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Solid Waste in Agricultural Soils: An Approach Based on Environmental Principles, Human Health, and Food Security

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Abstract

In recent decades, projections involving population growth, changes in consumption patterns, modifications of the wastes produced, and a significant increase in resource extraction have caused concern in the scientific world, in treatment companies, and in environmental and governmental agencies throughout the world, regarding the destination of the large volume of solid wastes generated, the relatively high contents of potentially toxic, carcinogenic and mutagenic substances and pathogenic microorganisms. Waste management has become very important to ensure elementary resources such as water, phosphorus, and food in the future. The recycling policy thus requires that wastes be classified in terms of their appropriateness for new uses and also based on their origins and hazardousness of handling. These classifications are essential in order to allow a minimum of rationality in their new destinations. Currently, several studies have been performed to use solid wastes from human activities as soil conditioners and/or fertilizers for increasing crop productivity. Therefore, studies that monitor organic waste effects on agricultural soils deserve the attention of the international scientific community, as it enables increases in the productivity of agricultural crops, fiber, and biomass energy combined to reduce risks to human, plant, and animal health and environment.

Keywords: organic fertilizer, human health, environmental security, agricultural approach

1. Introduction

The term “organic waste” commonly used in the literature refers to any type of solid, semi-solid, gaseous, or liquid organic materials with different physicochemical characteristics, with a highly complex composition. In this chapter, we shall discuss the term regarding the possible reuse and use of organic solid wastes (SWs) in agriculture and the challenges of this proposal.

In Brazil, as in other countries in South America, Latin America, North America, and Europe, the combination of industrial development, demographic pressure, and increased consumption by the population has caused significant increments in the volume of municipal solid wastes. In the context of the change in consumption patterns and urban and industrial development, sustainable management of waste is one of the most important aspects of planning urban infrastructure, since, without sustainable waste management there would be risks to the environment, human health, quality of life, and the economy.

Water, which up to the last generation was considered an abundant natural resource, has become a limiting factor that was compromised because of high pollution in some regions, as a result of the inadequate discharge of urban sewage which is today the main polluter of water sources. However, sewage treatment generates a sludge rich in organic matter and nutrients whose final disposal in the environment should be planned already during the planning phase of Treatment Plants, thus avoiding partially canceling out the benefit of effluent collection and treatment [1].

The evaluation of processes that protect the environment alongside resource and energy consumption from the most favorable to the least favorable actions is known as waste management hierarchy. The waste hierarchy is a set of priorities for the efficient use of resources, such avoidance including action to reduce the amount of waste generated by households, industry, and all levels of government, resource recovery including reuse, recycling, reprocessing, and energy recovery, consistent with the most efficient use of the recovered resources and disposal including management of all disposal options in the most environmentally responsible manner. However, the waste hierarchy recognizes that some types of waste, such as hazardous chemicals or asbestos, cannot be safely recycled and direct treatment or disposal is the most appropriate management option [2].

Conceptually, it is essential to consider the disposal, not the discarding of wastes. The former, disposal involves an organized action for the purpose of using and not only eliminating wastes, and reutilization of waste is definitely the most useful option from the economic, environmental, and social standpoint. The second, discarding, on the other hand, is defined as the act or effect of getting rid of something that is no longer useful or which is no longer wanted, or even anything that that is separated because it has been rejected or set aside. Thus, discarding is performed randomly, without great care, and the main interest is to get rid of the waste [3].

Currently, worldwide, organic wastes are most commonly disposed of in controlled landfills, incineration, and applying them to agricultural soils (e.g., home composting, central composting plants). Since incineration is a very expensive and environmentally criticized technique, other recycling or reusing options are considered better.

It is estimated that currently there are about 3 billion inhabitants generating 1.2 kg per person per day, almost 1.3 billion tons of municipal solid waste (MSW) a year or 1.2 kg per capita per day. In 2025, this will probably increase to 4.3 billion tons from urban residents, about 1.42 kg per inhabitant per day of MSW (2.2 thousand millions of tons a year). However, they are highly variable since there are differences in the rates of waste generation between countries, between cities, and even within cities [4].

In Brazil, with a population of 206 million inhabitants, daily about 218,874 thousand tons of urban solid wastes (USWs) are produced, generated in the country, and the main form of final disposal of USW is in sanitary landfills (58.7%). According to IBGE, rural occupation in Brazil corresponds to 30 million people, which is approximately 15% of the total population of the country. And rural garbage collection is insufficient, since it only covers 20% of the domiciles in the country. In general, a rural waste collection system is inefficient, and the wastes are discarded in the environment, burned in most cases, or simply dumped in the open, due to the lack of waste collection and treatment.

Many countries around the world have been incorporating the organic wastes from sewage treatment plants (STPs) or from the selective collection of urban garbage into the soil for several decades now, and have created and altered a few preventive rules against possible problems with the contaminants present in them, emphasizing potentially toxic metals, organic contaminants, and pathogens.

