Organic Compost and Manufactured Fertilizers: Economics and Ecology

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Abstract Compost is a highly diverse group of organic soil amendments which provides substantial nutritive fertility to soils. The benefits of compost addition to soils are vast and have been well documented by a growing body of research. Composts are manufactured in a variety of methods and scales from simple localized plots to large scale commercial operations. This review examines the role of organic matter in soils, the process of composting, and the physical, chemical, and biological properties of compost. The global use of compost and its agro-ecological implications is explored. The review concludes with appropriate uses of compost, its comparison to traditional commercial fertilizer, as well as some limitations for its proper use.

1 Introduction

A variety of soil amendment products and potential nutrient sources provide flexibility for agricultural and horticultural systems. However, comparing the cost and value of these different soil amendments is not as simple as it might seem.

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Dairy manure compost, for example, supplies not only the major nutrients (N, P, and K), but also a broad range of secondary nutrients, micronutrients and organic matter. These plant nutrients have economic value, which can be used to estimate compost value for comparisons with traditional fertilizer materials. Organic matter applications, such as dairy manure, can also improve water and nutrient holding capacity of the soil, reduce erosion, and reduce fluctuations in soil pH.

Nutrients in compost products are more stable and are typically released gradually over three or more years; whereas inorganic fertilizers are generally formulated to release nutrients within a year of application. Thus, a realistic assessment of compost value requires at least a 3-year time frame. Also, since compost nutrient ratios and release rate may not be optimal for crop needs, some supplemental inorganic fertilizer (particularly N) may be necessary. The following information provides steps to determine the economic feasibility of using compost as an alternative or a supplement to inorganic fertilizers.

Currently, the need for reducing environmental impact requires diverse processes that permit an integrated reuse of solid residues, from which products or commodities of industrial importance can be obtained. The waste generated by communities is composed of diverse materials that vary according to climate, urbanization, and socio-economic stratum. Approximately 38% of all trash produced is biodegradable organic matter that does not have a market. This organic trash generates a serious environmental problem, even when it can be used for the production of compost or other uses (Garcia 1993).

The solution to the problem of urban and agro-industrial solid waste is to process them, but adequate techniques should comply with the following requirements:

- To provide a cost that is accessible by the community that will use it.
- Have a capacity to eliminate risks to human and environmental health, and not generate additional unforeseen waste as a part of the processing technology.
- Be able to consistently process the waste that is generated, which implies a general capacity to process high volumes and the flexibility to absorb fluctuations in the quantity of daily waste produced.

There are three techniques available for the treatment of urban solid waste:

- Sanitary landfills
- Composting
- Incineration

In most cases, the application of these techniques individually or combined, permits a satisfactory economic and sanitary solution.

Studies conducted around the world have used different types of agricultural and agro-industrial residues such as straw, stubble, cane chaff, and pineapple pulp, as well as the biodegradable fraction of urban solid waste for the production of antibiotics, enzymes, detoxified feeds for cattle, biofertilizers and substrate for cultivation. In all cases, employing solid fermentation techniques is an efficient technological alternative (FAO 1991).

Due to the impact from contamination by solid waste, investigations have been carried out to transform the organic matter into products of utility for agriculture. Processes such as composting arose from this idea which, when studied scientifically, can contribute to the solution of important problems affecting modern society (e.g. the sanitary disposal of organic waste) to provide humus for field application, to maintain fields in adequate condition for cultivation, and to induce the destruction of pathogenic microorganisms (Guerrero 1993).

This review defines the important characteristics of compost, describes its various manufacturing methods, and presents factors that directly influence the economic viability of using compost versus industrial fertilizer for agricultural production.

2 Soil Organic Matter

Soil organic matter (SOM) is generally defined as the organic fraction of the soil exclusive of undecayed plant and animal residues. Organic constituents within the soil have dramatic impacts on a range of soil properties, the use and management of the soil, and soil taxonomic classification.

Frequently, SOM is defined by its level of degradation from its original plant/animal sources. The level of SOM degradation varies widely and is characterized by a number of different organic substances within the soil to include humic and fulvic acids. Humic acid (humus) is aptly described as dark in color (black or dark brown), colloidal, and negatively charged given the high amount of oxygen (O^{2-}) within its macromolecular structure. Fulvic acid is a biologically stable, highly oxidized, water soluble complexing agent with a general chemical formula of $C_{20}H_{12}(COOH)_6(OH)_5(CO)_2$ (Schnitzer 1969). It is ubiquitous in nature and dramatically affects plant nutrient uptake. Humic and fulvic acids are functionally differentiated by their solubility; the former representing material that can be extracted from soil with dilute alkali and other reagents and precipitated by acidification to pH 1–2 (Soil Science Society of America 2010). Collectively, humic and fulvic acids are known as humic substances. The highly negative charge of humus gives it a large cation exchange capacity, on the order of 200 cmol kg^{-1} (Havlin et al. 2005; Brady and Weil 2002). Thus, a wide variety of cationic plant essential elements (Cu^{2+}, Fe^{2+}, Mg^{2+}, Mn^{2+}, K^{+}, Zn^{2+}, and Mo^{2+}) and metals (Al^{3+}, Cd^{2+}, Cr^{3+}, and Pb^{2+}) are sorbed to humus. The sorption of polyvalent cations is especially important as these can serve as bridges between negatively charged electrostatic clays. As these particles are joined together by cationic bridging, submicroaggregates of individual particles begin to form. Submicroaggregates grow and combine into microaggregates, where the foundations of soil structure start to emerge. Annabi et al. (2007) studied the influence of three urban composted materials (municipal solid sludge compost, sewage sludge/green waste, and biowaste compost) at two different stages of decomposition (immature and mature) on soil aggregate stability. They concluded that composts at both stages of decomposition enhance soil aggregate stability through fungal biomass stabilization and an improved resistance to slaking. Soil structure represents a feature of temporal pedogenic development where soil aggregates into one or more of six soil structural units (subangular blocks, angular blocks, plates, columns, prisms, or granules). The degree of structure development and expression are a function of developmental time under optimal (undisturbed) conditions. Soil structure dramatically impacts a number of soil properties including porosity, bulk density, water infiltration and percolation.

In many areas of the world, soil organic matter represents an essential nutrient source for agronomic production where commercial fertilizers are not available. It also plays a key role in governing the form of nutrients available for plant uptake. For instance, a common indicator of organic matter nitrogen content is the carbon to nitrogen (C:N) ratio. Organic materials with a C:N ratio of less than 25:1 are considered N rich. Nitrogen in this system is subject to mineralization, the conversion of plant-unavailable N to plant-available forms (NH_4^+ and NO_3^-). Brady and Weil (2002) describe the process as follows: Organic N (unavailable to plants) largely exists as amine groups ($R\text{-}NH_2$) in proteins or as part of humus. Microbial degradation of these compounds leads to the formation of simple amino acid compounds such as lysine (CH_2NH_2COOH) and alanine (CH_3CHNH_2COOH). Hydrolysis of the amine groups on these compounds leads to the formation of NH_4^+ which can finally be oxidized to NO_3^-. Organic materials with a C:N ratio of greater than 25:1 are considered N poor. Nitrogen in this system is subject to immobilization, the conversion of plant available N to plant-unavailable forms. In this process, microbes consuming dead organic material effectively incorporate the available N into their cellular structure. In doing so, free ionic species of N (NO_3^- and NH_4^+) are removed from the system and made unavailable for plant uptake.

The application of organic matter to soils has the potential to alter N dynamics of an ecosystem. If N is not bound by organic or mineral sources, excessive concentrations of free ionic species can pose water quality problems and health risks. Soil systems overwhelmed with nutrients (either via organic matter or inorganic fertilizer application) lose the potential to sorb those nutrients from soil solution. The electrostatic attraction of cations to the negatively charged surface of many clays and humus or the attraction of anions to structural cations along clay particle edges are finite. Ions in direct sorptive contact with the surfaces of electrostatically charged particles constitute the stern layer; the layer most strongly bound to the particles. Beyond the stern layer, diffuse double layer theory defines the inverse relationship between distance from the charged particle surface and attraction to that surface. If the charged particle surface is fully saturated with ions, the addition of more ions via organic matter application or fertilizer will allow such ions to remain in soil solution and will be prone to leaching through deep percolation into the water table or surface water runoff. If N enters surface waters via runoff, eutrophication can occur. Eutrophication is defined as the accumulation of nutrients that support a dense growth of algae and other organisms, the decay of which depletes shallow waters of oxygen. Human consumption of nitrate laden waters (either from surface or aquifer sources) can lead to a serious health condition known as Methemoglobinemia, where the hemoglobin of blood fails to properly bind oxygen, causing hypoxia (Kross et al. 1992).

