9

Recycling Organic Waste Products in a Tropical Context

9.1. Definition, typology and main characteristics of organic waste products

9.1.1. *Definition of organic waste products and associated issues*

Organic waste products are defined as all residues of an organic nature and of agricultural, urban or agricultural–industrial origin emphasized in agriculture. A millennial practice competed by mineral fertilization in the 20th Century, the recycling of these organic waste products is arousing a strong revival of interest because of agronomic, environmental and societal issues. Indeed, there are several agronomic interests. Increasing the organic matter content of soils improves their physical properties (stability, aggregation, porosity, water retention capacity, etc.), chemical properties (pH, cation exchange capacity [CEC]) and biological properties (quantity, diversity and activity of microorganisms). By promoting the recycling of organic waste product fertilizers at the expense of synthetic fertilizers, farmers save fossil fuels used for their manufacture and store carbon in the soil; the international initiative 4 ‰ promotes this effect [DER 16, MIN 17]. In addition, for phosphorus resources which are limited, closing the biogeochemical loops appears to be indispensable in the long term [RIN 14]. For farmers, in addition to the direct benefits (costs, availability of organic

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waste products), there are possible services rendered (recycling of waste, sustainability of agricultural systems and resources), which make this practice part of an essential societal approach [JON 13].

In tropical contexts, and particularly in sub-Saharan Africa, the decline in soil fertility is partly linked to decreases in organic matter levels, particularly in sandy textured soils, where cation exchange capacities are the lowest [AUN 97, HAR 06, VAN 92]. A sustainable rehabilitation of these impoverished soils necessarily involves adding organic matter with improving properties [BAT 91, DE 90]. However, all these organic waste products have an ambivalent character, given that they possess undeniable agronomic qualities, but, moreover, can induce environmental risks. It is therefore fundamental, in the first instance, to know the methods and the main techniques of characterization of organic waste products. Their fertilizing properties are more difficult to deal with than with mineral fertilizers, but organic waste products also have soil amendment properties. Beyond the direct agronomic benefits, the potential environmental risks must be known and controlled. Lastly, the use of organic waste products is of interest both in highly intensified systems, such as peri-urban market gardening, and in systems where intensification levels are low.

9.1.2. *Typology of organic waste products*

9.1.2.1. *Origin of organic waste products*

Organic waste products are generated by agricultural, urban and agroindustrial activities. In this sense, most of them have basic properties (origin, physical characteristics and chemical composition, transformation, etc.) and usages that are quite similar to those of developed countries. Organic waste products of agricultural origin are the most diversified and present the biggest volumes [SMI 14]. In Africa, recoverable animal feces[1] are mainly poultry droppings, on different types of support (rice straw, shavings, etc.), cattle dung recovered from corrals and horse dung [BLA 14]. Organic waste products of urban background are mainly sewage sludge, municipal solid waste compost and household waste. In recent decades, the development of large cities has been very rapid in the countries of the South.

1 Animal manure produced directly in the field is sometimes not counted, although it can contribute greatly to soil fertilization.

Most of the infrastructures related to waste and wastewater collection have not been able to keep up with this frenetic pace and the effectiveness of these collections has repercussions on the volumes recovered, and even on their characteristics. Organic waste products of agro-industrial origin are essentially slaughterhouse waste, liquid effluents from the agro-food industries and, depending on the context, fishmeal, sugar cane molasses, peanut shells, empty fruit bunches, oil cakes, etc.

These different organic waste products can be spread alone, mixed together and, furthermore, undergo biological, physical or physical–chemical treatment (Table 9.1). Thus, in addition to the initial diversity of organic waste products, there are numerous possible treatments and mixtures that are ultimately generating a multitude of organic waste products with variable characteristics and properties [BLA 14].

Origin / Treatment	Agricultural	Urban			Agro-industrial
	Livestock manure	**Sludge from sewage treatment plants**	**Green waste**	**Household waste and biowaste**	**Effluents**
No treatment	Alone	Alone		Alone	Alone
Composting	Alone or mixed	Mixed	Alone or mixed	Alone or mixed	Alone or mixed
Anaerobic digestion	Alone or mixed	Alone	Mixed	Alone or mixed	Alone or mixed
Physical and physical–chemical treatments	Thickening, drying	Thickening, dehydration, drying, liming		Manual sorting, liming	

Table 9.1. *Typology and use of organic waste products; classified according to their origin and biological, physical and possible physical–chemical transformation*