2. Definition and classification of wastes

The intensification of the industrial process and the rapid population growth and the consequent demand for consumer goods have provoked an increase in the volume of wastes generated. Therefore, there is a concern, on a global scale, to solve the problem of excessive generation and environmentally safe final disposal.

Considering the complexity involved in the discussion of the concept of solid wastes, it is important to begin by performing a comparative analysis of the terms: garbage and waste. Garbage is a polysemic term which is related to several words and can be interpreted in different manners, varying in time and in space according to the socioeconomic and cultural contexts in which it is used. From the semantic standpoint, it corresponds to all of the useless materials, all materials discarded in a public place, everything that is “thrown away,” in other words, old objects without value [2].

The National Policy of Solid Wastes (NPSW, Brazil), Law 12,305/10, presents a broad definition of solid wastes, including gases and liquids, as described in paragraph XVI of article 3.

[...] discarded material, substance, object or goods resulting from human activities in society, whose final disposal is done, proposed to do or mandatorily performed in the solid or semi-solid states, as well as gases in containers and liquids whose specificities make it impossible to discharge them into the public sewage system or into bodies of water, or that for this require solutions that are technical or economically unfeasible considering the best technology available [2].

Garbage and waste have different connotations and may be understood as byproducts generated by the different human activities. The difference lies in the relationship between people and the material to be discarded, since although garbage can be reused, people consider it something useless and valueless that must be thrown away. On the other hand, waste (residue) is seen as material with commercial value that can be reutilized to produce new products [5, 6].

The topic of “wastes” has been a priority since the Second United Nations Conference on Environment and Development (UNCED), which also became known as ECO-92 or Rio-92, because it took place in the city of Rio de Janeiro in 1992. It was a conference on a global scale, both of the rich countries and the poorer ones, because it contributed directly or indirectly to global warming and climate changes [7]. At this conference, Agenda 21 was elaborated, a document that includes among its programs a few actions relating to the management of urban-industrial solid wastes. In this document, the management of domestic solid wastes must include not only its disposal or even its reuse, but also the adoption of measures that will be able to alter society’s patterns of production and consumption. Furthermore, every country and city must establish programs to comply successfully with the agreement, according to local conditions and even their economic capacity [8].

However, the management of solid wastes in urban areas is based historically on the linear logic that considers collection as the removal of wastes from the vicinity of the population and final disposal as putting them on soil in garbage dumps and landfills. This concept, besides manifest pollution in all forms, has led to the saturation of sites for the final disposal of the wastes [6, 9].

According to Ref. [10], in society, there is a lack of social concern about “rural garbage” with a mistaken notion of the urban population over the rural one, in which the former considers that due to the small number of people who live in the countryside—approximately 19% of the population—garbage is an insignificant problem. However, one does not perceive that this environmental damage in the rural area has major consequences on the quality of life of the urban zones, including water supplied to the cities. These types of wastes are generated by various activities, but if they are not well managed, they may cause various types of environmental damage [11].

Besides the significant increase in the generation of these wastes, in recent years there have been significant changes in their composition and characteristics and increased hazardousness [12]. These changes are the result especially of the development models with programmed obsolescence and discardability of the products and the change in consumption patterns based on excessive and superfluous consumption.

There are several ways of classifying the solid wastes. The recycling policy thus requires that wastes be classified in terms of their appropriateness for new uses, and also based on their origins and hazardousness of handling. These classifications are essential in order to allow a minimum of rationality in their new destinations. As every country has its specific classification, in Brazil the Brazilian Association of Technical Standards [13], through NBR n° 10.004/2004, establishes that solid wastes can be classified regarding their hazardousness as: Class I, hazardous; Class II, noninert; Class III, inert. As follows:

Class I or hazardous: Those that because of their intrinsic characteristics of flammability, corrosiveness, toxicity, or pathogenicity present risks to public health due to the increased mortality or morbidity, or else have adverse effects on the environment when handled or disposed of inadequately.

Class II or noninert: These are wastes that may present characteristics of combustibility, biodegradability, or solubility, which may result in risks to health or to the environment, and which cannot be included in the classifications of Class I wastes, hazardous or Class III, inert.

Class III or inert: Due to their intrinsic characteristics, these do not offer a risk to health and to the environment and when sampled representatively, according to Standard NBR 10,006 and submitted to a static or dynamic contact with distilled or deionized water, at ambient temperature, with a solubilization test according to Standard NBR 10,006, none of their constituents are solubilized at concentrations higher than the water potability standards, according to List number 8 (Annex H of NBR 10.004), except for the standards of aspect, color, turbidity, and taste.

Another criterion for classification looks at the origin of the wastes, i.e., the generating sources. According to the Manual for Integrated Management of Solid Wastes [14], wastes can be classified, as to generating source, into three categories: urban solid wastes, industrial solid wastes (ISWs), and special wastes.

Urban solid wastes (USWs) are wastes resulting from households (domiciliary or domestic), health service wastes, civil construction wastes, wastes from pruning and grass-cutting, wastes from ports, airports, bus terminals, train terminals, and the wastes of services that cover the commercial wastes, wastes from cleaning manholes, and wastes from sweeping, markets, and others [15].