2.1 Composting

Compost is generally defined as a mixture of various decaying organic substances used for fertilizing the soil. Colloquial claims concerning the virtues of compost are widespread and have led to some skepticism by the scientific community. The difficulty in quantifying the benefits of compost use stems from its dynamic nature; specifically, its variable source materials changes over time and methods of application. Nonetheless, the use of compost has become more widespread in recent years given new concerns over environmental sustainability and recycling.

Essentially, the process of composting involves accelerating the degradation of organic materials by optimizing conditions for microorganisms. Depending on its intended use, compost can manifest itself in a variety of products including general use compost, erosion control compost, and compost manufactured topsoil. Each of these products has unique properties and will be independently discussed. Furthermore, a broad array of methods for producing compost exists. Misra and Roy (2002) categorize a wide variety of composting methods into (a) traditional methods and (b) rapid composting methods. Traditional methods of facilitating anaerobic digestion include the Indian Bangalore Method and Passive Composting of Manure Piles. Traditional methods of facilitating aerobic decomposition through passive aeration include the Indian Indore Method (pit and heap methods) and Chinese Rural Composting (pit and high temperature methods). Large scale passive aeration is accomplished via turned windrows or passively aerated windrows. Rapid composting methods include the use of shredding and frequent turning, mineral N activators, effective microorganisms, cellulolytic cultures, forced aeration, in-vessel composting, and vermicomposting (Misra and Roy 2002). In the United States, commercial compost production is most commonly accomplished via turned windrows and will be the focus of the discussions that follow.

2.2 Origins of Compost: Feedstocks and Processing

The source materials of compost can come from a variety of origins and are often referred to as *feedstocks*. Common compost feedstocks include animal manures (cow, chicken, swine, horse, goat, and rabbit), bagasse, bonemeal, citrus waste, cottonseed meal, cotton gin trash, grass clippings, leaves, paper, rice hulls, sawdust, and sewage sludge (Fig. 1) (Martin and Gershuny 1992; Rynk 1992). In some instances, feedstocks may be purchased as byproducts of other industrial processes. In other instances, the feedstocks may be provided to a composter free of charge, saving the feedstock generator disposal fees. However, the transportation and storage of compost feedstocks can be cumbersome as the materials often contain appreciable water or emit foul odors from manure or slaughter waste. Feedstocks are often heterogeneous in their chemical composition and physical size, necessitating further processing to produce high quality, uniform compost.

Fig. 1 Feedstocks from common landscape operations in Dallas, Texas, USA (*clockwise from upper left*): wood, woody debris, fallen leaves, and grass clippings (Photos courtesy of Lawns of Dallas)

When compost is not an adequate mix of organic waste, the process of composting is slow and the final product is of low quality. To avoid this loss of quality, other materials can be added to improve the chemical composition and structure of the piles. According to Dalzell et al. (1991), these materials are:

Activators. Substances that enhance decomposition, and contain a large quantity of proteins and amino acids, as in manures and organic waste in general.

Inoculants. These are special bacterial cultures or media containing the agents responsible for the decomposition of organic matter. They include bacteria of the genus *Azotobacter*, mature compost, ground phosphorite, calcium phosphate and soil. Presently, many products exist on the market that can be used as biological inoculants, such as Ultrazyme® and Bio-Compost®. These products increase the rate of decomposition and reduce the time to obtain mature compost.

Enrichers. These are commercial fertilizers that can be incorporated into the composting process to increase the nutrient content.

Large feedstock materials such as tree and shrub waste (leaves or wood) are typically processed with a tub grinder (a large diesel powered grinding machine mounted on a tractor-trailer). Tub grinders are fed with an articulated loader and effectively reduce materials to a size of <5 cm. To ensure that the ground products are adequately processed, a set of large sieve shakers is used to separate the ground material into different size fractions for specific job requirements. Large objects retained by the sieves can be re-ground. For composts that seek to mix a variety of feedstocks, grinding is the ideal time to combine them.

When grinding has produced a material of the desired size, the materials are placed into long, linear rows termed *windrows*. Several key factors govern the composting process including aeration, moisture, C:N ratio, pH, temperature, and particle size. Once ground material is placed into windrows, it may remain as static piles for passive aeration, be aerated artificially through turning of the windrows, or be actively aerated through a system of aeration pipes running through the pile. Functional degradation of organic feedstocks is accomplished by a number of aerobic fungi, bacteria, and actinomycete species which operate under two different thermal ranges: mesophilic (10–40°C) and thermophilic (>40°C) (Rynk 1992). Thermophilic composting is preferred as pathogens, weed seeds, and fly larva are destroyed at >63°C. Heat and CO_2 are generated as the microorganisms begin to degrade freshly added feedstock. As the degradation proceeds, heat can begin to limit microorganism activity. Similarly, as O_2 is consumed by the aerobic organisms, degradation slows as windrows turn anaerobic, generating H_2S, NH_3, and CH_4. For this reason, regular aeration or turning of the windrows is critical. Another critical factor in composting is moisture. For optimal degradation, windrows should contain 40–65% moisture (Rynk 1992). Below 40%, microbial activity is inhibited and above 65% moisture displaces oxygen causing anaerobic conditions within the windrow. Moisture rate reduction can be accomplished via the incorporation of cellulosic bulking agents such as bagasse, paper, peanut shells, and sawdust (Iqbal et al. 2010). The C to N (C:N) ratio is critical for facilitating organic matter degradation. Rynk (1992) found that C:N ratios of 25:1–30:1 were ideal for active composting, but ratios of 20:1–40:1 produced acceptable results. The C:N ratio of feedstocks varies widely with green, tender vegetation and sawdust having ratios of 12:1 and 400:1, respectively (Martin and Gershuny 1992; Rynk 1992). Optimal and acceptable conditions for composting are given in Table 1.

As compost reaches the end of active degradation, heat generation will decline, even after turning or aeration. The original volume of feedstocks can be reduced up to 50% by the composting process (Rynk 1992). Finished compost is said to be *cured* and should not contain foul odors. Cured compost need not be completely homogenous in its composition, but it should not be undergoing active degradation.

Windrows are one of the most utilized composting techniques and are utilized under aerobic conditions. This technique is also known as biopiles, biocells, or composting piles (Iturbe-Argüelles et al. 2002). The biopiles are a form of composting in which piles are formed. The system can be opened or closed, permits the addition of nutrients and water, is placed in a treatment area, and may include systems for the collection of leachates and some form of ventilation (Eweis et al. 1998).

Choosing the type of biopile system depends chiefly on the climatic conditions and the structure of the volatile organic compounds in the organic material. Generally, the biopiles are designed as closed systems, because they maintain temperature and avoid saturation with rainwater. As well, they reduce the evaporation of water and volatile organic compounds. Two of the most used biopile systems are extended biopiles (Fig. 2) and static biopiles (Fig. 4). The difference between these

Table 1 Optimal conditions for composting in windrows (Rynk 1992)

Factor	Optimal	Acceptable
C:N ratio	25:1–30:1	20:1–40:1
Moisture (%)	50–60%	40–65%
Oxygen content (%)	20%	>5%
Particle size (cm)	Variable[a]	0.3–1.3 cm
pH	6.5–8.0	5.5–9.0
Temperature (°C)	54–60°C	43–65°C

[a]Depends on intended use

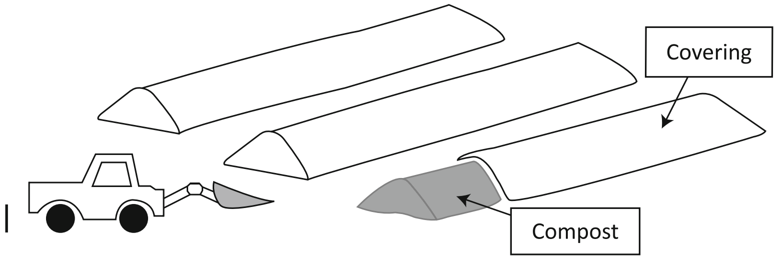

Fig. 2 Schematic representation of an elongated biopile system

Fig. 3 Windrow/biopile turning machines in Texas, USA (Photos courtesy of Saqib Mukhtar)

