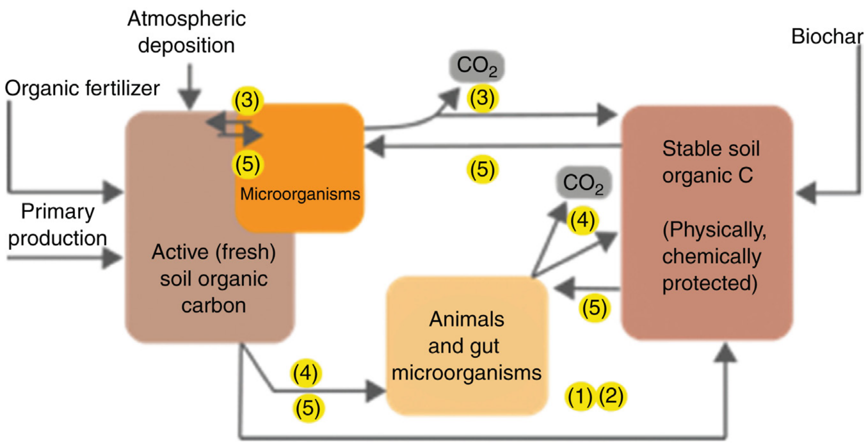


**Figure 7.1** ***How carbon is sequestered into soil.*** (1, 2) Root and shoot debris are formed into soil organic matter (SOM); (3) microorganisms respire C compounds and their biomass eventually becomes part of the SOM pool; (4) plant matter is ingested by animals and residues are transferred to the SOM pool; (5) microorganisms (and soil animals) thrive on SOM and form new biomass.

turnover of organic C in nonwaterlogged topsoil that allows for the effects of soil type, temperature, soil moisture, and plant cover on the turnover process. RothC was originally developed and parameterized to model the turnover of organic C in arable topsoil from the Rothamsted long-term field experiments and was later extended to model turnover in grassland and in woodland and to operate in different soils and under different climates. RothC is designed to run in two modes: "forward" in which known inputs are used to calculate changes in soil organic matter (SOM) and "inverse," when inputs are calculated from known changes in SOM. External input may be fed into these models, which, in general, are very suitable predictors of SOC dynamics.

In a metastudy comprising 21 long-term experimental sites with various management regimes, distributed all over the North American subcontinent, Insam et al. (1989) and Insam (1990) found a distinct relationship of climate and the organic C balance. As the best climatic predictor, they found the precipitation/evaporation ratio (P/E-ratio) (Fig. 7.2). Their C equilibrium model described the $C_{mic}$-to-$C_{org}$-ratio as approaching the minimum when the PE-ratio was around 1 (mean annual precipitation equaling pan evaporation). Any measured $C_{mic}$-to-$C_{org}$-ratio deviating from the model equilibrium line would indicate an imbalance in the SOC status. In particular, $C_{mic}$-to-$C_{org}$-ratio higher than the prediction for a certain climate would

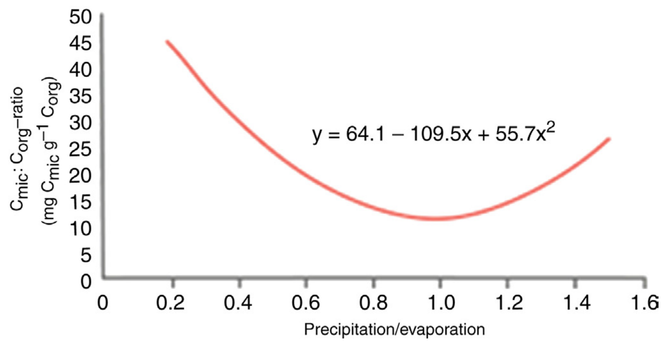


**Figure 7.2** ***Baseline for organic C balance.*** If the $C_{mic}$-$C_{org}$-ratio is above the equilibrium line, a soil is gaining carbon, otherwise it is losing carbon under the prevailing climatic condition *(after Insam, 1990)*.