Industrial solid wastes (ISWs) include the wastes of processing industries, radioactive wastes, and agricultural wastes. They are extremely varied and present diversified characteristics, since they depend on the kind of product manufactured and must therefore be studied case by case. Radioactive wastes (nuclear wastes) are those that emit radiation above the limits allowed by Brazilian standards, generally resulting from nuclear fuels, which, according to the legislation that specifies them, are in the exclusive purview of the National Committee of Nuclear Energy.

Agricultural wastes are those generated by activities pertaining to agriculture and livestock, such as containers of fertilizers, agricultural pesticides, feed, remnants of harvests, and manure. Since agrochemical containers are highly toxic they have specific legislation.

Some wastes are also considered special because of their differentiated characteristics, which include tires, batteries, and fluorescent lamps.

Generally, urban solid waste in Brazil is composed of 61% of organic matter, 15% of paper, 15% of plastic, 3% of glass, 2% of metal, and 5% of others. Despite meeting the specific legislation of each municipality, commercial garbage, up to 50 kg or liters, and domiciliary garbage are the responsibility of the city administrations, while the others are the responsibility of the generator himself. The wastes generated in rural, industrial, and residential activities, such as packaging and batteries, products that no longer work, and others, are the responsibility of the company that manufactured them, and this company must collect and dispose correctly of this material [2].

When solid wastes (SWs) are badly managed, they become a sanitary, environmental and social problem. The basic instrument to manage them is to know the sources and types of solid wastes through data on their composition and rate of generation [16]. However, the composition and rate of generation of solid wastes are a function of a number of variables, including the socioeconomic situation of the population, the degree of industrialization of the region, its geographical location, the sources of energy, and the climate [17].

The law of the National Policy on Solid Wastes [2] defines as its objective to establish regulations for the disposal of wastes, the responsibility of the manufacturers, of the consumers, and of the authorities. As regard the agricultural sector, the law establishes that the reverse logistics system should be applied. This is a tool for economic and social development characterized by a set of actions, procedures, and means destined to make it feasible to collect and reconstitute solid wastes to the business sector, for reuse, in its cycle or in other production cycles, or another environmentally appropriate final disposal. In the rural area, this instrument is applied to pesticides, its wastes and packaging, as well as to other products whose packaging, after use, constitute dangerous wastes. There may be shared management of the urban and rural wastes, involving the manufacturers, importers, distributors, and vendors, consumers, and heads of the public cleaning services.

3. Waste management and use in agricultural soils

Worldwide daily millions of tons of solid wastes are generated, which must be collected, selected, treated, and disposed of appropriately. In China, India, and other countries, such as Turkey, Mexico, and Brazil, almost 90% of the solid wastes that are composed mainly of the organic fractions are usually sent to landfills and garbage dumps, freely releasing huge amounts of CO_2 and CH_4 into the atmosphere [18, 19].

Waste management in urban and rural areas is one of the great challenges to Public Administration and Society. The National Policy on Solid Wastes (NPSW, Law 12,305/2010) [2] encouraged considerable changes in solid waste management in Brazil. According to Ref. [20], among the various challenges for NPSW is sending wastes mandatorily to recycling and composting of the organic fraction of the urban solid wastes (USWs). The organic fraction of USW should not be placed in the landfill but improved by biological treatment [21]. And composting appears as one of the most promising alternatives for an essentially agricultural country like Brazil, and is very important because it allows the recycling of the organic molecules that have a nutritional function and also because it diminishes the polluting and contaminant potential of the wastes [22].

Domestic solid wastes in Brazil present a high percentage of organic residues formed by remnants of food, and fruit and vegetable peels and even gardening wastes, but composting of organic wastes present in the urban garbage is relatively rarely practiced [22]. According to Ref. [23] cited by Ref. [21], in Brazil there are 211 composting plants in operation. They receive urban, industrial, agricultural, and forestry wastes. Each of these plants has a capacity to recycle an average of 10,000 tons a year, but this amount is too small to cover the total need for the treatment of wastes generated in Brazil.

Sewage sludge is a material that results from the primary and secondary sewage treatment processes and it has a highly complex composition. Because of its composition, which is rich in organic matters, nitrogen and phosphorus, sewage sludge has been strongly suggested for use in agriculture as a soil conditioner and fertilizer. The benefits that could be obtained from