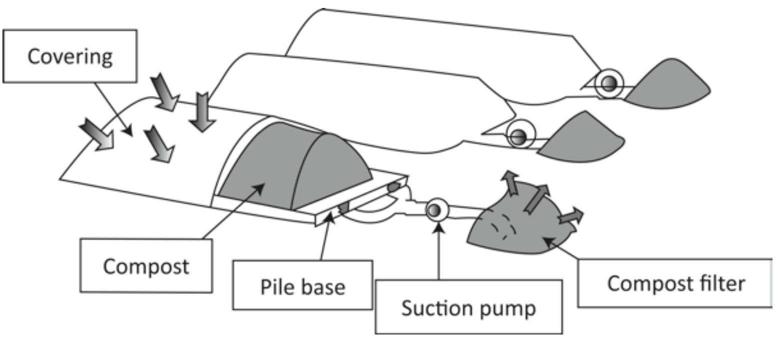

Fig. 4 Schematic representation of a static biopile system

technologies lies in the method of ventilation that provides oxygen to the composting process (Eweis et al. 1998). The system of elongated biopiles (windrows) is the most economic and simple composting process.

The material to compost is stacked on a platform in extended piles (Fig. 2) and ventilation is carried out by manually or mechanically mixing the compost (Fig. 3), a process that at the same time permits homogenization of temperature. The mixing of the compost provides for equitable material distribution (nutrients, water, air, contaminants and microorganisms) and facilitates biodegradation of the pathogens. The frequency of mixing the pile depends on the microbial activity which can generally be determined from the temperature profile of the compost; typically measured daily (EPA 1995) or monthly (Sellers et al. 1993).

In contrast, static biopiles do not need to be mixed mechanically since ventilation and equalization of heat in the compost is carried out via a system that injects (compressor) or extracts (suction) air using pipes placed in the base that are aligned in parallel along the pile (Fig. 4). In static biopiles, an air extraction system is normally employed that permits the capture of a certain fraction of the volatile organic compounds so that they can be removed from the organic material during the ventilation process. These vapors are sent to a biofiltration system or for catalytic oxidation processing (Eweis et al. 1998). The use of an injection or extraction system for air in this type of biopile permits manual or automatic control of the velocity of airflow to provide oxygen to the composting process. Thus, a temporal relationship between airflow and microbial activity can be established.

Important factors in the design and operation of a compost biopile (Dalzell et al. 1991) include economic (commodity) factors, materials cost, availability and durability, commodity reproduction, and appearance. Chemical materials or variables used in processing include pH (degree of acidity or alkalinity), capacity for cationic exchange, nutrient content, and soluble salt content. Physical and structural aspects important in evaluating final compost quality include particle size, density, porosity, ventilation, and water retention capacity. According to Garcia (1993), the feasibility of the composting process is determined by the degree of control over the percentage of humidity, since this process can be completed in a relatively short time (2–4 months).

2.3 Compost Properties

In an effort to standardize characterization and analysis of composts, the United States Composting Council (USCC) in partnership with the US Department of Agriculture (USDA) (2002) established *Test Methods for the Evaluation of Composts and Composting (TMECC)*. Guidelines from TMECC have become the industry standard for quantifying physical, chemical, and biological properties of compost in the USA. Application of the TMECC protocols is facilitated through the Seal of Testing Assurance (STA) program (administered by the USCC), whereby certified laboratories provide analysis of composted products.

2.3.1 Physical

Finished compost is typically dark in color and described as very dark gray (10YR 3/1), very dark brown (10YR 2.5/2) or black (10YR 2.5/1). However, feedstocks can influence compost color. Particle size is a function of processing and is variable according to the product's intended use. The Texas Department of Transportation (2004) specifies the following particle size limits:

- *Compost Manufactured Topsoil (CMT).* Consists of 75% topsoil blended with 25% compost measured by volume. For use, CMT is either blended on-site (BOS), blended in-place (BIP), or pre-blended (PB), as specified on the plans.
- *Erosion Control Compost (ECC).* Consists of 50% untreated wood chips blended with 50% compost measured by volume. Wood chips must be less than or equal to 12.7 cm in length with 95% passing a 5.1 cm screen and less than 30% passing a 2.5 cm screen.
- *General Use Compost (GUC).* Consists of 100% compost, with 95% passing a 1.6 cm screen and 70% passing a 1 cm screen.

The bulk density of compost is known to vary widely based on feedstock particle density, moisture, and porosity. However, bulk density is important for calculating loading rates and transportation costs. Weindorf et al. (2006) found the bulk density of compost derived from grass clippings and leaves to be 0.70 g cm^{-3}. Van Ginkel et al. (1999) evaluated the bulk density of chicken manure/wheat straw compost and found ranges of 150–950 kg m^{-3}. They linked such wide variation to moisture content and compaction stemming from the height of the compost piles.

2.3.2 Chemical

The chemical properties of finished compost are essential to its use as a viable soil amendment. Typical chemical properties evaluated include compost pH, salinity, nutrient (elemental) content, and heavy metal content. As an amendment promoting soil fertility, the pH of compost should ideally serve to facilitate a pH of ~6.5 (slightly acidic). Slightly acidic conditions allow for the best overall availability of both soil macro- and micronutrients. Similarly, compost salinity must be carefully monitored so as not to exacerbate soil conditions where salinity can be harmful. Plant tolerance of salinity is highly species specific. For example, onions, oranges, beans, carrots, broccoli, corn, grapefruits, and tomatoes are moderately sensitive or sensitive to salinity (Maas and Grattan 1999). Sorghum, oats, soybeans, beets, asparagus, and artichokes are moderately tolerant or tolerant of salinity (Maas and Grattan 1999).

Elemental analysis of composts focuses on two key parameters: nutrient content and trace metals. The total quantity of plant essential nutrients within composts varies widely based on feedstock and composting methods. The C:N ratio is of particular importance to agronomic and horticultural applications and is sometimes adjusted to the ideal 25:1–30:1 (Table 1) by the addition of fertilizer N. Other commonly evaluated elements include Ca, Mg, K, P, Fe, Cu, Mn, Zn, Mo and Cl. Trace metal content is of particular concern where the application of composts could pose threats to surface water quality or environmental degradation. The US EPA 40 CFR § 503.13 sets forth the ceiling concentrations, cumulative pollutant loading rates, monthly average concentrations, and annual pollutant loading rates permissible for land application of organic materials (US EPA 2010). Trace elements covered under all or part of these regulations include As, Cd, Cu, Pb, Hg, Mo, Ni, Se, and Zn.

2.3.3 Biological

While a range of different biological organisms are known to reside within composted products, they are generally classed as microscopic and physical decomposers. The former concerns bacteria, actinomycetes, protozoa, and fungi within compost. Up to 25% of the mass of finished, stable compost is comprised of living and non-living cellular material from microbes (US Composting Council-USDA 2002). The population dynamics of this group vary considerably based on feedstock, aeration, moisture, and heat within the compost. Bacteria are single celled organisms which reproduce via binary fission. They typically produce enzymes which functionally degrade the material on which they reside, serving as a food source for their life and propagation. In doing so, bacteria and fungi generate up to 90% of the CO_2 produced by living organisms on the earth (Nardi 2003). However, bacteria are generally less mobile than other microorganisms and thus, unable to escape unfavorable environments. This causes bacteria populations to proliferate and then die in cyclical patterns. Actinomycetes are vital to humus formation and are known to produce rudimentary antibiotics (Nardi 2003). As they decompose organic substances, they liberate C, N, and NH_3. Protozoa are single celled organisms that consume large amounts of bacteria as food (Nardi 2003). However, they have limited persistence to high temperatures of the thermophyllic phase of composting (Martin and Gurshuny 1992). Fungi represent one of the final stages of microscopic degradation. They essentially act as primitive plants, but lack chlorophyll and depend on organic substrates for survival. Various forms of fungi thrive in compost from 21°C to 49°C (Martin and Gurshuny 1992).