9.1.2.2. *The main treatments for organic waste products*

Composting is an aerobic process of transforming organic matter. Sugars, amino acids and other easily degradable compounds are used by naturally occurring microorganisms and fungi, causing an increase in temperature of up to 70°C. Then, during the maturation phase, the temperature gradually decreases. The main benefits of composting are the reduction of volume (up to 50%) and mass (up to 60%), by loss of water and carbon, hygienization during the rise in temperature, stabilization of carbon and nitrogen, and conservation of most mineral elements of agronomic interest [MIS 05, MUS 09]. In tropical contexts, composting is carried out on platforms (Figure 9.1), in piles (Figure 9.1), in windrows or in pits (Figure 9.2). It lasts several months and requires a certain technicality and significant manpower in order to regularly overturn the compost, water it and monitor its evolution [MIS 05].

Figure 9.1. *On the left, two different compost piles at the edge of the field. On the right, a small composting platform, a few square meters in size, where crop residues are stored pending mixing with liquid effluents, such as digestates of methanation (photos: F. Feder). For a color version of this figure, see www.iste.co.uk/valentin/soils5.zip.*

Anaerobic digestion (or methanation) is also a biological process of degradation of organic matter, but which takes place in the absence of oxygen here. The transformation is incomplete and produces, on the one hand, a liquid digestate and, on the other hand, biogas that can be recovered and used [MOL 08]. Domestic biodigesters in rural areas are a few cubic meters big (Figure 9.2) and the sources of organic matter are mainly agricultural (cow dung, etc.); the biogas produced are used for cooking or heating, thus reducing wood cutting and combustion fumes in homes [TUM 14]. Because of the large volumes of waste produced, the storage facilities for agro-industrial effluents (slaughterhouse waste, distillery residues, sewage plant sludge, etc.) represent large areas. The digestates produced can be used directly or composted; their fertilizing value is little modified by the anaerobic digestion process. In Africa, Latin America and Asia, many programs have been set up to develop this technology in rural areas[2].

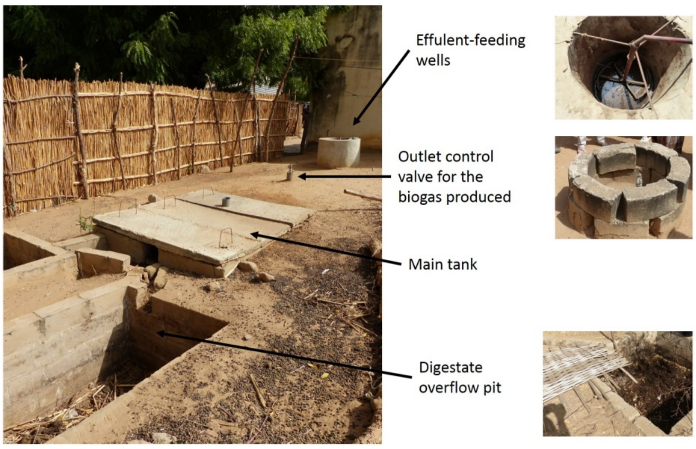

Figure 9.2. *Rural domestic biodigester buried with, in the background, the feed well and, in the foreground, the digestate overflow pit (source: F. Feder). For a color version of this figure, see www.iste.co.uk/valentin/soils5.zip*

9.2. Analytical characterizations of organic waste products

NOTE.– For organic waste products, it is customary, depending on the situation, to deal in raw matter (RM) or dry matter (DM). Especially for agricultural organic waste products, a farmer will chiefly know the weight, or the volume, of his contributions and the quantities necessary. In contrast,

2 One example is the Africa Biogas Partnership Program (ABPP), which brings together five African countries (Ethiopia, Kenya, Tanzania, Uganda and Burkina Faso). Other countries have their own national programs such as Senegal (PNB-SN) and Indonesia (Indonesia Domestic Biogas Program, BIRU).

the analyses provide results in DM and it should therefore always be specified whether or not these results have been converted to RM.

Dry matter contents are usually between 10% for organic waste product liquids such as manure or digestates, and 80% for compost, poultry droppings, etc.

9.2.1. *Chemical elements of agronomic interest (C, N, P, K)*

In organic waste products, the chemical elements of agronomic interest, and whose analysis is essential, are carbon, nitrogen, phosphorus and potassium, and secondarily, calcium and magnesium [GOS 13]. It is common to measure out organic carbon and total carbon, including carbonates, separately. Similarly, some analyses differentiate organic nitrogen[3] from other forms of mineral nitrogen (nitrate and ammonia). Although phosphorus is also in organic and mineral form in organic waste products, due to the complexity of its subsequent evolution in soils, only total analysis is commonly performed on said products. Potassium, calcium and magnesium are measured out after total dissolution, since they never show an organic fraction.