**Table 7.1** mg $C_{mic}$ $g^{-1}$ $C_{org}$ for the two main groups of fertilization and cropping practice

| Mineral fertilizer | | Manure | |
|---|---|---|---|
| **Monoculture** | **Crop rotation** | **Monoculture** | **Crop rotation** |
| 16.6 ± 0.4 (66) | 19.9 ± 0.3 (102) | 18.0 ± 0.5 (48) | 22.5 ± 0.7 (54) |
| 18.3 | | 20.3 | |

Mean ± standard deviation (in parentheses, number of observations, *n*).
Source: From Insam, H., Parkinson, D., Domsch, K.H., 1989. Influence of macroclimate on soil microbial biomass. Soil Biol. Biochem. 21, 211–221.

indicate that the soil would be in the status of C gain, or below the equilibrium line a C loss would be indicated. Comparing differently managed soils, it was shown that both fertilization practice (mineral fertilizer versus manure) and cropping practice (monoculture versus crop rotation) had a significant impact on SOC status (Table 7.1). Extra organic input (manure) increased $C_{mic}$-to-$C_{org}$-ratio from 18.3 to 20.3, an indication of increasing C accumulation.

## ORGANIC WASTES AND PRETREATMENT OPTIONS

Domestic waste composition, collection, and treatment have considerably changed all over the world since the onset of the aforementioned afforestation experiment. Nowadays, in many countries organic waste is source-separately collected, or there is at least a mechanical sorting of the original waste to obtain an organic fraction. Wastewater treatment with resulting aerobic or anaerobic sludges is implemented in many places, and the residual slurries are often in a quality that may allow for utilization for agricultural, horticultural, or forestry purposes. The impact of manure-based biogas fermentation residues (digestates) on soil fertility has been recently reviewed by Insam et al. (2015). Agricultural wastes have long been used for fertilizing soils, or for maintaining SOM. However, due to an industrialization of agriculture, wastes like manure, liquid manure, or straw are often found in centralized operations where an ultimate use on soils is impossible.

The use of appropriate management technologies, involving the stabilization of the waste prior to use or disposal, could mitigate the health and environmental risks associated with the local overproduction and the application of excessive amounts of organic waste (Gómez-Brandón and Podmirseg, 2013). Composting and vermicomposting have been used, either separately or in combination with each other, for processing wastes from different origins under aerobic conditions (Gómez-Brandón and Domínguez, 2014). Unlike composting, vermicomposting depends on the joint action of earthworms and microorganisms and does not involve a thermophilic phase as classical composting does. During these biological processes organic wastes are transformed into a safer and more stabilized product, with benefits for both agriculture and the environment, thereby resulting in a more balanced nutrient mix and increased nutrient bioavailability for plants in comparison with the untreated waste (Gómez-Brandón and Domínguez, 2014). Indeed, composted materials have been shown to provide manifold benefits when used as soil amendments, as they increase SOM levels, soil porosity, and aggregate stability. They may also lead to an increase in soil microbial biomass and activity (Ros et al., 2006a,b), which could be attributed to the activation of the indigenous soil microbiota by the supply of C-rich organic compounds contained in the composts. Furthermore, C addition to soil seems to select for specific microbial groups that feed primarily on organic compounds therefore also leading to changes in microbial community composition (Carrera et al., 2007; Ros et al., 2006b).

Anaerobic digestion (AD) has also become an important technology for recycling wastes from different origins due to the fact that the available fossil fuel reserves are decreasing, and the biogas produced by AD can be utilized as an ecofriendly energy source (Insam et al., 2015). However, the sustainability of the production of biogas depends on the proper use of the digested material, which must be treated, disposed of, or reused properly, to avoid any negative environmental impacts (Insam and Wett, 2008; Insam et al., 2015). The use of the digested material as an organic fertilizer in agriculture seems to be an optimal option for its use, because it contains significant amounts of residual organic C and nutrients for plants (Alburquerque et al., 2012a,b). According to Odlare et al. (2011) the C in biogas residues is more easily degradable than that of composts because the mineralization is less efficient under anaerobic conditions. Consequently, when biogas residues are applied to soil, their C is expected to be more rapidly metabolized, leading to an increase in soil microbial biomass in the short term (Insam et al., 2015). However, Gómez-Brandón et al. (2016) found that the addition of digestates was not accompanied by a significant long-term increase in soil microbial biomass and activity assessed as substrate-induced and basal respiration, compared to the unamended soil and raw manure, after 15 and 60 days of incubation.