Macroscopic physical decomposers include mites, millipedes, centipedes, sow bugs, snails, slugs, spiders, springtails, beetles, flies, ants, nematodes, and earthworms. The presence of these decomposers in compost forms a complex web of interdependence with microscopic organisms, which form their primary food source.

Typical assessment of biological properties of compost includes pathogen testing (fecal coliforms) and a measure of biological activity via some form of respirometry. Adani et al. (2003) evaluated the dynamic respiration index (DRI), static respiration index (SRI), and specific oxygen uptake rate (SOUR) and found that the three methods were well correlated and aptly characterized biological stability of organic materials. A commonly employed field technique utilizes the Solvita Maturity Test; a colorimetric test for qualitatively assessing CO_2 and NH_3 generation from a given quantity of compost. Changa et al. (2003) concluded that such tests provided useful information

Table 2 Class A and B biosolids limits (US EPA 2010)

Pathogen	Density limits
Class A biosolids	
Salmonella	<3 MPN $(4\ g)^{-1}$ TS
OR	
Fecal coliforms	<1,000 MPN g^{-1} TS, and
Enteric viruses	<1 PFU $(4\ g)^{-1}$ TS, and
Viable helminth ova	<1 $(4\ g)^{-1}$ TS
Class B biosolids	
Fecal coliforms	<2,000,000 (MPN or CFU)g^{-1} TS

for identifying potential toxic plant responses to excessive NH_3 in a simple, broadly applicable field test. However, they concede that the Solvita test is no replacement for actual lab respirometry. Pathogen testing typically focuses on salmonella and/or fecal coliforms. The US EPA 40 CFR § 503.13 distinguishes two classes of compost products: Class A biosolids and Class B biosolids (Table 2) (US EPA 2010). It is important to note that proper thermophyllic composting typically results in finished compost which meets Class A biosolids limits. However, if composting temperatures are minimal, fecal coliforms may remain viable in manure-based feedstocks, posing potential health risks to humans.

According to Guerrero (1993) and Coronado (1997), the incorporation of compost into soils as a source of organic matter produces several positive effects in its biological, physical, and chemical properties including:

- Contributing essential nutrients (e.g. N, P, K, S, B, Cu, Fe, Mg) for plant growth during the process of decomposition (Koepf 1965).
- Contributing to the biological activity of soils by incorporating organic acids and alcohols during their decomposition such that they serve as sources of C for the microorganisms and N fixers which produce substances for growth such as tryptophan and indole-acetic acid.
- Providing food for the microorganisms that are active in the process of decomposition, and that produce antibiotics that protect plants against disease, thus contributing to plant health (Koepf 1965).
- Incorporating intermediate metabolites produced during decomposition that can be absorbed by the plants to increase their growth. When organic matter is in the form of humus it provides more benefits (Guerrero 1993).
- Incorporating segregated substances that favor soil structure to improve water and air transport, diminish compaction, and favor the development of the plant roots and plowing of the soil (Crovetto 1992).
- Buffering against abrupt modifications of pH (Buchanan 1993).
- Providing metabolites such as phenols that contribute to plant respiration, improved P absorption, and plant health (Guerrero 1993).
- Increasing soil organic material to improve retention of soil humidity (Crovetto 1992).
- Reducing inorganic fertilizer requirements.
- Improving water infiltration and drought tolerance.

- Reducing soil compaction and crusting.
- Improving root growth and yields.
- Increasing populations of microbes and earthworms in the soil.
- Improving plant resistance to disease.
- Slowly releasing nutrients to plants.
- Improving nutrient holding capacity.
- Increasing ease of cultivation.
- Increasing pollution prevention and remediation.

Specifically, the application of organic matter positively influences the soil microbial community of bacteria and fungi, enlarging their abundance and diversity. The application of organic fertilizers increases the production of cultivation and increases resistance against pests and diseases. Due to the large reservoir of N in the soil, the application of nitrogenous fertilizer only favors plant vegetative growth and not that of the soil microbial fauna (bacteria, fungi, nematodes). As well, the exclusive and continuous use of chemical fertilizers leads to the reduction and disappearance of organic matter, favoring the loss of soil structure and the increase of soil compaction (Córdoba 2009; Neely et al. 1991).

Also important is that the quality of the compost can be considered as a 'fertilizer' or 'soil conditioner', depending on its effect on plant nutrition. 'Fertilizers' are a source of quickly available nutrients that have a direct effect, reflecting a short time in plant growth. 'Soil conditioners' affect plant growth indirectly by improving the physical properties of the soil by improving water retention, aeration, structure and drainage, properties that are intimately related to the prevention of soil erosion, the recovery of degraded soils (López-Martínez et al. 2001; Castellanos et al. 1996), and the favoring of diversity and microbiological activity (Neely et al. 1991). That being said, composted materials in some countries are not specifically labeled for sale as 'fertilizer' due to requirements in uniformity of material (guaranteed analysis) and testing.

3 Global Compost Dynamics

The type of materials composted worldwide is expansive. However, composting is most often carried out to provide disposal of unwanted organic refuse, reuse/capture of a nutrient stream where resources are limited by availability or financial constraints, or to protect environmental quality as a nutrient management practice. Certain conditions serve to assure the effectiveness of composting operations. First, the supply of feedstocks must be continuous and located physically near to the composting operations. As such, local organic waste streams often govern the types of compost produced in a given area. Transportation of many feedstocks and composted products is difficult since the appreciable water content of the products makes them heavy. Large scale operations require heavy equipment for loading, mixing, and moving the compost. Large trucks must be utilized to carry the finished product to end-users, requiring fuel and labor. Second, the compost should be uniform, consistent in its properties, and free from foreign inorganic matter such as plastics or glass. Organic products are inherently variable, but thorough mixing and processing will provide a consistent, appealing product. Last, effective composting requires ‘buy-in’ by end-users; they must appreciate the benefits of compost and believe in its proper use.

Worldwide, one of the most commonly composted feedstocks is manure from livestock. The proliferation of confined animal feeding operations (CAFOs) for industries such as dairies and feedlots has exacerbated the need for environmentally responsible manure management. Huang et al. (2008) evaluated the nutrient content of 120 manures from composting and farm operations across 22 Chinese provinces and documented the levels of K, Ca, Mg, Fe, and Zn using near infrared spectroscopy. They found that the near infrared spectroscopy technique is a potential method for predicting nutrient metal content of animal manure compost products. Mupondi et al. (2006) studied the inclusion of goat manure in pine bark compost in South Africa. They concluded that the addition of goat manure enhanced cabbage seedling growth compared to pine bark compost with no manure. In central Texas, USA, Butler et al. (2008) compared corn yield from fields supplied with dairy manure compost versus inorganic fertilizer. They found comparable yield performance between the two nutrient supply strategies, but noted that some accumulation of salinity and adjustment in soil pH were evident with repeated compost application. They concluded that the combined use of some manure compost and some inorganic fertilizer would be a feasible strategy for optimal corn production.

Another major feedstock for composting operations is municipal sewage sludge or urban wastes. In some areas, solid urban wastes are applied directly to soils as fertilizers for crops. For example, Ouagadougou in Burkina Faso, Africa, is a city of >1.2 million residents generating 300,000 tons of solid urban waste annually (Kabore et al. 2010). Traditionally, waste products have been applied to soils directly, providing high crop productivity of cereal and legume crops. However, in an effort to reduce pathogen prevalence, pit composting has been employed to process solid urban waste prior to agricultural use. Kabore et al. (2010) recommend mixing household waste, slaughter house waste, and tree leaves to accelerate organic matter stabilization and produce compost with higher available N content. In India, urban populations are expected to reach 341 million by 2010, generating 65 million tons of municipal solid waste (Kumar and Gaikwad 2004). Bhattacharyya et al. (2003) compared municipal solid waste compost to cow dung manure with and without the addition of urea and fertilizer for rice production in West Bengal. Rice production was greater with cow dung manure + urea, and municipal solid waste compost + urea compared to fertilizer. Furthermore, they noted that rice uptake of heavy metals (Zn, Cu, Pb, and Cd) was still within safe limits. Soumare et al. (2003) compared the use of mineral fertilizer and municipal solid waste compost as soil amendments supporting the growth of ryegrass in Mali. They found that mineral fertilizers and 50 T ha^{-1} municipal solid waste compost increased dry matter yields by 69.7%, 65%, 10% and 17.5% for the Gao and Bgda soils, respectively. While inorganic fertilizer provided the most production, increases in soil organic carbon, available P, Fe, Mn, Zn, Cu, K, and pH were linked to compost, confirming its appropriateness as a soil amendment. Farrell and Jones (2009) argued that even after composting of municipal solid waste, caution must be applied to its prudent agricultural use. Risks from sharp objects like glass shards, organic pollutants, and heavy metals remain, though they conclude that the latter poses limited risks for plant uptake and environmental degradation. Nonetheless, they advocate careful investigation of contaminant levels and detailed risk assessment prior to the application of municipal solid waste compost.