9.2.2. *Specific analyses of organic properties*

The organic carbon content provides information on the ability of an organic waste product in order to provide the energy needed by microorganisms for its mineralization; nitrogen is also necessary for their growth. Thus, historically, the C/N ratio has been used to assess the degradability of an organic waste product: between 6 and 12, mineralization is rapid and produces a lot of mineral nitrogen, while beyond 15 nitrogen will be immobilized by microorganisms. Nevertheless, this report is very insufficient to describe organic waste product mineralization due to the diversity of the nature of organic matter.

Derived from Van Soest’s biochemical fractionation method (1963), the biological stability index (ISB) reflects the compartments of an organic waste product much better: lignin, cellulose, hemicellulose, soluble elements

3 The Kjeldahl method commonly allows the determination of organic nitrogen after deduction of the ammonium content.

and mineral fraction. More recently, the organic matter stability index (Ismo) includes mineralized carbon after 3 days, giving the index chemical and biological characteristics (XP U44162 standard, Afnor 2009). The value of Ismo is inversely correlated to the mineralization potential of organic waste products.

Over time and under controlled conditions, the measurement of organic waste product mineralization potential is also commonly used to differentiate organic waste product degradation kinetics over several months and determine the amounts of carbon lost as CO_2 and the nitrogen supply to the soil [THU 16].

These different measures are robust, accurate and standardized, but often long and costly. Other approaches can be considered by coupling very specific analyses to predictive models that are precalibrated [PEL 12, THU 16]. Additionally, using calibration equation, near-infrared spectrometry makes it possible to acquire these indices, as well as certain parameters from the organic waste product [PEL 11] transformation simulation models.

9.2.3. *Organic and metallic trace contaminants*

Trace metal (TM) have been defined and described in Chapter 6. The quantification of the total content in organic waste products is initial information that is now easily accessible. Precautions to be taken to avoid contamination of the sample remain the main difficulty for all trace analyses, regardless of the matrix. Nevertheless, just as in soils, knowledge of the total content of an element in an organic waste product is insufficient given that, according to its speciation, in other words, its chemical form, its properties (solubility, mobility, bioavailability, etc.) differ [GOS 13]. Different techniques make it possible to quantify TMs according to their speciation or availability. The most common technique is chemical fractionation: the selective dissolution of TMs by reagents of increasing aggressiveness makes it possible to quantify TMs in fractions that have a functional reality (exchangeable, adsorbed, complexed, etc.). Moreover, in diffusive gradients in thin films, the TMs of a mixture of soil and organic waste product diffuse through a gel before being trapped in a resin and then quantified; this method approximates a measure of the purely chemical availability of TMs [ZHA 94]. The rhizotest [BRA 10] is a biological measurement: a mixture of soil and an organic waste product is placed in contact with a root tissue, which extracts the TM; these are then measured out. This method approximates a measure of the bioavailability of TMs. Lastly, it is also possible to carry out physical splits in order to separate the TMs according to granulometric or densimetric fractions.

In organic waste products, organic contaminants belong to chemical families and have very varied physical–chemical properties [GOS 13]. PCBs and PAHs[4], dioxins and furans are best known, particularly in sewage sludge, because they are subject to regulatory monitoring. Many others exist: plasticizers (phthalates, biphenols), detergents (nonylphenols, linear alkylbenzene sulfonates, etc.), polymers, antimicrobial products (triclosan, paraben, etc.), pharmaceutical compounds, etc. The measurement of these organic trace contaminants is much more complex than for TMs, given that the sample must first be preserved in order to prevent it from changing (for TMs, the total concentrations remain constant), then, these compounds must be extracted by a solvent (as complete as possible, but without transforming them) before being measured out. To date, the analysis of trace organic contaminants continues to face the following problems: diversity of molecules, very low concentrations and over a wide range, efficiency of extraction steps and differences in analytical methods [HOU 16].