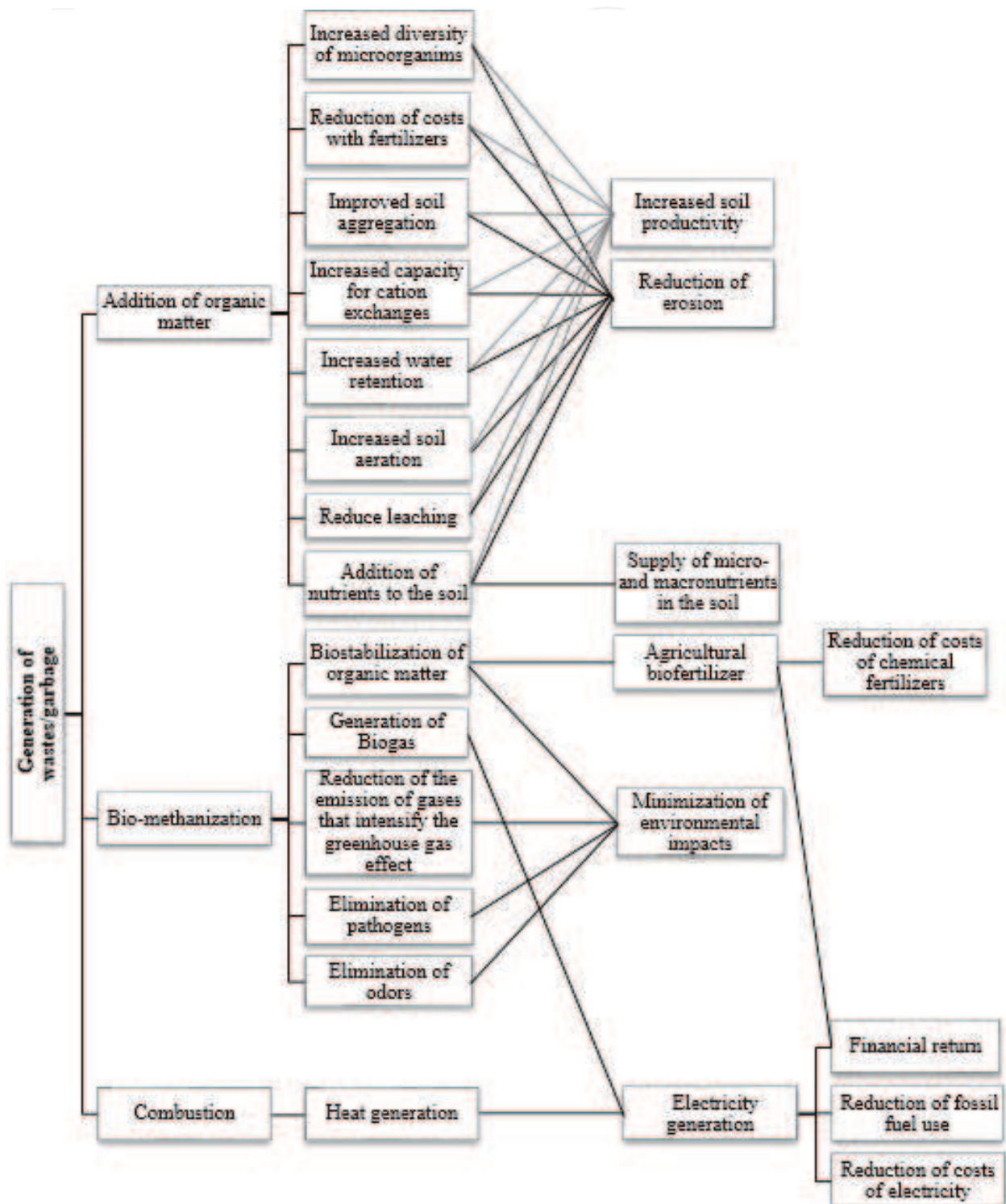


Figure 1. Positive impacts of using wastes (adapted from Ref. [26]).

its use would be the recycling of organic matter and supplying nutrients to soil, improving its physical, chemical, and biological properties and agricultural productivity. However, since the sludge contains high concentrations of contaminants, this practice may result in the direct addition of various pathogens and undesired chemical substances to agricultural soil and consequently to the food chain [24].

In Brazil, the criteria and procedures for the agricultural use of sewage sludge generated in sanitary sewage treatment plants and its byproducts are defined in National Council for the Environment (CONAMA) Resolution 375/2006 [25]. Among the criteria for sewage sludge use, Article 12 establishes that

“It is forbidden to use any class of sewage sludge or byproduct for pastures and the cultivation of vegetables, tubercles, roots and flooded cultures, as well as the other cultures whose edible part is in contact with the soil.”

Recycling wastes in agricultural soils is emphasized. This is a much-used alternative in several countries, such as the United States, Holland, Australia, and others. The use of wastes in agriculture (applying them on soils in a controlled manner) and the generation of energy, for instance, may mean environmental and economic gains, besides minimizing the negative impacts of the disposal and inadequate discharge, as described in **Figure 1**.

For instance, the use of urban organic wastes is disseminated worldwide as fertilizers and/or soil conditioners. Garbage compost and sewage sludge are outstanding among them. It is also worthwhile mentioning among the organic wastes those from agribusiness, because, due to their origin, there is a low probability of contaminants in their composition. A good example for this class is wastes generated by the sugar and alcohol industry, filter cake, soot, and vinasse, which are recycled in the agricultural areas of the plant itself [3].