Other examples of composted products around the world include mushroom waste in Ireland (Courtney and Mullen 2008), cabbage waste and sawdust in South Africa (Manungufala et al. 2008), and sweet sorghum bagasse combined with pig slurry and sewage sludge in Spain (Negro et al. 1999). While composted products are widely heralded as beneficial soil amendments for agricultural production, deleterious results also are possible. Levy and Taylor (2003) evaluated the effects of four composted products (horse manure/bedding, mink farm waste, municipal solid waste/sewage sludge, and pulp mill waste) on the growth and establishment of tomatoes, cress, and radish. They found that horse manure/bedding and mink farm waste dramatically stimulated vegetative growth, but municipal solid waste/sewage sludge and pulp mill waste were strongly inhibitory, producing vegetative deformity and stunted growth.

3.1 Cost and Scale of Application

Generally, conventional costs for technologies like incineration or the construction and management of controlled confinements oscillate between \$250 and \$1,000 USD/m^3 (Van Deuren et al. 1997). For the particular case of biopiles, the estimated costs are between \$25 and \$150 USD/m^3 (Semple et al. 2001; Potter 2000). These costs vary according to the quantity and type of soil to treat, the volume of agent availability, the type of contaminants, the type of process to employ, the need of prior and subsequent processing, the need of equipment for the control of volatile organic compounds, and climatic conditions.

According to Echeverry (2002), in a comparative study between organic and inorganic fertilization in the cultivation of bananas in Colombia, the cost of organic fertilization was approximately \$80 USD ha^{-1}, equivalent to 33% of the cost of chemical fertilization (\$240 USD ha^{-1}), which is clearly favorable in terms of cost. There was no statistical difference in the weight between racemes produced with chemical or organic fertilizers. The advantages of employing organic fertilizers are their lower cost and contribution to the improvement and conservation of long-term soil fertility.

In Cuba, where the tendency is to develop solutions and techniques of fertilization to avoid the destruction of the environment and to eliminate high dependence on imported chemical fertilizers, investigations have focused on filter-cake compost obtained from waste generated by sugarcane production. This material contributes a high quantity of nutrients for the production of compost on a large scale. According to Rodriguez (2002), 35 tons ha^{-1} of filter-cake applied to soils provides:

- 312 kg urea with a 2002 value of $84–$106 USD per ton
- 282 kg triple superphosphate with a 2002 value of $129–$138 USD per ton
- 70 kg potassium chloride with a 2002 value of $112–$116 USD per ton

Organic compost application represented a savings of $2,980 USD for 13.4 ha and had a residual effect for 5 years, guaranteeing increments in performance of 6–15%. In the preparation of biological compost, only enhancers were used to expedite the process.

3.2 Scale of Application

In order to choose the size of the site required for composting, the following factors should be taken into consideration: the anticipated volume of raw materials, the technology to be used (the higher the level, the less space required), the equipment to be used (which depends on the method and raw materials), and the projections for growth. Also important is accessibility (roads suitable for traffic and convenient to feedstocks, or raw materials), population density (no houses within half a mile), and type of neighbors (some industries require a clean atmosphere and no flies). Some characteristics of a desirable site include slightly sloped land (for drainage), a firm soil type that packs well, not located in a flood plain, convenient utilities, and a rectangular or square site, which is more efficient than a circular or irregularly shaped site. Key to the success of any composting operation is a marketing or distribution program for compost products. The compost must be of consistently high quality so as to develop long-term markets.

The application of compost for agricultural production, as a means of recycling green waste that is produced by communities and agricultural and livestock activities, may be a sustainable and inexpensive solution. However, the large quantities produced necessitate the development of education and organization of compost producing infrastructures and equipment programs, particularly in developing countries.

When dealing with compost application at a relatively small spatial scale, the need for infrastructure, financial resources and a labor force may not represent a major concern because the compost volumes that are to be transported and the costs involved are smaller compared to those for large scale compost application. It is well known that a significant fraction of the solid waste generated in the world is organic material that can be recycled through small scale composting (Fig. 5). There are many advantages to this strategy of waste management. For instance, households, businesses and institutions may save money by composting items such as food scraps and yard trimmings while sending less waste to landfills and incinerators. In addition, small scale composting is often the most environmentally sound way of recycling organic materials.

Fig. 5 Small scale composting in Malawi and Costa Rica (Photos courtesy of David C. Weindorf)

However, for big projects that run at a large scale, the economics and the infrastructure requirements will be two of the key factors taken into consideration, since the cost in creating the required infrastructure for production and distribution may be considerable. In both cases, the environmental benefits justify the investments involved.

From the social and economic perspectives, small scale projects can be more suitable for developing countries or individual households. Large scale projects normally involve great financial investment and the establishment of a network of compost production sites and centralized sites, which must be properly equipped to compost the increasing volumes of waste produced and to meet a growing demand from the agricultural sector. This large scale approach can be of greater applicability in developed countries, although its cost of implementation can be much greater than at smaller scales.

The application of compost at both small and large scales allows farmers to minimize the use and cost of commercial fertilizers, replacing them locally with an economical and sustainable alternative. Thus, farmer agricultural productive activities become more environmentally friendly and competitive. The compost can be used to mulch landscaping, enhance crop growth, enrich topsoil, and provide other benefits. Reduction in the need for inorganic fertilizers and pesticides when using compost is highly beneficial to the aquatic ecosystems, flora, fauna, and human health.

4 Organic and Inorganic Fertilization: Culture, Economics, and Sustainability

Presently, modern agriculture bases its productivity, to a large extent, on the use of inorganic fertilizers, including urea, nitrates and its by-products. Such use has yielded deteriorations in field productive capacity, problems with soil hydricity and erosion, soil compaction, salinization, loss of soil structure, and water contaminated with chemical compounds such as nitrates and insecticides (Pérez 2008).

According to the Mexican Association of Ecological Farmers (1992), composting is a fertilizer technique founded in the larger topic of organic agriculture. The use of compost, as opposed to inorganic fertilizers, is characterized by its low solubility because it delivers nutrients more slowly to the plants, has a greater duration, and reduces nutrient loss through leaching. As well, the varied nutrient composition of compost responds to the needs of the plants (Narea and Valdivieso 2002). According to Gross (1986), most improvements in farming occur with soil fertility and productivity. Investigations in Germany and the Netherlands (Table 3) have shown that nitrate filtration levels are significantly lower with organic agriculture than in traditional farming systems. The purpose for using compost in agriculture is to reduce contamination and prevent environmental degradation by using more sustainable methods of cultivation (FAO 2003).

In the framework of sustainable development, the process of composting presents important perspectives for resolving many problems produced by contamination in Mexico. Composting technologies particularly and bioremediation in general, are viable processes for application since most of the country has adequate climatic conditions for farming, with annual average temperatures that oscillate between 18°C and 26°C, temperatures favorable for implementing the aforementioned types of composting (Cooperband 2002).

Nevertheless, before using the process of composting for remediation of any given site, it is necessary to include complete local information (origin of the contamination, characterization of the soil and of the contamination to be treated) and to establish tests of contaminant biodegradation by indigenous and exogenous microorganisms to select the type of technology based on the costs and the availability of materials and equipment to carry out the treatment (Zechendorf 1999).

According to Soil and More, Mexico (2010), a private company dedicated to the production of compost in Mexico, the use of compost improves the economic

Table 3 Reduction of nitrate filtration indices with organic agriculture compared to traditional inorganic agriculture (From Stolze et al. (2000); cited by FAO (2003))

Percentage filtration	Authors
>50	Smilde (1989)
>50	Vereijken (1990)
57	Paffrath (1993)
50	Reitmayr (1995)
40	Berg et al. (1997)
64	Haas (1997)

situation of the agricultural producers in the area, as well as the social development and environmental conditions of the region. Application of high quality compost increases crop production, and reduces the cost of chemical fertilizer and pesticide applications, considerably improving the economic situation of the agricultural producers. Compost application is a sustainable means of developing the fertility of soils degraded by agricultural activities in the region. The practice more efficiently uses irrigation water because it increases the retention of humidity in the soil. Because of the natural microbiological community, the compost also acts as a natural filter for removing many agricultural pathogens.