Overall, AD appears not to negatively affect the SOC status in the long term (Insam et al., 2015) compared to composting. Nonetheless, as pointed out by de la Fuente et al. (2013) a posttreatment of digestates via liquid–solid separation or composting, might further increase their C sequestration potential. All in all, this will help to maintain the organic matter in the soil after the use of biogas residues as organic amendments and ultimately, it will lead to positive effects on crop yields and soil microbial functions (Abubaker et al., 2012; Insam et al., 2015). Future research dealing with longer term studies and varying the source and application rate of digestates will contribute to gain knowledge into the agronomic effects of biogas residues into soil and their impact in SOC.

## Agricultural, Horticultural, and Silvicultural Sources

An overview of the various sources of organic wastes and their potential use as biofertilizers after appropriate treatment and quality-check/risk assessment is given in Fig. 7.3. The constraints and the potential for the use of these organic wastes in agriculture will be discussed, bearing in mind that organic farming—based on recycling of organic wastes/by-products—is considered as the backbone of sustainable agriculture with the chief objectives: (1) to adopt ecofriendly and modern techniques to recycle rather than discard precious organic material; (2) to reduce the environmental impact, health issues, and high cost of landfilling (on average 80 € $T^{-1}$ landfilling tax in EU) or diverse storage (e.g., random piles); (3) reduce the environmental impact of chemical fertilizers; and (4) produce high amounts of high-quality products. All in all, there is still the urgent need of finding and/or applying sustainable solutions for modern agriculture and economies (Hofer, 2009).