Filter cake presents a high percentage of humidity (70–80%) and high contents of organic matter and phosphorus, besides nitrogen, calcium, and potassium, and it is used mainly in sugar cane plant fertilization with savings for the farmer in the costs of implementing this crop [27].

4. Environmental risk and public health

The use of municipal waste is a source of fertilizers and correctives in agriculture and it is one of the alternatives used worldwide to minimize this conflict. However, long-term studies are needed to evaluate the potential and impact of using wastes from different human activities on the quality of agriculture, environment, and human health.

Wastes as a source of plant nutrients have been used in some countries for decades [28–30]. However, research has shown that applying these wastes to the soil may cause environmental problems due to the addition of excess N, pathogens, heavy metals [31–34], acidification [35], and salinization of agricultural soils [36].

Among the various substances that contaminate water and soil, heavy metals have aroused concern among the population because of their high toxic, mutagenic, and carcinogenic power [37]. Heavy metals are elements with an atomic number greater than 20, and a density greater

than 5 mg cm^{-3} . This group includes any element that could damage the plant and animal organisms, including metalloids and semimetals such as selenium (Se) and arsenic (As) [38]. All these elements have high reactivity and under normal conditions are traces in the mineralogical composition of soils [39]. Therefore, their initial concentrations in soil depend on the composition of the bedrock and on the pedogenetic processes that originated it [40].

Heavy metals have important functions in the biosphere, acting as essential micronutrients for plants (Cu, Fe, Mg, and Zn), or as beneficial (Mo and possibly Ni) to microorganisms (Co and Mo genus *Rhizobium* bacteria) and to animals (Co, Cr, Mo, Cu, Se, and Zn) [41, 42]. However, when these elements are found at high concentrations they are toxic to superior organisms, just like nonnutritional elements or without biological effect, such as Cd, Pb, and As [41].

All heavy metals are toxic to the biological systems. The level of risk is a function of the quantity of contaminant and the time the organism is exposed to it [43]. **Table 1** shows the heavy metal ions, the main sources of pollution and the toxicological characteristics caused by exposure to As, Cd, Cr, Cu, Zn, and Pb.

Domestic sewage sludge and biosolids that are generated in cities due to household garbage may present over 140 types of enteric viruses that cause diseases, especially in children. Pathogenic

Ions	Main sources of pollution	Toxicological characteristics
Arsenic (As)	Herbicides, insecticides, fungicides, mining, and glassware. Paints and dyes industry.	Generally, the inorganic compounds are considered more toxic. As^{3+} is more toxic than As^{5+} at least at very high doses. Various organs and tissues are affected, such as the skin, respiratory system, cardiovascular system, reproductive system, gastrointestinal system, and nervous system [44].
Cadmium (Cd)	Industrial effluents, electroplating, production of pigments, electronic equipment, lubricants, photographic accessories, insecticides, and fossil fuels.	In rat studies in which the respiratory tract of the animals was exposed continuously to an aerosol with a low concentration of CdCl_2 , a high incidence of lung cancer was observed and evidence was shown of the relationship between dose and response. High levels of Cd inhalation cause lethal pulmonary edema [45].
Chromium (Cr)	Industrial effluents, production of aluminum and steel, paints, pigments, explosives, paper, and photography.	The toxic effects of Cr^{3+} occur only through parenteral administration. Humans and other animals, when exposed to Cr, develop cancer. Cr^{6+} in the diet affects the gastrointestinal tract, the kidneys, and the hematological system and causes several genetic damages. In some studies, the CrCl_3 was found accumulated in the cell nucleus [46, 47].
Copper (Cu)	Pipe corrosion, domestic sewage, algicides, fungicides, pesticides, mining, foundries, and metal refinement.	Few cases of acute effects of Cu have been reported. Among them the main ones are gastric burning, nausea, vomiting, diarrheas, lesions of the gastrointestinal tract, and hemolytic anemia. Chronic effects are rarely reported, except for Wilson's disease, responsible for the accumulation of copper in the liver, brain, and kidney [48].

Ions	Main sources of pollution	Toxicological characteristics
Zinc (Zn)	Electroplating, mining, wood combustion, waste incineration, domestic sewage and iron, and steel production.	The accumulation of Zn does not cause profound deficiencies. For this reason, it is considered as having low toxicity. The excessive intake of Zn may provoke gastrointestinal disorders and diarrhea [49].
Lead (Pb)	Industrial effluents, tobacco, paints, pipes, metallurgy, and electrodeposition industry.	After the Pb is absorbed by human body it can be found in the blood, soft, and mineralized tissues [50]. According to Ref. [51], for neurological, metabolic, and behavioral reasons children are more vulnerable to the effect of Pb than adults. Among their main effects are diminished intelligence quotient, effects on the nervous system, reduction of sensory functions, involuntary nervous and kidney functions, and premature births [52–54].