In sustainable agriculture, the application of organic materials to the soil is indisputably necessary, since they are a vital source for reconstructing its organic matter and for supplying nutrients (Álvarez et al. 2006). The employment of compost in agriculture unites aspects of cultivation, ecology, economy and society in an integrated manner, to substitute for or complement the use of traditional fertilizers at the farm level (Echeverry 2002).

5 Limitations of Composts as Fertilizers

Composts rarely provide nutrients to plants in exactly the right balance. This is especially the case for macro-nutrients such as excess P or deficient N. For example, bovine manure usually has a higher P:N ratio than what non-leguminous crops require. Once composted, that P:N ratio is even greater after N loss to volatilization (McDowell and Sharpley 2004).

As a result of nutrient imbalances as well as improper management, composts have been identified as potential environmental threats. In some cases, especially with animal manure, compost-N can overwhelm soil capacity to hold it until plants can effectively utilize it (Daliparthy et al. 1994). This is particularly the case in soils with shallow water tables where leaching quickly carries soluble nitrates to those tables or in cold climates when crops are absent or dormant. Composting those manures lowers N concentrations and mitigates this problem but results in deficient soil-N for most crops. Where water tables are further from composts on the soil surface, excessive P contribution to surface water runoff is more likely to be problematic (McGechan et al. 2005). When these composts are surface-applied to perennial forage fields where incorporation into the soil via tillage is not possible, negative impacts of P on downstream surface water quality have been identified (Sharpley and Syers 1979). In such cases, quantities applied to the crop may be limited by environmental considerations rather than crop requirements.

6 Manufactured Fertilizers Versus Composts as Fertilizers

Industrially manufactured fertilizers are used throughout the world and are generally credited, along with genetic manipulation and selection of key crops, for the huge increases in food production known as “The Green Revolution” (De Datta et al. 1968). Before the widespread production and use of manufactured fertilizers, crop productivity, especially from non-legume grain crops, was limited by inherent soil fertility. Once nutrients were “mined” from the soil by years of cropping, the production rates of those soils declined along with the capacity for a reasonable return on labor and seed invested. Basically, nutrients in soil organic material were converted into crop products and once these were exhausted, soils lost their fertility. Pre-industrial farmers mitigated this decline by various means, including:

- Moving on to other virgin soils
- Resting the land via fallows for several years
- Rotating with green manure crops (usually legumes) grown specifically for organic matter production
- Rotating with fertility-enhancing food crops such as legume pulses
- Collecting and incorporating animal wastes such as cattle manure or bat/bird guano
- Incorporating composts created from human and animal waste

As modern human population increased, demand for food production (i.e., mining soil fertility) climbed. The age-old methods for maintaining soil fertility simply could not keep up with market demand as society moved away from farms into urban areas. More people needed to be fed from less land. Mining and concentrating nutrients such as P or fixing atmospheric N into plant-available forms became possible using fossil fuels. The advantages of manufactured fertilizers compared to compost fertilizers were various, including:

- Ease of transport due to high nutrient concentration
- Low costs, reflecting low fossil-fuel costs
- Ease of incorporation into soils
- Near total nutrient availability
- Nearly unlimited raw material
- Precise nutrient balance reflecting varied crop and soil fertility needs
- Immediate availability to plant roots

It is easy to see, then, why compost fertilizers lost traction to what became known as industrial fertilizers. But soils, and eventually the environment, may have paid a price for this switch (Lappé et al. 1998). Many of the advantages manufactured fertilizers brought to agricultural production also carried dangers. These include:

- Changes in soil chemistry, especially pH
- High nutrient availability (solubility) making them easily leached into the environment
- Application of primary nutrients (mostly N, P and K) depletes or masks minor elements
- Soil cation exchange capacity (CEC) and/or OM is unable to hold nutrients as efficiently until plants need them

As the cost of fossil fuels rises and human population continues to grow, farmers are faced with a dilemma: starve populations by reducing crop yields or run the risk of damaging the environment by the continued heavy use of industrial fertilizers. The "dead zone" in the Gulf of Mexico is considered a prime example of the latter (USGS 2010), due at least in part to agricultural runoff into the Mississippi River of North America. The first option is politically and socially unacceptable while the latter inevitably will cost future generations.

A third option may be to join the two approaches by making old soil fertility methods more productive and new fertilizer uses more sustainable. Improving soil organic matter by using greater incorporation of composts, crop rotations and green manures, while boosting crop yields with judicious use of industrial fertilizer regimens may be the best compromise. In this manner, farmers realize dual benefits via:

- Stretching limited soil, compost, green manure, and organic matter resources
- Correcting nutrient imbalances/deficiencies of composts/green manures with industrial fertilizers
- Binding pesticides long enough to allow them to decompose before causing environmental concerns
- Improving industrial fertilizer nutrient delivery and balance
- Improving industrial fertilizer retention and slow release by association with soil OM

Numerous investigations have verified that the productive and ecological benefits of using compost as organic fertilizer are greater than those obtained from the use of chemical fertilizers alone (Bizzozero 2006; Barzaga et al. 2004; FAO 2003). As well, the use and application of chemical fertilizers is presently limited, not only by their effects on the environment, but because their price has grown rapidly, nearly 105% during 2007–2008 alone (Seceña 2010). Hence, the production of compost is a highly beneficial alternative, not only for producing good agroecological conditions, but also because the waste utilized can be acquired at a very low cost (Sandoval and Stuardo 2001).

In a comparative analysis carried out by the Cuban sugar company "Dos Rios", with only one application of filter cake compost due to the slowness of its decomposition (and therefore applied for the entire life cycle of the crop), a low cost of only \$131.00 ha^{-1} would be incurred against a cost of \$562.25 ha^{-1} by using inorganic fertilizers (chemical) for sugarcane cultivation. This translates to a savings of \$431.25 ha^{-1}, and only for the fertilizer (Barzaga et al. 2004). According to these

Table 4 Changes in soil sustainability indicators produced by using organic fertilizers in Chile (Bizzozero 2006)

Indicators	1994	1998
Soil erosion	60 tons ha^{-1}	12 tons ha^{-1}
Organic matter	2.1%	3%
Water retention/humidity	8%	11%
Biodiversity (Shannon index)	1	2.28
Aluminum saturation	4.8	2.4
Sum of magnesium, calcium, sodium	5.75	8.8

authors, for those companies capable of producing a quality product, the production of this biofertilizer constitutes an important source of income.

In China, in a comparative study between conventional and organic berry production systems, the supplies, products and net income of the organic system were higher than from the inorganic system. The greater supplies for the organic system consisted mostly of labor, especially for the task of fertilizer application, but costs of purchasing chemical fertilizers and insecticides were lower. Given that yield and net income was higher, the high cost of manual labor is offset by the high revenue from the product (FAO 2003).

In Chile, where the most important problem was soil erosion, compost was used in an agricultural fertilization project to recover some soil properties. Toward the end of the project in 1998, significant changes were observed. Organic management not only controlled erosion, but improved the structure and fertility of the soil (Table 4). The improvement in humidity retention, the reduction of erosion, and the introduction of rotational cropping resulted in a variety of food and forage with greater productivity (approximately 20% in the case of cereals, and between 20% and 60% for horticulture). As well, the area destined for horticulture grew by 260%, significantly increasing income by approximately $1,300 USD in 1994, and more than $6,000 USD annually in 1998 (Bizzozero 2006).

According to Bizzozero (2006), yield is the quantity (in kg ha^{-1}) of product obtained from a current production system with regard to the surface area utilized to provide financial gain. This parameter does not consider the form of the product obtained, the ecological impacts generated during its production, the supplies contributed or the cost of the same, nor the social impacts. Positive impacts also have been observed from organic fertilizers on crops, such as increasing the number of seedlings, shortening the cultivation cycle by 7–10 days, increasing flowering and fruition, and increasing performance between 5% and 20%, as well as obtaining fruits with greater commercial quality (appearance and size).