9.3. Agricultural interests and environmental risks

9.3.1. *Fertilizing aspects of organic waste products*

The elements of agronomic interest contained in organic waste products are distributed in organic and mineral form. Potassium, calcium and magnesium are all in mineral form and therefore dissolve quickly after an organic waste product is brought to the field. Thus, when supplied by an organic waste product, these elements are fully available, as with conventional mineral fertilization; the total concentration measured in these organic waste products can be directly used to calculate the quantities of said products to be supplied. On the other hand, nitrogen and phosphorus are present together in organic and mineral forms and in very variable proportions according to organic waste products [GUT 05]. While mineral forms are quickly usable for crops, organic forms must first be mineralized. Also, to calculate the fertilizing value of an organic waste product, in other

4 Polychlorinated biphenyls and polycyclic aromatic hydrocarbons.

words, the fraction that can be used by the plant during its cycle, the use of fertilizer equivalence coefficients is essential.

The equivalence coefficients are determined experimentally in the field. They indicate what proportion of the element under consideration (nitrogen or phosphorus) is available for cultivation compared to a mineral fertilizer. These coefficients vary greatly from one organic waste product to another. They also depend on the type of inputs and, to a lesser extent, on the soil, climate and crops. They can also be used to compare the efficiencies of organic waste products (Figure 9.3).

EXAMPLE.– A farmer brings about 1 kg of horse manure on a 10 m^2 board on a short-cycle vegetable crop. The total nitrogen content of this manure is 18 g/kg of dry matter and its fertilizer equivalence coefficient is 20% for nitrogen. The dry matter content of this horse manure is 33%.

The contribution of 1 kg/10 m^2 is equivalent to 1 t/ha. The nitrogen content of 18 g/kg of dry matter is equivalent to 18 kg/t or 6 kg/t of raw matter. Thus, its total nitrogen input is 6 kg/ha, to which the fertilizer equivalence coefficient of 20% is applied. The amount of nitrogen actually available for cultivation is therefore 1.2 kg/ha.

At the scale of this crop cycle, the remaining 80% is either lost, notably through volatilization or remains stored in the soil. This nitrogen, in organic form, is likely to mineralize and provide mineral nitrogen to subsequent crop cycles.

One of the main difficulties, when one wishes to base fertilization with organic waste products, is its multielementary and unbalanced nature. Indeed, the respective proportions of nitrogen, phosphorus and potassium are never in accordance with the theoretical needs of the crops, even when the fertilizer equivalence coefficients have been applied. Several lines of argument are then possible depending on:

– knowledge of nutrient contents in organic waste products and their efficiency;

– knowledge of the necessity of the crop during its cycle and, in particular, specific elements of necessity at certain stages of its physiological development;

– the will to punctually overfertilize in one element;

– the cost and availability of organic waste products and mineral fertilizers.

Thus, farmers often supplement their initial organic fertilization with mineral fertilization, mainly to cover essential nitrogen needs, or with other organic waste products that have complementary mineral element contents. When organic waste products are mixed during a crop cycle, fertilization management is complex, especially if they are brought at different dates.

9.3.2. *Amending aspects of organic waste products*

9.3.2.1. *Increase in soil organic matter levels*

Not all organic waste products are equally effective at increasing soil organic matter levels over the long term (Figure 9.3). Indeed, it is mainly the degree of stability of organic matter, and not its total quantity, that dictates this dynamic. The more stable the organic matter is in organic waste products, the more it will contribute to increasing the soil stock more sustainably than the inputs will [DIA 10]. Conversely, very rapidly degradable organic matter may even stimulate microbial activity to such an extent that the soil organic matter itself will be stressed and mineralized[5]. Experiments conducted over several decades have roughly classified organic waste products according to their ability to increase soil carbon stocks. Composts of various kinds are significantly the most efficient, followed by sewage sludge and cattle manure, and then cattle slurry [HOU 16].

The analytical characteristics of organic waste products presented in section 9.2.2 allow the assessment of the amending effects. Ismo, in particular, meets this need by avoiding long experiments on multiple products and different cultures. In addition, numerous tools and models exist in order to simulate this evolution in soil organic matter levels over the long term [PEL 11].

These amending effects are only measurable and noticeable after many years [DIA 10]. In addition, they are not directly sought after, especially by farmers who work land that does not belong to them, or whose use could change in the short term.