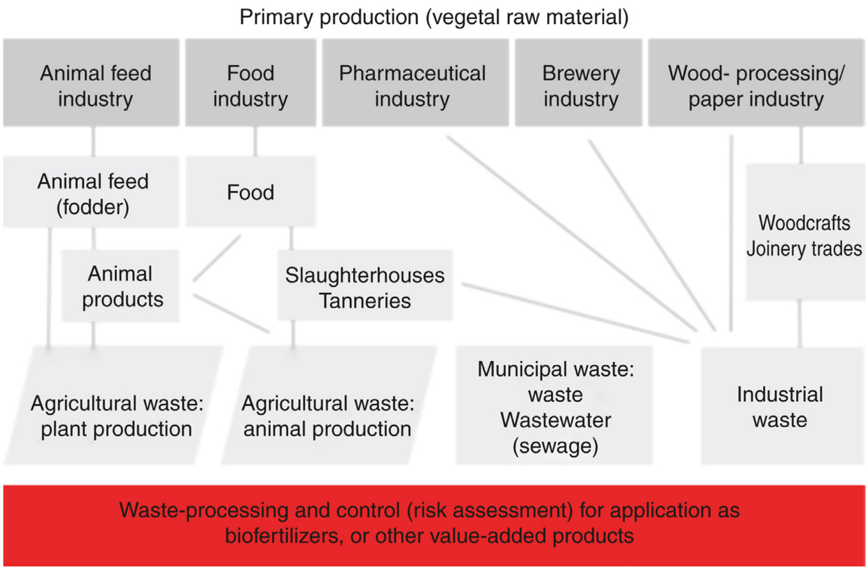


**Figure 7.3** ***Different sources of wastes as potential biofertilizers or other value-added products.***

### *Animal Production*

Large amounts of livestock products, for example, manure, litter, compost, and wastewater, are readily available due to an increased growth of confinement livestock and poultry operations. Their use in agriculture for crop and forage production is convenient for multiple aspects: cost-effective strategy to beneficially manage large amounts of by-products from animal production; supply of plant nutrients (especially N and P), ideal for contrasting the N and P limiting crop production; increase of SOM with benefits for plant growth and yield. Anyway, in order to guarantee the environmentally friendly use, adequate storage, use and land application recommendations have to be strictly followed, so as to prevent/avoid any potential public health and environmental impact (Sorathiya et al., 2014), for example, contamination of (1) surface and groundwater by excessive N (mobile nitrate); excessive P (stimulation of aquatic plant growth with risk of eutrophication); organic matter associated with manure (reduction of dissolved oxygen in water bodies); heavy metals (e.g., Cu, Zn, As); harmful pathogens (e.g., bacteria and viruses); antibiotics; and (2) air quality due to odors associated with animal production, as a result of decomposition of organic material, such as feed, manure, and mortalities; among the most frequent noxious gases resulting from anaerobic decomposition of complex liquid biological wastes are $CH_4$, $H_2S$, $CO_2$, and $NH_4$ (Gerber et al., 2005). In fact, livestock waste is a major source of pollution, pathogens, odor, and greenhouse gases (GHG). Of the global GHG production, 16% is methane, of which approximately 20%–25% directly are derived from livestock (Sorathiya et al., 2014). Livestock waste can be recycled in many modern ways in order to combat rising energy prices, promote sustainable agriculture, and reduce the environmental threats from traditional livestock waste management practices (Sorathiya et al., 2014), and most importantly used for sequestering C into the organic soil pool.

### *Agricultural Primary Production*

Johansson et al. (2010) have constructed a database of global agricultural primary production to estimate its net energy content and postharvest losses, focusing on sustainable recycling of crop residues and bioorganic wastes for efficient biofuel production. This database enables calculating the energy content of crops and residues globally, and for the member states of the European Union. Within the context of global change, the mitigation of GHG emission has been placed at the top of the global issues to be addressed. Considering agricultural soils as potential sinks for atmospheric $CO_2$ due to their C sequestration potential, sustainable cropping management has become crucial for the global C budget (Liu et al., 2014; Wang et al., 2016).

The annual SOC sequestration rate of cropping systems with recommended management was estimated to be 0.4–0.8 Pg C globally, accounting for 33.3%–100% of the total potential of soil C sequestration worldwide (Liu et al., 2014). Straw return is among the most convenient recommended management strategies, capable of increasing SOC sequestration in croplands. Liu et al. (2014) performed a meta-analysis on the net global warming potential balance of straw C input (straw-return practice) to manage C sequestration in agricultural systems, based on the dataset derived from >170 field studies, by calculating the response ratios of SOC concentrations, GHGs emission, nutrient contents, and other important soil properties to straw addition. These authors concluded that straw return significantly increased (1) both the total and active SOC concentrations; (2) $CO_2$ emissions in both upland and paddy systems, (3) $CH_4$ emissions only in rice paddy soils; and (4) $N_2O$ emission in paddy soils, while a decline was recorded in upland soils. The aforementioned information about C budget effects (i.e., straw return increased C sink in upland soils but increased C source in paddy soils due to enhanced $CH_4$ emission), points out the importance to differentiate between upland and paddy soils for future agroecosystem models and cropland management. Overall, the potential of straw-return practice to improve SOC accumulation, soil quality, including soil nutrient status, and crop yield has led to (1) positive correlations between macroaggregates and crop yield with increasing SOC concentration; (2) significant effects on SOC dynamics of the straw-C input rate and clay content; and (3) a significant positive relationship between annual SOC sequestered and duration, suggesting a soil C saturation after 12 years under straw return.

Recently, Wang et al. (2016) used the soil C model RothC to assess the critical C input for maintaining SOC stocks in wheat systems at global scale as a baseline for assessing soil C dynamics in croplands under changing scenarios (management practices vs. climate). The critical C input was estimated to be 2.0 Mg C $ha^{-1}$ $yr^{-1}$, with a large spatial variability depending on local soil and climatic conditions. Due to the higher soil C stocks present in wheat systems of central United States and Western Europe, higher C inputs are required. The authors suggested a metamodel driven by current SOC level, mean annual temperature, precipitation, and soil clay content to be capable to effectively estimate the critical C input, so as to reduce or reverse C loss in agricultural soils.