In Europe, even the water treatment plants favor the employment of organic fertilizers in areas of water resource protection. This is an economically efficient solution to reduce the costs of drinking water purification and to minimize groundwater contamination with nitrates and insecticides. When imposed as a regulation in organic agriculture, it has resulted in the low presence of N in organic operations. That implies lower costs, since the cost of production on the farm for 1 kg of N in organic operations can surpass 7–16 times the cost of the inorganic or mineral fertilizers. Therefore, contrary to what occurs on conventional farms where fertilizers and sewage sludge are a general waste problem, organic farmers develop efficient strategies for the management of N. For example, intercropping, cover crops, the optimum incorporation of legumes in the land or the limited use of liquid manure to avoid the volatilization (loss to the atmosphere) of N are common practices (FAO 2003).

7 Conclusions

Composts are dynamic substances generated worldwide as technological alternatives for the bioremediation and organic fertilization of soils. They permit improvement and conservation equilibrium of nutrient flows and minimize the use of external resources. Composting is based on the same system that is used naturally to maintain nutrient recycling (Granados and López 1996). It is a process of solid phase aerobic fermentation which takes advantage of automatic heat production by the different native microbial populations for the total or partial biodegradation of organic matter to obtain organic compost that is black, stable, homogeneous, and nutrient-rich (Semple et al. 2001). Composting is employed as an alternative to the use of industrial fertilizers for soils supporting a wide variety of crops across the world. The source materials (feedstocks) and composting methods employed vary with geographic location and available resources, but play an important role in sustainable agricultural production.

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References

Adani F, Gigliotti G, Valentini F, Laraia R (2003) Respiration index determination: a comparative study of different methods. Compost Sci Util 11:144–151

Álvarez SE, Vázquez AA, Castellanos JZ, Cueto WJ (2006) Efectividad biológica de abonos orgánicos en el crecimiento de trigo. Terra 24:261–268

Annabi M, Francou C, Poitrenaud M, Bissonnais YL (2007) Soil aggregate stability improvement with urban composts of different maturities. J Soil Sci Soc Am 71:413–423

Barzaga UJ, Pérez JA, Santana S (2004) Producción de compost y resultados preliminares de su aplicación en áreas de la empresa azucarera “Dos Rios”. Jornada Científica por el 40 Aniversario del Instituto Nacional de Investigaciones de la Caña de Azúcar Sede Tecnológica 11 y 12 de Noviembre de 2004. http://www.santiago.cu/hosting/etica/Sede40/index.htm. Accessed July 2010

Berg M, Haas G, Köpke U (1997) Grundwasserschonende Landbewirtschaftung durch Organischen im Vergleich zu Integriertem und Konventionellem Landbau. VDLUFA-Schriftenreihe 46:615–618

Bhattacharyya P, Chakraborty A, Bhattacharya B, Chakrabarti K (2003) Evaluation of MSW compost as a component of integrated nutrient management in wetland rice. Compost Sci Util 11:343–350

Bizzozero F (2006) Tecnologías apropiadas. Biofertilizantes. Nutriendo cultivos sanos. CEUTA, Montevideo, 47 pp

Brady NC, Weil RR (2002) The nature and properties of soils, 13th edn. Prentice Hall, Upper Saddle River

Buchanan M (1993) Agricultural markets for yard waste compost. Biocycle 34(9):33–36

Butler TJ, Han KJ, Muir JP, Weindorf DC, Lastly L (2008) Dairy manure compost effects on corn silage production and soil properties. Agron J 100:1541–1545

Castellanos JZ, Marques OJ, Etchevers JD, Aguilar SA, Salinas JR (1996) Long-term effect of dairy manure on forage yields and soil properties in an arid irrigated region of northern Mexico. Terra 14:151–158

Changa CM, Wang P, Watson ME, Hoitink HAJ, Michel FC (2003) Assessment of the reliability of a commercial maturity test kit for composted manures. Compost Sci Util 11:125–143

Cooperband LR (2002) Paper mill residuals and compost effects on soil physical properties in an irrigated vegetable rotation. J Environ Qual 31:2086–2095

Córdoba VCA (2009) Efecto de dos tipos de compost y un biofertilizante sobre poblaciones microbianas edáficas en un cultivo de hortalizas en Risaralda, Colombia. Revista Brasiliana de Agroecología 4:1159–1162

Coronado M (1997) Agricultura orgánica versus agricultura convencional. Primer encuentro: Abonos orgánicos vs. Fertilizantes químicos. CIED. http://www.ciedperu.org/articulos/organico.htm. Accessed Oct 2003

Courtney RG, Mullen GJ (2008) Soil quality and barley growth as influenced by the land application of two compost types. Bioresour Technol 99:2913–2918

Crovetto C (1992) Rastrojos sobre el suelo. Una introducción a la cero la branza. Editorial Universitaria. Santiago, Chile, 312pp

Daliparthy J, Herbert SJ, Veneman PLM (1994) Dairy manure applications to alfalfa: crop response, soil nitrate and nitrate in soil water. Agron J 86:927–933

Dalzell HW, Biddlestone AJ, Gray KR, Turairajan K (1991) Manejo del suelo: producción y uso del composte en ambientes tropicales y subtropicales, vol 56. Boletín de Suelos de la FAO (FAO), Roma, 178 pp

De Datta SK, Tauro AC, Balaoing SN (1968) Effect of plant type and nitrogen level on growth characteristics and grain yield of indica rice in the tropics. Agron J 60:643–647

Echeverry NE (2002) Fertilización orgánica vs fertilización inorgánica de plátano Cachaco común en Colombia. Agronomía INFOMUSA 10(2):7–10

EPA (1995) An analysis of composting as an environmental remediation technology. EPA530-R-98-008. http://mie.esab.upc.es/ms/informacio/usos_compost/Composting%20as%20remediation%20technology%20EPA%201.pdf. Accessed Aug 2010

Eweis JB, Ergas SJ, Chang DP, Schroeder ED (1998) Bioremediation Principles. McGraw-Hill, Boston, London, 296 pp.

FAO (1991) Manejo del suelo. Producción y uso del composte en ambientes tropicales y subtropicales. Organización de las Naciones Unidas para la Agricultura y la Alimentación, Roma, 178 pp

FAO (2003) Agricultura orgánica, ambiente y seguridad alimentaria. Serie: Environment and natural resources management. ISBN: 9253048190 Y4137/S. 4: 262. http://www.fao.org/documents/pub_dett.asp?lang=es&pub_id=152711. Accessed Aug 2010

Farrell M, Jones DL (2009) Critical evaluation of municipal solid waste composting and potential compost markets. Bioresour Technol 100:4301–4310

García MI (1993) Elaboración de compostas a partir de los desechos sólidos biodegradables. Reporte No.153907. UAM-Iztapalapa, 11 pp

Granados D, López G (1996) Agroecología. Universidad Autónoma Chapingo, México, 54 pp

Gross A (1986) Abonos. Guía práctica de la fertilización. Edición Mundi-Prensa, Madrid, 560 pp

Guerrero J (1993) Abonos orgánicos: Tecnología para el manejo ecológico de suelos. RAAA, Lima, 189 pp

Haas G (1997) Leistungen des Ökologischen Landbaus zur Verringerung von Gewässerbelastungen. In: Dohmann M (Hrsg.) 30. Essener Tagung für Wasser- und Abfallwirtschaft, Aachen, 13/1–13/13

Havlin JL, Beaton JD, Tisdale SL, Nelson WL (2005) Soil fertility and fertilizers, 7th edn. Prentice Hall, Upper Saddle

Huang G, Han L, Yang Z, Wang X (2008) Evaluation of nutrient metal content in Chinese animal manure compost using near infrared spectroscopy. Bioresour Technol 99:8164–8169

Iqbal MK, Shafiq T, Ahmed K (2010) Characterization of bulking agents and its effect on physical properties of compost. Bioresour Technol 101:1913–1919

Iturbe-Argüelles R, Flores-Torres C, Chávez-López C, Roldán-Martín A (2002) Saneamiento de suelos contaminados con hidrocarburos mediante biopilas. Ingeniería, Investigación y Tecnología III 1:25–35