Table 1. Characteristics intrinsic to the ions of heavy metals and risk to human health.

organisms that cause infections depend on the resistance of organisms to sewage treatment, and the environmental conditions, the dose of infection, pathogenicity, susceptibility, degree of host immunity, and degree of human exposure to the foci of transmission [55].

The use of sewage sludge presents several good results. However, in some cases, the sludge may be harmful to the plants and also worsen the diseases due to the presence of pathogenic microorganisms, mostly saprophytes. The main pathogens present in the sludge are bacteria, viruses, and parasites (**Table 2**). The quantity of these microorganisms is very variable, depending on the time and season of the year. In order to use the sludge in agriculture, it is necessary to characterize and quantify the chemical contaminants and pathogenic microorganisms present [56, 57].

Organisms	Disease and symptoms
Bacteria	
<i>Salmonella</i> sp.	Salmonellosis (of the typhoid fever type)
<i>Shigella</i> sp.	Bacillary dysentery
<i>Vibrio cholerae</i>	Cholera
<i>Campylobacter jejuni</i>	Gastroenteritis
<i>Escherichia coli</i> patogênica	Gastroenteritis
Enteric viruses	
Hepatitis A	Infectious hepatitis
Norwalk and Norwalk-like	Gastroenteritis with severe diarrhea
Rotavirus	Acute gastroenteritis

Organisms	Disease and symptoms
Enterovirus	
Poliovirus	Poliomyelitis
Coxsackievirus	Meningitis, pneumonia, hepatitis and fever
Reovirus	Respiratory infection, gastroenteritis
Astrovirus	Gastroenteritis
Calicivirus	Gastroenteritis
Protozoa	
<i>Cryptosporidium</i>	Gastroenteritis
<i>Entomoeba histolytica</i>	Gastroenteritis
<i>Giardia lamblia</i>	Giardia (including diarrhea, abdominal pain and weight loss)
<i>Balantidium coli</i>	Diarrhea
<i>Toxoplasma gondii</i>	Toxoplasmosis
Helminths	
<i>Ascaris lumbricoides</i>	Digestive problems and nutritional disorders, abdominal pain
<i>Trichuris trichiura</i>	Abdominal pain, diarrhea, anemia, weight loss
<i>Toxocara canis</i>	Abdominal discomfort, muscle pains, neurological symptoms
<i>Taenia saginata</i>	Nervousness, anorexia, abdominal pain, digestive disorders
<i>Necator americanus</i>	Ancylostomiasis

Table 2. Organisms that may be present in sewage sludge and are a risk to human health (adapted from Ref. [25]).

Thus, systematic treatment of the sewage sludges or urban wastes before their use in agricultural soils diminishes the risk to human and animal health through infection because it reduces the chances of survival of these pathogenic organisms.

5. Monitoring soil and water

The organic substances present in wastes can maintain or even raise the organic matter content in the soil, which is extremely advantageous from the agronomic standpoint, because the organic fraction is directly connected to a number of functions that are important to maintain soil fertility and quality. However, some wastes, especially those from agriculture and livestock activities, can have in their composition fecal coliforms, a few pathogenic microorganisms

(e.g., *Salmonella* spp) and persistent organic molecules that can cause biological imbalances in soil and water [3]. These substances, however, may originate in other sources, from sanitary inspections of animals, and also from activities such as deworming and the application of agricultural pesticides to crops and pastures [58].

Inorganic substances, on the other hand, are represented mainly by elements that are essential or beneficial to plants and are usually found in wastes from industrial activities, such as mining and steel foundries and from the sanitary treatment sector in urban centers [59]. Some wastes generated in these activities usually present high micronutrient contents, such as the following elements: copper, iron, manganese, and zinc. However, these elements present constantly in unbalanced proportions for plant nutrition. This may promote the practice of high doses, overloading the natural functions of soil and causing imbalances [3].

Thus, wastes with a potential for use in agriculture also present as possible sources of contaminants and are a risk for the quality of soil and groundwater. Therefore, this practice should be verified by the environmental control and monitoring agencies of each state or territory. The most common and effective tool developed by these countries is the formulation of specific laws to monitor and protect the quality of soils and groundwater, which are in turn based on surveys of the critical contents of these substances, as well as studies of their respective potential for damage to the environment and to human health [60, 61].

In Brazil, this monitoring is performed based on the experiences and models practiced in countries like Holland and Germany. The National Council of the Environment (CONAMA) through Resolution n° 420 of December 28, 2009 determined the criteria for the elaboration of guiding values of soil and groundwater quality regarding the presence of chemical substances and established the guidelines for environmental management of areas contaminated by these substances as a result of anthropic activities, and also stipulated the maximum values for the same substances in groundwater [62].

Therefore, according to CONAMA, the guiding values are concentrations of chemical substances that provide guidance regarding the quality and changes in soil and groundwater. The resolution also determines that the guiding values are classified into three groups according to the contents of the elements investigated, which are quality reference value (QRV), prevention value (PV), and investigation value (IV).