5 This is the *priming effect* phenomenon [KUZ 00].

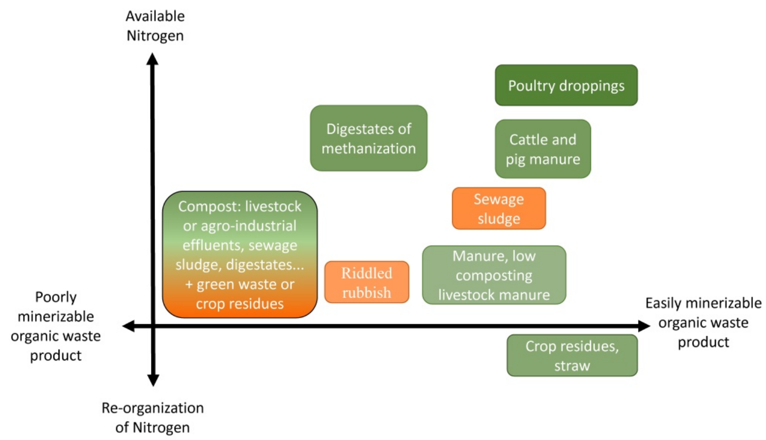

Figure 9.3. *Schematic representation of amending values and nitrogen fertilizers of some major types of organic waste products. For a color version of this figure, see www.iste.co.uk/valentin/soils5.zip*

9.3.2.2. *Improvement of physical, chemical and microbiological properties*

In the long term, many of the physical properties of soils are, in most cases, improved by organic waste products. The effect is mainly a function of the measurement applied and their frequency, the type of organic waste product and therefore its chemical characteristics and not simply the quantity of organic matter applied. Cultural practices, particularly tillage and the burying of organic residues, also influence the evolution of these physical properties. Depending on the type of soil and its initial properties (structure, grain size, type of clay, etc.), these effects will be expressed to varying degrees. Thus, aggregation and structural stability are improved, especially for the most stable organic waste products and when they are brought in large quantities. The soils are then less likely to form a slaking crust [PAR 13]. In addition, the regular application of organic waste products increases the soil's infiltration capacity and porosity; all pore sizes are affected. Indirectly, the improvement of all these properties reduces the risk of erosion by runoff and facilitates root development, while the work of earthworms is improved. As a result, the bulk density decreases [HAR 06]. Lastly, soil water retention capacity is generally higher, but depending on soil texture, the increase is observed at the wilting point or retention capacity [KHA 81]; the consequences will be all the more beneficial for sandy soils in dry climate.

Some soil chemical properties, such as CEC, pH or salinity, are also affected by organic waste products. First of all, the organic waste product CEC is stronger than most soils. Thus, the amended soil CEC will increase proportionally with the dose of an organic waste product provided. In contrast, due to the numerous negative charges carried by organic matter, the increase in soil CEC is correlated with carbon contents [DIA 10]. However, after contributions of the organic waste product, the evolution of the pH is variable according to the initial pH of the organic waste product, but also of the soil and its capacity buffer. Indeed, mineralization produces protons that acidify the soils, but these can be neutralized by the cations of these same organic waste products. This effect depends on the nature of the organic matter in the organic waste product and the type of soil. In addition, as the nitrification process releases protons, mineral fertilizers containing ammoniacal nitrogen are more acidifying than organic waste products, with an equivalent amount of nitrogen [GOS 13]. Lastly, when soil CEC is low, as is often the case in sandy soils, soil salinity can increase rapidly due to the salt content in some organic waste product soils, such as manure. This effect can be a problem when they are mainly monovalent ions (degradation of soil structure, dispersion of clays) or it can be a problem for certain crops that are sensitive to the salt content of the soil or, indirectly, if the organic waste products provided promote reduction processes in soils that are inducing toxicity (sulfides, dissolved organic matter). However, although little documented and very specific to the agro-pedological context, organic waste product applications are generally rather beneficial in soils that are already impacted by salinization [GRU 15].

Changes in the biological characteristics of soils, after the input of organic waste products, are revealed on macrofauna (hymenoptera, etc.), microorganisms (bacteria, fungi, algae, etc.) and their activities. When organic waste product carbon is readily available for use by microorganisms, the growth and activity of the latter are fast and intense. Conversely, this stimulation is slower, but more durable, if the organic carbon is poorly mineralizable. The increase in microbial biomass not only results from this stimulation of microorganisms already present in the soil, but also from those provided by organic waste products. Enzyme activities are good indicators of soil functioning and biodiversity [NAN 02]; the production of extracellular or intracellular enzymes reflects a good functioning of major biogeochemical cycles (carbon, nitrogen, phosphorus, sulfur, etc.) that are directly related to soil organic matter mineralization. These enzymatic activities are stimulated by organic waste product inputs and, just like for microbial biomass, they are all the more durably as the carbon slowly mineralizes. The diversity of communities in soils[6] is a guarantee of resistance to natural or anthropogenic disturbances; it is most often modified, and even amplified by the contributions of organic waste products. In conclusion, all these changes in the biological properties of soils therefore depend mainly on the degradability of organic carbon and, to a lesser extent, on the doses applied, the long-term duration of these inputs, their diversity (different organic waste products) and their physical–chemical characteristics. The initial intrinsic properties of soil also play a key role.