Kabore TWT, Houot S, Hien E, Zombre P, Hien V, Masse D (2010) Effect of the raw materials and mixing ratio of composted wastes on the dynamic of organic matter stabilization and nitrogen availability in composts of Sub-Saharan Africa. Bioresour Technol 101:1002–1013

Koepf H (1965) Compost. Reprinted from Bio-Dynamic issue N°77. Bio–Dynamic farming and gardening association, Inc. 18 pp

Kross BC, Ayebo AD, Fuortes LJ (1992) Methemoglobinemia: nitrate toxicity in rural America. Am Fam Physician 46:183–188

Kumar S, Gaikwad SA (2004) Municipal solid waste management in Indian urban centres: an approach for betterment. In: Gupta KR (ed) Urban development debates in the new millennium – studies in revisited theories and redefined praxes. Atlantic Publishers, New Delhi, pp 100–111

Lappé FM, Collins J, Rosset P (1998) World hunger: 12 myths. Grove, Greenwich

Levy JS, Taylor BR (2003) Effects of pulp mill solids and three composts on early growth of tomatoes. Bioresour Technol 89:297–305

López-Martínez JD, Díaz EE, Martínez RE, Valdez CD (2001) Abonos orgánicos y su efecto en propiedades físicas y químicas del suelo y rendimiento en maíz. Terra 19:293–299

Maas EV, Grattan SR (1999) Crop yields as affected by salinity. In: Skaggs RW, van Schilfgaarde J (eds) Agricultural drainage, Agronomy Monograph 38. ASA, CSSA, SSSA, Madison

Manungufala TE, Chimuka L, Maswanganyi BX (2008) Evaluating the quality of communities making compost manure in South Africa: a case study of content and sources of metals in compost manure from Thulamela Municipality, Limpopo province. Bioresour Technol 99:1491–1496

Martin DL, Gershuny G (eds) (1992) The Rodale book of composting. Rodale, Emmaus

McDowell RW, Sharpley AN (2004) Variation of phosphorus leached from Pennsylvanian soils amended with manures, composts or inorganic fertilizer. Agric Ecosyst Environ 102:17–27

McGechan MB, Lewis DR, Hooda PS (2005) Modeling through-soil transport of phosphorus to surface waters from livestock agriculture at the field and catchment scale. Sci Total Environ 344:185–199

Mexican Association of Ecological Farmers (1992) Decisions research on sustainable agriculture. Agronomy News, January 1992, pp. 26–29

Misra RV, Roy RN (2002) On-farm composting methods. Food and Agriculture Organization of the United Nations, Rome

Mupondi LT, Mnkeni PNS, Brutsch MO (2006) Evaluation of pine bark or pine bark with goat manure or sewage sludge composts as growing media for vegetable seedlings. Compost Sci Util 14:238–243

Nardi JB (2003) The world beneath our feet – a guide to life in the soil. Oxford University Press, New York

Narea G, Valdivieso C (2002) Agricultura orgánica: Situación actual, desafíos y técnicas de producción. Servicio Agrícola y Ganadero. Departamento de Protección de Recursos Naturales Renovables. Santiago, Chile. 150pp

Neely CL, Beare MH, Hargrove HW, Coleman DC (1991) Relationships between fungal and bacterial substrate-induced respiration, biomass and plant residue decomposition. Soil Biol Biochem 23:947–954

Negro MJ, Solano ML, Ciria P, Carrasco J (1999) Composting sweet sorghum bagasse with other wastes. Bioresour Technol 67:89–92

Paffrath A (1993) N-Dynamik auf ausgewählten Flächen des Boschheide Hofes und des konventionellen Vergleichsbetriebes. In: MURL (ed), Abschlußbericht Forschungs- und Entwicklungsvorhaben "Alternativer Landbau Boschheide Hof" 1979–1992. Forschung und Beratung 49: 56–66

Pérez ER (2008) Contaminación agrícola y políticas públicas en México. XI Jornada de economía crítica. 27 al 29 Marzo. Bilbao, V. España, pp 1–23

Potter CL (2000) Biopile treatment of soils contaminated with hazardous waste. Seminar Series on Bioremediation of Hazardous Waste Sites 10:1–5

Reitmayr T (1995) Entwicklungen eines rechnergestützten Kennzahlensystems zur ökonomischen und ökologischen Beurteilung von agrarischen Bewirtschaftungsformen–dargestellt an einem Beispiel. Agrarwirtschaft Sonderheft, 147 pp

Rodríguez CS (2002) El potencial de desarrollo de la agricultura cañera cubana sobre bases sustentables. http://www.nodo50.org/cubasigloXXI/economia/castellon3_311202.pdf. Accessed July 2010

Rynk R (ed) (1992) On-farm composting handbook. Natural Resource, Agriculture, and Engineering Service – Cooperative Extension, Ithaca

Sandoval A, Stuardo A (2001) El compost; una buena alternativa. Centro de Semillas de Árboles Forestales. Facultad de Ciencias Forestales, Universidad de Chile. http://www.uchile.cl/facultades/cs_forestales/publicaciones/cesaf/n13/2.html. Accessed May 2003

Schnitzer M (1969) Reactions between fulvic acid, a soil humic compound and inorganic soil constituents. J Soil Sci Soc Am 33:75–81

Seceña MJC (2010) Evaluación del manejo del nitrógeno en el agroecosistema caña de azúcar. Tesis de Doctorado. Colegio de Postgraduados, Campus Veracruz, 114 pp

Sellers K, Pederson TA, Fan C (1993) Review of soil mound technologies for the bioremediation of hydrocarbon contaminated soil. In: Calabrese E, Bell C (eds) Hydrocarbon contaminated soil, vol 3. Lewis Publishers, Boca Raton

Semple KT, Reid BJ, Fermor TR (2001) Impact of composting strategies on the treatment of soils contaminated with organic pollutants. Environ Pollut 112:269–283

Sharpley AN, Syers JK (1979) Phosphorus inputs into a stream draining an agricultural watershed. II. Amounts contributed and relative significance of runoff types. Water Air Soil Pollut 11:417–428

Smilde KW (1989) Nutrient supply and soil fertility. In: Zadoks JC (ed) Development of farming systems. Pudoc, Wageningen, The Netherlands, p 25–31

Soil and More, Mexico (2010) http://www.soilandmore.nl/node/28. Accessed Aug 2010

Soil Science Society of America (2010) Glossary of soil science terms. https://www.soils.org/publications/soils-glossary. Accessed Mar 2010

Soumare M, Tack FMG, Verloo MG (2003) Effects of municipal solid waste compost and mineral fertilization on plant growth in two tropical agricultural soils of Mali. Bioresour Technol 86:15–20

Stolze M, Piorr A, Häring A, Dabbert S (2000) The environmental impacts of organic farming in Europe, vol 6, Organic farming in Europe: economics and policy. University of Hohenheim, Department of Farm Economics, Stuttgart

Texas Department of Transportation (2004) Standard specifications for construction and maintenance of highways, streets, and bridges. Texas Department of Transportation, Austin

US Composting Council-USDA (2002) Test methods for the evaluation of composts and composting. Composting Council Research and Education Foundation, Holbrook, CD-ROM computer file

US EPA (2010) Electronic code of federal regulations – Title 40: Protection of environment – Part 503 – Standards for the use or disposal of sewage sludge. 503.13 Pollutant limits. http://ecfr.gpoaccess.gov. Accessed Mar 2010

USGS (2010) The Gulf of Mexico hypoxic zone. United States Geologic Survey, Washington, DC. http://toxics.usgs.gov/hypoxia/hypoxic_zone.html

Van Deuren J, Wang Z, Ledbetter J (1997) Remediation technologies screening matrix and reference guide, 3rd edn. Technology Innovation Office, US EPA, Washington, DC. http://www.epa.gov/tio/remed.htm. Accessed Aug 2010

Van Ginkel JT, Raats PAC, Van Haneghem IA (1999) Bulk density and porosity distributions in a compost pile. Neth J Agric Sci 47:105–121

Vereijken P (1990) Integrierte Nährstoffversorgung im Ackerbau. Schweizerische Landwirtschaftliche Forschung 29:359–365

Weindorf DC, Zartman RE, Allen BL (2006) Effect of compost on soil properties in Dallas, Texas. Compost Sci Util 14:59–67

Zechendorf B (1999) Sustainable development: how can biotechnology contribute? Trends Biotechnol 17:219–225