The quality reference value or QRV corresponds to the concentration of a given substance that defines the natural quality of the soil, and it is determined based on the statistical interpretation of physicochemical analyses of samples of various types of soil, being used as a reference in actions to prevent soil and ground water pollution and to control contaminated areas.

Prevention value (PV) is the concentration of the limit value of a given substance in the soil, such that it can sustain its main functions. It is predetermined by CONAMA and is used to educate through educational measures and penalties applied to those responsible for possible alterations in the environment.

Investigation value (IV) is the concentration of a given substance in soil or in groundwater, above which there are direct or indirect potential risks to human health, considering a

standardized scenario of exposure. For the soil, it is calculated using a procedure to evaluate the risk to human health in different contexts: agricultural, residential, and industrial. When the intervention values are surpassed, immediate actions must be taken due to the finding of a potential risk of a deleterious effect on human health [63].

The QRVs are determined from the survey of natural contents of the elements in soil. For this it is necessary to sample the soil taking into account the diversity of soil classes and the original materials existing in the region, seeking to perform the collections in minimally preserved soils, with little or no apparent signs of anthropic interventions, since the pedogenetic processes and the geochemical formation of each region interfere directly with the natural contents of these substances [42, 64, 65].

Therefore, Brazilian law determines that the QRVs for soils should be established by each state of the federation and it is not recommended to use the values of one state for another state [63]. **Table 3** shows some inorganic and organic substances and their respective guiding values for soils and groundwater in the state of São Paulo, as an example of the model adopted by the country to organize its monitoring tool.

Given the complexity of the relations that may occur between the substances present in the wastes and the soil attributes, current legislation cannot foresee all the long-term scenarios and behaviors of these substances. This is a weakness in the environmental monitoring system that requires constant investment and updating. Ref. [59] emphasize that all components of the agricultural environment should be periodically monitored, such as soil, water, and their biological fractions, in order to avoid problems caused by the intermittent use of wastes for long periods.

Substance	Soil (mg kg ⁻¹ dry weight)				Groundwater (µg L ⁻¹)	
	Quality Reference value (QRV) ¹	Prevention value (PV) ²	Intervention value (IV) ²			
			Agricultural	Residential	Industrial	
Inorganics						
Antimony	<0.5	2	5	10	25	5
Arsenic	3.5	15	35	55	150	10
Barium	75	120	500	1300	7300	700
Boron	- ³	nd	nd	nd	nd	2400
Cadmium	<0.5	1.3	3.6	14	160	5
Lead	17	72	150	240	4400	10
Copper	35	60	760	2100	10,000	2000
Mercury	0.05	0.5	1.2	0.9	7	1
Molybdenum	<4	5	11	29	180	30
Nickel	13	30	190	480	3800	70

Substance	Soil (mg kg ⁻¹ dry weight)					Groundwater (µg L ⁻¹)
	Quality Reference value (QRV) ¹	Prevention value (PV) ²	Intervention value (IV) ²			
			Agricultural	Residential	Industrial	
Nitrate	-	nd	nd	nd	nd	10,000
Silver	0.25	2	25	50	100	50
Selenium	0.25	1.2	24	81	640	10
Zinc	60	86	1900	7000	10,000	180
Volatile aromatic hydrocarbons						
Benzene	na	0.002	0.02	0.08	0.2	5
Styrene	na	0.5	50	60	480	20
Ethylbenzene	na	0.03	0.2	0.6	1.4	300
Toluene	na	0.9	5.6	14	80	700
Organochlorinated pesticides						
Aldrin	na	0.02	0.4	0.8	6	0,03
Endrin	na	0.001	0.8	2.5	17	0,6
Carbofuran	na	0.0001	0.3	0.7	3.8	7

¹Value determined by the State.

²Determined by CONAMA.

Note: nd: not determined in the legislation; na: not applicable to organics.

Table 3. Guiding values for soils and groundwater in the state of São Paulo (adapted from Ref. [66]).

It should also be pointed out that the model adopted to establish the legislation in countries with a tropical climate is based on the experiences of developed countries, usually situated in temperate climate regions, which justifies the need to continue studying the behavior of the potentially toxic substances and their relations with the soil, groundwater, and their biological agents under local climatic conditions, in order further improve the monitoring mechanisms for risk activities such as the reuse of wastes in the agricultural and livestock chains of countries with a tropical climate.

6. Potential of productivity for the agricultural crops

Liming is the first process to be performed to prepare the soil for crops. The purpose of the technique is to correct the soil pH, elevating base saturation, and reduction of exchangeable aluminum in the soil solution to levels appropriate to the crops. Currently, several studies have been performed to use solid wastes from human activities as an alternative substitute

to correct soils for cultivation. Outstanding among the wastes studied are steel mill slag and urban sewage sludges. These wastes have proved to be an excellent substitute for limestone, since besides correcting the pH they are a major source of nutrients for the plants [67–70].