### *Wastes From Forestry/Wood Industries*

The forest-products industry based on the use of wood as raw materials, for example, lumber, furniture, paper products, and pulp, can be divided into (1) primary wood-products industry (from lumber production to the manufacture of finished products (Burton et al., 2003; Pentti et al., 2002); and (2) the value-added or secondary forest-products industry processing raw or semiprocessed materials (e.g., production of pallets and light furniture), both generating large amounts of wood wastes, that is, unsuitable material for the production of wood products, including also low-quality raw material (e.g., bark, small chips, saw dust, wood edges) (Murphy et al., 2007; Top, 2015). Wood wastes, classified into bark, coarse and fine waste, are potential biomass resources (Skog et al., 2011) for either (1) *energy applications* (combustion in wood burners or larger biomass boilers to cover energy demands of homes or industrial enterprises; at an industrial scale, forest residues and waste wood can be converted into advanced biofuels or intermediates through various thermochemical pathways (http://biofuelstp.eu/forest.html); or (2) *nonenergy applications* (production of composite boards and wood pulp; land reclamation; animal bedding material; landscaping; agricultural mulch; and landfilling (Murphy et al., 2007; Top, 2015).

The technological platform "European Biofuels" (https://ec.europa.eu/energy/en/topics/renewable-energy/biofuels) offers insights into the state of the art of advanced technologies of bioenergy and biofuels production from different types of forestry sources: (1) residues from harvest operations that are left in the forest after stem wood removal, such as branches, foliage, roots; (2) complementary fellings, which describe the difference between the maximum sustainable harvest level and the actual harvest needed to satisfy round wood demand; (3) wood wastes from, for example, construction or demolition wastes; and (4) waste from manufacturing of wood-based products. Furthermore, this web-platform also highlights the environmental and commercial benefits of harvesting biomass to both maintain and optimize forest health (e.g., removing diseased and hazardous trees) and to provide valuable feedstock for bioenergy production.

Importantly, some forest residues must be left in situ to provide ecological benefits, for example, to provide various habitats and as such preserve biodiversity, guarantee soil nutrient status, and improve overall soil quality. In fact, deadwood plays an important role in the functioning of forest ecosystems and their structure, contributing to maintaining the biodiversity and natural regeneration in forests, as well as influencing nutrient cycling and overall C storage (Gómez-Brandón et al., 2017; Petrillo et al., 2016).

## Domestic Wastes in Their Broader Sense

### *Separately Collected Organic Part of the Solid Waste*

Source-separate collection (Fig. 7.4) has been a major push for proper recycling programs for organic matter in many countries. As an example of a straightforward strategy, the Austrian Compost Ordinance (2001) offers an unprecedented end-of waste-option for organic waste that underwent precisely defined treatment, that is, composting. Beyond conventional agriculture, the end-product compost may even be used in organic agriculture as long it meets certain additional specifications, for example, related to heavy-metal contents. Since 2001, nearly 100% of Austrian organic waste is composted, or treated in analogy by AD. No data are available about how this has changed overall organic matter content of Austrian soils but based on the data we know from various models, the impact must have been considerable. Per capita, the annual production is 111 kg organic waste, or more than 4 mio T per year for the country. At an estimated water content of 80%, this is 800.000 T per year organic dry matter of which around 400.000 T remain after the composting process. With this amount, it may


**Figure 7.4** ***Source-separate collection is a prerequisite for good quality recycling.***

be estimated that each of the 1.3 Mio ha of agricultural land in Austria has, per year, received more than 3 T of additional high-quality organic matter, which is, in the long term, a considerable amount! Nonsource-separate collection of organic waste would not provide a recycling product of a quality good enough to allow for long-term agricultural use.