9.3.3. *Metallic, organic and biological contaminants*

9.3.3.1. *Metallic and organic trace contaminants*

Because of their residual origins, organic waste products frequently contain organic and metallic trace contaminants [DOE 16, GOS 13]. In Chapter 6, contamination in the agricultural context caused by trace elements was presented. In Chapter 7, some organic contaminants found in soils were also presented. For most of these organic trace contaminants, the data are still patchy, although some of them are known to be toxic (endocrine disruption, cytotoxicity, carcinogenicity, etc.), even at very low doses. In order to assess the potential risks in the various compartments of the ecosystem, the approach first consists of measuring the flows provided by organic waste products, then their persistence in soils and, lastly, transfers to plants, animals and water resources [DOE 16].

The quantification of the flows provided by organic waste products is based on a mass balance calculation. The persistence or degradation of organic contaminants, which is complete or partial, is often approximated by estimating their half-lives[7] in soils. Persistent contaminants have little or no degradation and have half-lives up to several decades. On the other hand, non-persistent contaminants can disappear in a few days, degraded by biotic or abiotic

6 This diversity can be seen from different angles: structural, metabolic or functional.

7 The half-life time of an organic molecule, often called DT 50, is the time it takes for its concentration to be halved.

processes. Lastly, by taking their ubiquitous nature in the environment into account, the quantification of organic waste product flows provided makes it possible to compare the predicted environmental concentration and the measured environmental concentration.

When present in soils, trace organic contaminants remain essentially adsorbed on soil organic matter or from the organic waste product brought in. Under agronomic dose conditions, studies show that transfers to water or plants are very low. However, the diversity of characteristics (half-life time before disappearance, sorption constants, etc.) of these contaminants cannot be generalized.

9.3.3.2. *Biological contaminants*

The main biological contaminants are pathogens and parasites: bacteria (*Salmonella*, *E. coli*, *Listeria*, *Clostridium*, etc.), viruses, worms and protozoa. Organic waste products that originate from wastewater treatment and animal waste are particularly concerned. Transfer to humans or animals mainly occurs by ingestion of contaminated plants or water.

9.3.3.3. *Impact of organic waste product transformation processes*

Although this is not their primary objective, organic waste product transformation processes (composting, methanization, etc.) reduce some of the contamination previously mentioned. Whatever these treatments are, they never impact total TM concentrations. However, they can modify their speciation and thus their harmfulness [DOE 16]. In contrast, all processes reduce organic and biological contaminant concentrations to varying degrees. Composting, when properly controlled, significantly reduces almost all pathogens during the thermophilic phase. Methanization is less effective due to lower temperature rise. The concentrations of certain organic contaminants may also decrease following treatment, especially aerobic treatment, although the processes involved are not always clearly identified.

9.3.4. *Other environmental impacts*

Other negative environmental impacts are mainly:

– nitrogen losses in gaseous form (ammonia volatilization) or by leaching (nitrate);

– greenhouse gas emissions (nitrous oxide, methane, carbon dioxide).

9.3.4.1. *Nitrogen losses through volatilization and leaching*

Beyond affecting the actual fertilizer value of organic waste products, nitrogen losses through ammonia volatilization contribute to the eutrophication of ecosystems and the genesis of acid rain. Indeed, in organic waste products, mineral nitrogen is predominantly in ammoniacal form. During spreading and in the following days, depending on the weather conditions (winds, rain, temperatures, etc.), the type of intakes (bare soil, landfill, etc.), the characteristics of the organic waste product (pH, ammonium concentration, etc.) and the soil (humidity, infiltration capacity, CEC, etc.), a significant proportion of ammoniacal nitrogen can be directly lost by volatilization[8].

Nitrate leaching is not fundamentally correlated with the characteristics of organic waste products or their intake methods, given that it mainly depends on water conditions that induce drainage at a given depth. However, when nitrates come from organic waste product mineralization, they are neither produced immediately, nor in their entirety, and are thus susceptible to leaching before being removed by crops [FED 15]. Conversely, these leaching losses can be significant when the nitrates are brought in mineral form in a single intake. Moreover, because of their content in certain iron oxides, tropical soils often have an anionic exchange capacity that slightly counterbalances this process [FED 07].