Refs. [71, 72] using steel mill slag to produce guava seedlings found that besides the corrective action of pH, the rise in the sum values base saturation, the waste proved to be a source of micronutrients such as zinc, copper, manganese, and boron. There was also a positive effect on the concentrations of calcium, magnesium, and phosphorus in the roots and aerial parts of the seedlings. In addition, using this waste is limited when it contains traces of metals, such as lead and chromium in its constitution.

Ref. [73] incorporate domestic sewage sludge and sewage sludge from a dairy establishment into the soil, observed increased macronutrients in the aerial part and roots of Physic Nut Seedlings (*Jatropha Curcas* L.) plants in both treatments. In these soils, they found that using dairy waste sludge raised the pH in soil, while domestic sludge did not change the soil pH. According to the authors, the initial treatment of dairy sewage sludge consists basically in a biological process with the addition of limestone or lime (CaCO_3 or CaO) to eliminate pathogens and promote waste stabilization. Therefore, the carbonate reacted with the hydrogen present in the soil solution (liquid phase of the soil) and water and CO_2 . Meanwhile, the domestic sewage sludge did not receive this conditioner at the treatment plant.

The next stage of soil preparation is fertilizing, which consists in applying nutrients in forms available for root absorption. According to Ref. [73], the organic matter in plant nutrition may certainly be substituted, with even better yields, by chemical fertilizers, but their indirect effect on crop development cannot be substituted, whatever the chemical industry product. For this reason, organic matter from urban solid wastes, which constitute approximately 90% of the total mass of sanitary landfill wastes, as well as the domestic sewage sludges can and should be used as a source of nutrients in plant production, although it is necessary to have a greater volume than that of the mineral fertilizers because of the lower concentration of nutrients, although greater attention is required as to the presence of organic, mineral toxic contaminants, or pathogenic microorganisms.

If we perform a very simple analysis of the dynamics of nutrients in the production process in agroecosystems, we conclude that, biomass and nutrients are removed in the harvesting, breaking down the efficient cycling that would occur in natural environments. In this way, the external supply of nutrients, be it in a concentrated chemical form or organic, is necessary to maintain this balance. Otherwise, the producer will be performing unsustainable, predatory production, which will impoverish the soil that supports him [74].

Many research studies have demonstrated the rise in crop productivity when they are fertilized with organic wastes [75]. In research using the filter cake to fertilize different lettuce cultivars increased yields were obtained in all cultivars evaluated. In Ref. [76] utilizing sewage and industrial sludges to produce physic nut seedlings they concluded that the wastes used promoted the production of quality seedlings with a significant increment in root length and in the aerial part of the seedlings. Ref. [77] using solid organic wastes (*Copernicia prunifera* waste and chicken litter) and swine wastewater as a source of nutrients for the production of

monkfish (*Enterolobium contortsiliquum* (Vell.) Morong) found that organic waste contributes to growth and nutritional balance of the seedlings. The use of these organic wastes as primary source of nutrients consists of an important environmental management practice.

The effects of adding solid wastes to the soil on agricultural production are not limited to supplying nutritional elements. The organic matter it contains acts significantly to improve the physical, chemical, and biological quality of soil, and is a source of energy for the beneficial edaphic fauna, which has an antagonist action on phytopathogens (nematodes, bacteria, and fungi) and for symbionts, such as the diazotrophs (atmospheric N fixing microorganisms), or phosphate solubilizers (mycorrhizal fungi and rhizobacteria).

Worms, insects, and other organisms of edaphic fauna, in the metabolization of this substrate, release cementing substances that help form aggregates in the soil, significantly improving its drainage and aeration and making it easier to store and drain water and to develop the root system of the crops [73].

During the process of decomposing the organic wastes, the cations present in them are released in the soil solution and/or retained on the colloid surfaces, and are available for absorption by the roots. Simultaneously, humus is formed, another product that is very important for the physicochemical improvement of many sandy soils or highly weathered type 1:1 clays that are chemically poor, which commonly occurs in the soils of the Cerrado and Amazon biomes. Therefore, there must be a constant attempt to increase the organic matter in soil, be it through management (minimum cultivation, no till farming with crop rotation, green fertilization, and others) or added in organic fertilization (animal manure, organic compost from sanitary landfills, sewage and tannery sludges, and others).

7. Final considerations

The economic growth rates of various countries keep up with the rapid urban development with the intense production of solid wastes. In this way, public policies should emerge to help adopt a new management logic, which will take into account the sustainability principles of reducing the wastes generated, reuse, and recycling, treatment and environmentally safe final disposal.

There is a broad discussion regarding the appropriate forms of disposal and use of the solid wastes, and their reuse on agricultural soil has been considered the most interesting option, both from the environmental standpoint and the economic one. However, their use in agriculture should be preceded by an analysis of environmental and economic impact and the indiscriminate use of wastes may lead to contamination.

National and international public policies for solid waste management are already a historical advance, taking into account the mandatory regulation of responsibilities by the management, mainly of urban solid wastes; however, this in itself does not guarantee that it will be done, since the consolidation of these policies requires behavioral and cultural changes that will attenuate deep-rooted practices in individual and collective action.

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