### *Waste Water and Sewage Sludge*

As a result of rapidly increasing population, urbanization, and industrialization, wastewater production and sewage sludge generation have increased manifold (Usman et al., 2012). While sewage sludge was regarded in the past as a waste product due to its expected high level of contaminants (e.g., harmful pollutants, pathogens, heavy metals, and synthetic materials) and therefore mainly incinerated, dumped on occasion or landfill, nowadays, due to escalating high cost of mineral fertilizers, there is an increasing trend of processing and using sewage sludge in sustainable agriculture. In fact, sewage sludge/biosolids, the by-products of municipal and industrial wastewater treatment, are rich in organic matter, macro- and micronutrients, and as such potential and low-cost sources as fertilizer and soil conditioner for food, vegetable crops, horticultural plants, and pasture, which in most cases can be beneficially recycled (Usman et al., 2012).

Among the most effective treatment processes of sewage sludges are pasteurization; mesophilic AD; thermophilic aerobic digestion; composting (windows or aerated piles); lime stabilization of liquid sludge; liquid storage; and dewatering and storage. Among the different types of sludge used in Europe there are (1) liquid sludge (resulting from sedimentation of screened sewage; 2%–7% dry solid containing up to 75% OM); (2) untreated sewage cake (formed by dewatering of liquid sludge with soil-similar consistency and farm yard manure-similar microbiological characteristics); (3) conventionally treated sludge (digestion); (4) enhanced treated sludge (heat treatment of dried, lime pasteurized, or digested sludge); (5) composted sludge (odorless friable soil-like material rich in P); and (6) lime-treated sludge (lime amendment of undigested sludge cake generates friable products with high pH) (Usman et al., 2012).

Compost as a product from both source-separate collected organic waste as well as sewage sludge needs to make sure to meet the basic requirements for both stability and hygienization. In terms of stability it is recommended to use mature compost, if possible of Rottegrad V (Table 7.2). The more mature a compost is, the more humified is the organic matter and the longer will the half-life of the carbon be.

Danon et al. (2008) showed that after maturation, the microbial community composition of composts is still changing while no changes in chemical properties can be found. An additional *curing phase* that improves the benefit of composts is still disputed. Plant-disease suppressiveness, one of the main properties of good composts, has not been shown to improve with prolonged curing, but it may be possible that the mobilization of soil indigenous organic matter through addition of fresh composts (also known as priming effect) is reduced. This could mean an additional benefit for the long-term SOM status.

**Table 7.2** Rottegrad of composts is measured by a self-heating test in Dewar-flasks

| Rottegrad | $T_{max}$ in °C | Product |
|---|---|---|
| I | >60 | Fresh compost |
| II | 50–60 | Fresh compost |
| III | 40–50 | Mature compost |
| IV | 30–40 | Mature compost |
| V | <30 | Mature compost |

#### *Organic Fraction of the Waste (Collected in Bulk, and Then Separated)*

Municipal or household wastes, generated from several sources with variable human activities, and from different socioeconomic areas all over the world, are highly heterogeneous in nature (Miezah et al., 2015; Valkenburg et al., 2008) having variable, source-dependent physical characteristics (e.g., food waste, yard waste, wood, plastics, papers, metals, leather, rubbers, inert materials, batteries, paint containers, textiles, construction, and demolishing materials), which makes their utilization as raw materials challenging. Therefore, prior to figuring out any appropriate treatment process, there is the need of source sorting/waste fractionation, so as to obtain qualiquantitative data on the various waste fractions (organic versus nonorganic wastes). In fact, effective recycling relies on effective sorting. Among the most common methods for waste sorting adopted by waste disposal companies in Europe there are (1) trommel separators/drum screens; (2) Eddy current separators; (3) induction sorting; (4) near infrared sensors (NIR); (5) X-ray technologies; and (6) manual sorting (https://waste-management-world.com/a/waste-sorting-a-look-at-the-separation-and-sorting-techniques-in-todayrsquos-european-market).