9.3.4.2. *Emissions of nitrous oxide, methane and carbon dioxide*

Carbon dioxide, methane and nitrous oxide are greenhouse gases, and their global warming potentials are, respectively, 1 (by convention), 25 and approximately 300 (depending on the time scale considered). These gases play a relatively small direct agronomic role, but have a major environmental impact [PAU 16]. Nitrous oxide is mainly of agricultural origin and results from soil microbiological nitrification and denitrification processes. Its emission dynamics are mainly linked, on the one hand, to the percentage of water saturation in the pores of the soil and to temperature, and, on the other hand, to mineral nitrogen levels in the soil and the carbon available for microorganisms. Methane emissions are especially important during the storage and potential transformation of organic waste products, especially livestock manure. Lastly, carbon dioxide emissions, which are

8 Volatilization losses from urea-based mineral fertilizers can also be significant, reaching 15%.

essentially related to direct organic waste product mineralization, are used to establish a global greenhouse gas balance following organic waste product intakes.

9.4. Examples of recycling organic waste products in tropical contexts

9.4.1. *In weakly intensified systems*

The inexorable decline in the organic matter content of tropical soils is mainly linked to their rapid mineralization due to high temperature and humidity variations as well as soil types [MIN 17, VAN 92]. Sandy soils, ferrasols, with low nutrient retention and organic matter accumulation capacities, are particularly vulnerable [HAR 06]. However, in order to increase these organic matter levels in these soils, or limit their decline, farmers practice several secular techniques in sub-Saharan Africa [GAN 01]. First of all, the regenerative effects of fallow are known and controlled. But the reduction, or cessation, of traditional fallow periods has been observed for several decades; the intensification of crop rotations thus aims to meet the growing needs of a constantly increasing population. Particularly in Africa, where livestock is a crucial element for farmers, one component of the integration of agriculture and livestock is the transfer of fertility to grazing lands or corrals. Lastly, many practices specifically adapted to the environment, such as half-moon holes or *zaï* [GRA 04, ROO 99], provide farmers with increased possibilities for managing the organic matter in their soils, in addition to water, which can be scarce in certain situations (Figure 9.4).

Nevertheless, organic waste product inflows are fundamental for low intensity systems, both for immediate fertilization and to avoid, in the long term, soil impoverishment as a consequence of their exploitation. These inflows can be coupled with other optimization techniques, such as *zaï*, dead or living vegetation cover, etc. Although the farmer's reasoning on the inputs of organic waste products appears empirical, since, on the one hand, he does not benefit from any analysis on the nutrient contents of organic waste products, and, on the other hand, the characteristics of his soil are unknown to him, from 1 year to the next, he adjusts them by taking the yields obtained and required into account.

Figure 9.4. *Plot of a weakly intensified system where the inflows, which are water and organic waste products, are made directly at the foot of the crop (photo: F. Feder). For a color version of this figure, see www.iste.co.uk/valentin/soils5.zip*

9.4.2. *In intensive systems*

Many intensive cropping systems using organic waste products exist in tropical contexts (sugar cane, palm oil, etc.); agroforestry could also be relevant (eucalyptus, rubber trees, etc.), but it makes little use of organic waste products because of the length of exploitation cycles and a deeply installed root system. Vegetable crops are less typical of the tropical environment, but in a peri-urban context, they emphasize the high stakes of food security and improved nutrition, particularly in micronutrients. Indeed, with the explosion in urban population, the supply of fresh produce in large African cities has increased and evolved in recent decades [BRI 16]. Market gardening requires high levels of inflows; organic waste products are very frequently used, whatever the context.

Organic waste product supply circuits are sometimes complex and there are numerous operators: organic waste product producers (breeders, slaughterhouse managers, wastewater treatment plant managers, etc.), possible “processing” intermediaries who group together, store, mix, compost, etc., transporters and lastly farmers, end users. The production of different organic waste products is fairly constant globally during the year; it is therefore in line with the demand from market gardening that is also constant during the year, in a tropical context, except at certain periods when heavy rains can be too disabling. For example, in the Dakar region, during the single rainy season between July and September, there is less market gardening and transporters leave to work in other regions where rain-fed crops require a punctual labor force. The supply of organic waste products can also be constrained by its liquid, or pasty nature, since the current means of transport are not always suitable. Organic waste product liquids (manure, distillery residues, etc.) or pastes (methanization digestates, sewage sludge) are either composted or used in the immediate vicinity of the production site. Lastly, distance and accessibility to plots are other factors that farmers need to take into account.