### Industrial Wastes

#### *Wastes From the Food Industry*

Among food-processing industry-derived wastes the main waste streams are fruit-and-vegetable wastes, wastes from dairy, olive oil, fermentation industries, meat, poultry, and seafood by-products (Kosseva, 2009, 2013) along with vast volumes of aqueous wastes (Grismer et al., 2002). The problem with the utilization of such wastes is often their centralized availability, incurring high transportation costs. Often, the production of biomethane, and a solid–liquid separation of the digestate make sense for its further utilization, for example, after a stabilization process by composting.

One example from the food industry is olive oil production. Due to different ways of extraction of oil from olives, different waste streams are known. Recently, the trend points toward the production of *alperujo*, wet solid lignocellulosic material also containing mashed olive stones. Alperujo may be composted and yields good quality in terms of nutrient content, stabilized and nonphytotoxic organic matter, and low heavy-metal contents best suited as a soil amendment (Alburquerque et al., 2011). While AD of olive mill effluents has proven feasible in combination with cattle manure, household waste, sewage sludge, poultry manure, wine-grape and slaughterhouse wastewater, and laying hen litter, there are only few studies that have shown the codigestability of two-phase olive mill wastes (TPOMW, alperujo); for example, Goberna et al. (2010) who found cofermentation of cattle manure with alperujo a suitable treatment option yielding biogas and fertilizer.

### *Wastes From the Pharmaceutical Industry*

Herbal pharmaceutical industries generate large volumes of wastewater containing alkaloids, plant extracts, heavy-metal ions, and toxic solutes (Vanerkar et al., 2015). This wastewater must not be discharged, but treatment efforts are necessary. A feasible option is the treatment with microalgae that may then be used for biomethanization, and composting as a posttreatment.

Organic wastes from the pharmaceutical industry often are based on the biomass of fungi or bacteria that are used for metabolite production. The study by Ceccherini et al. (2007) on how to "dis-activate" fungal biomass, that is, to degrade DNA (antibiotics encoding genes)—the by-product of antibiotics production (Cephalosporine from *Cephalosporium* sp.)—provided the basis for obtaining a European patent (EP 1 529 766 B1). Overall, it can be seen as a practical example of successful biowaste processing for environmentally safe agricultural application as biofertilizer, known to have beneficial effects on the biological, chemical, and physical properties of the soil (Aescht and Foissner, 1992; Haselwandter et al., 1988; Nannipieri et al., 2017a,b), and to avoid the risk of potential genetic exchange (horizontal gene transfer) in soil via natural transformation (Pietramellara et al., 2006, 2009).

It is beyond the scope of this review to address numerous further specific organic industrial wastes from tanneries, slaughterhouses, bakeries, fruit processors, breweries, and so on. Fact is, if there is no other added value that can be generated from such wastes, like bulk chemicals, or feed protein, stabilized organic matter would always be a beneficial product aiding soil functional properties.

## WHICH OPTIONS FOR WASTE UTILIZATION DO WE HAVE?

The utilization of by-products and waste materials from animal production (meat, poultry, and fish processing industries) has been recently reviewed by Jayathilakan et al. (2012). Furthermore, ecofriendly and modern methods of livestock waste recycling for enhancing farm profitability and reducing/avoiding public health and environmental concerns has been critically reviewed by Sorathiya et al. (2014). As mentioned earlier, there is a broad spectrum of available biomass resources for energetic use deriving from different industries or household (Fig. 7.3). Organic residues, by-products, and waste can be classified in herbaceous biomass (e.g., straw, landscape conservation material), wood (e.g., forest residual wood, industrial residual wood) and other biomass (e.g., excrements, organic industrial waste) (Hofer, 2009). In order to estimate their energetic biomass potential, not only the "technical potential" (the total amount of available biomass evaluated by considering technical restrictions), but also structural, environmental, and legal restrictions have to be considered (Hofer, 2009). The forest biomass potential includes the wood not used as a raw material, that is, firewood and forest residual wood (Hofer, 2009).

Next to recycling organic wastes for energetic purposes, there is the well-targeted production of plant biomass for green energy, estimating also the required amount of biomass to replace fossil oil (Henry, 2010) and the bioenergy production potential of global biomass plantations (Beringer et al., 2011). The example of targeted plant cultivation in Central Western Europe (e.g., Federal Republic of Germany) shows the cultivation of different types of plants for different purposes: (1) thermochemical conversion (mixed cultivation of lignocellulosic plants for producing solid biofuels); (2) physical–chemical conversion (e.g., rape-seed cultivation); and (3) biochemical conversion (two-culture system for producing substrates for biogas- and ethanol production) (Hofer, 2009).

A team of Swedish researchers (Röös et al., 2016) recently developed a promising model for designing and assessing the sustainability of "fair" diets, based on the globally available arable land per capita. The authors concluded that the proposed concept of using "ecological leftovers for livestock production" is capable to design diets using food produced on (Swedish) agricultural land that satisfy both nutritional and environmental recommendations. Anyway, although their model is advantageous with respect to current diets, the production of these "fair diets," including a drastically reduced consumption of meat, still results in environmental impacts that cause several planetary boundaries to be transgressed, but is suggested to provide a promising basis for sustainable livestock consumption.

Grape marc compost, as another example, is an excellent fertilizer and due to its high tannin contents, an excellent plant growth promoting and disease suppressive agent that, at the same time, is best suited to build up SOM (Carmona et al., 2012). Various other industrial wastes like those from the pulp and paper industry, tanneries, breweries, and other operations are available, however, their reutilization are not covered in this chapter.

## QUALITY CRITERIA FOR THE USE OF WASTES

If waste materials are eventually converted into products for use in agriculture, horticulture, or forestry it has carefully to be evaluated which valuables (amount and binding forms of micro-, macronutrients, carbon compounds) and pollutants they contain. The pollutants of concern are heavy metals, toxins, antibiotics, and xenobiotics. In particular, because of heavy-metal loads, sewage sludges have been poorly reputed for years, their qualities in terms of lowered heavy-metal loads, however, are increasing.

## GLOBAL CHANGE ASPECTS

The Marrakech Accords allow biospheric, including soil, C sinks and sources in forests, croplands and pastures to be included to meet emission reduction targets for the first commitment period of the Kyoto Protocol. It is estimated that European Union croplands lose 78 Tg (C) per year, thus there is significant potential to decrease the flux of C to the atmosphere from cropland, and for cropland management to sequester soil C, relative to the amount of C stored in cropland soils at present. The biological potential for C storage in European (EU 15) cropland is of the order of 90–120 Tg (C) per year, with a range of options available that include reduced and zero tillage, set-aside, perennial crops, deep rooting crops, and, importantly, efficient use of organic amendments (animal manure, sewage sludge, cereal straw, compost), improved rotations, irrigation, bioenergy crops, extensification, organic farming, and conversion of arable land to grassland or woodland. For socioeconomic and other constraints, a realistically achievable potential is estimated to be about 20% of the biological potential. If C sequestration in croplands is to be used in helping to meet emission reduction targets for the first commitment period of the Kyoto Protocol, the changes in soil C content must be measurable and verifiable, which is considered difficult within a 5-year commitment period. Soil C sequestration is a riskier long-term strategy for climate mitigation than direct reduction of C emissions. However, improved agricultural management often has a range of other environmental and economic benefits in addition to climate mitigation potential, and this may make attempts to improve soil C storage attractive as part of integrated sustainability policies (Marmo, 2008; Smith and Falloon, 2005; Wiesmeier et al., 2014).

## SOIL SUSTAINABILITY

Apart from the important effects on mitigation of climate change, we should still keep in mind the beneficial effects of high organic matter pools in soils that aid the maintenance of a high microbiological diversity, high water and nutrient holding capacity, better textural properties of the soils that altogether improve the resistance and resilience toward disturbances. Increasing SOM may always be seen in the context of making agricultural, horticultural, and forest operations more sustainable. SOM models should help in quantifying the effect of organic matter management by returning C from wastes to fields.

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