The first inflows of organic waste products are often made a few days before the start of the cultivation cycle (sowing, installation of plants previously grown in nurseries, etc.). The farmer’s choice of the type and quantity of organic waste product depends on his cash flow, the type of crop or even the previous inflow of organic waste product, which may be recent following a short cycle crop (salad, etc.). In these intensive market gardening systems where farms are small, farmers are rarely faced with soils with different properties. However, because of certain topographical or locally different situations, they can modify their inflows of organic waste product, just like they modify their practices, according to the characteristics of the soils. The choice of using some organic waste products is based on a knowledge, which is sometimes empirical, of the effects of organic waste products, specifically for certain cultures and for a given context. For example, farmers often acknowledge that they favor the use of poultry droppings for short-cycle crops, such as leafy vegetables. Indeed, the high contents of rapidly assimilable nitrogen, in this type of organic waste product, correspond well to the needs of these crops, in the short term. In addition, it is difficult for them to add several inflows of organic waste products; it is therefore crucial for farmers to provide sufficient nutrients to achieve the targeted yields. The use of mineral fertilizers may then also be justified, in addition to their negative effects (acidification, etc.), which are then counterbalanced [DE 90]. Conversely, for crops with the longest cycles, market gardeners will, first, allow themselves to use more composted organic waste products and aim to split the inflows. Their cash flow and technical feasibility will then dictate the nature and frequency of the additional organic waste product brought in during the cycle. These additional inflows can also be opportunistic if the farmer has access to a good quality and cheap source of organic waste product.

Figure 9.5. *On the left, the horse dung, which is brought in raw at the beginning of cultivation, is little decomposed and always visible. On the right, the sewage sludge, which is brought in regularly on this sandy ground, shows centimetric pieces that are badly degraded and fine fractions that give the soil a dark color (photo: F. Feder). For a color version of this figure, see www.iste.co.uk/valentin/soils5.zip.*

Most of the time, organic waste products are brought manually and are barely buried, if not at all. Thereafter, hoeing and manual weeding activities make it possible to distribute and homogenize organic waste products, in order to break them down if necessary (Figure 9.5) and to gradually bury them. Despite the manual inflow and the absence of burying organic residues, the temperature and humidity conditions promote the rapid mineralization of organic waste products. Currently, the recommendations for the use of organic waste products by agronomic or technical institutes in tropical countries are sometimes limited to quantities of (raw) matter, modulated for some major types of soil. When agronomic tests have been carried out, the recommendations are adjusted according to the crop and the type of organic waste product. Although these references are sometimes old, in the absence of analyses of both organic waste products and soils, it is rarely possible to be more any more precise [BLA 14].

The multiple positive consequences of repeated inflows of organic waste products in these market gardening systems (improvement of soil structure and microbiological composition, increase in organic matter levels, etc.) are detectable after a minimum of 10 years [DIA 10, HEM 10]. However, these systems are fragile; urbanization is not always easily controllable and environmental impacts are potentially numerous and only visible and quantifiable over the long term.

RESEARCH QUESTIONS.–

1) Organic waste products are sources of fertilizers and soil amendment, but they can also bring various contaminants. What is the fate of many organic contaminants? What are their multiple long-term impacts (transfers to plant production, effects on soil microorganisms, etc.)?

2) From the perspective of sustainable soil carbon storage, what are the interactions between the organic fraction of organic waste products and mineral phases? What are the mechanisms for this storage?

3) How can farmers be provided with rapid and accurate information and tools, adapted to their context, in order to assess the positive and negative impacts of organic waste product inflows in the short term and long term?

4) In a tropical context, during the same crop cycle, farmers sometimes bring several organic waste products or mix them with mineral fertilizers; they divide these inflows according to the crops or the availability of organic waste products. What are the agronomic consequences of these complex and little studied situations?

RECOMMENDATIONS.–

1) Farmers must train themselves or be trained in different techniques for processing raw organic materials. For each situation, a set of techniques and practices can be optimal depending on the goals sought.

2) A better knowledge of the soils and the organic waste products brought in is an essential prerequisite to limiting the risks of overfertilization or contamination.

9.5. References

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