DOI: 10.5433/1679-0359.2015v36n2p747

Disposição de resíduos sólidos no solo: efeito nos atributos físicos, químicos e na matéria orgânica[1]

Solid waste disposal in the soil: effects on the physical, chemical, and organic properties of soil

Vanessa Regina Lasaro Mangieri[2*]; João Tavares Filho[3]

Resumo

Atualmente existe crescente preocupação com o destino final dos resíduos sólidos gerados pela sociedade. As áreas de despejos não podem ser consideradas ponto final para as substâncias contidas ou geradas nos resíduos sólidos. Atualmente, o uso sustentável dos recursos naturais, especialmente do solo e da água, tem-se constituído relevante devido ao aumento das atividades antrópicas. O uso agrícola é uma alternativa de disposição dos resíduos sólidos (lixiviado, biossólidos), considerando a hipótese que o uso destes seja promissor para a agricultura, o que resulta em redução dos custos de tratamento, reaproveitamento de nutrientes e a melhora das condições físicas e químicas dos solos. Assim, buscou-se com esta revisão de literatura confirmar ou não a hipótese, a partir de dados já obtidos, quanto ao uso promissor destes resíduos na agricultura para diminuição do passivo ambiental que desafia os administradores públicos no desenvolvimento de uma gestão eficiente. Os seguintes sub-itens serão apresentados após a introdução: disposição atual de resíduos sólidos e problemas ambientais; uso dos resíduos sólidos na agricultura; efeito nos atributos químicos, físicos e na matéria orgânica do solo e considerações finais.

Palavras-chave: Resíduos sólidos, lodo de esgoto, biossolidos, lixiviado

Abstract

Currently, there is growing concern over the final destination of the solid waste generated by society. Landfills should not be considered the endpoint for substances contained or generated in solid waste. The sustainable use of natural resources, especially soil and water, has become relevant, given the increase in anthropogenic activities. Agricultural use is an alternative to solid waste (leachate, biosolid) disposal, considering the hypothesis that the agricultural use of waste is promising for reducing waste treatment costs, promoting nutrient reuse and improving the physical and chemical conditions of soil. Thus, this literature review, based on previously published data, seeks to confirm or disprove the hypothesis regarding the promising use of solid waste in agriculture to decrease the environmental liability that challenges public administrators in the development of efficient management. The text below addresses the following subtopics after the introduction: current solid waste disposal and environmental issues, the use of solid waste in agriculture, and the effect on the physical and chemical properties of soil and on organic matter, ending with final considerations.

Key words: Solid waste, sewage sludge, biosolids, leachate

---

[1] Parte da Tese de Doutorado do primeiro autor.

[2] Engª Civil, Universidade Tecnológica Federal do Paraná, UTFPR, Deptº de Projetos e Obras, Londrina, PR, Brasil. E-mail: vanessamangieri@utfpr.edu.br

[3] Prof. Associado C, Deptº de Agronomia, Universidade Estadual de Londrina, UEL, Londrina, PR, Brasil. E-mail: tavares@uel.br

[*] Author for correspondence

Recebido para publicação 16/10/14 Aprovado em 11/11/14

Introduction

Currently, there is growing concern over the final destination of solid waste generated by society. An exponential increase in waste production is the result of an increase in public consumption. Consumerist lifestyles and continuous trade growth in several countries have been followed by a rapid increase in urban and industrial solid waste production.

According to Renou et al. (2008), solid waste production continues to increase globally. Waste production in Rio de Janeiro, Brazil was 8,042 tons/day in 1997, compared with 6,200 tons/day in 1994, although the population growth rate during that period was nearly zero. Waste production has increased by 3% and 4.5% per year between 1992 and 1996 in Norway and the USA, respectively. In the 1990s, the annual waste production ranged from 300 kg to 800 kg per person in the most developed countries and was less than 200 kg in less developed countries (WARAH, 2001). The French produced 24 million tons of solid waste in 2002, i.e., 391 kg per person (ADEME, 2002). In Brazil, household waste production was approximately 219.72 g/day/person in 2008, reaching 331.6 g/day/person when added to the waste from public spaces and roads (IBGE, 2008).

Given such a large volume of waste produced by the population, the final destination of waste is currently deemed a key issue of environmental quality in urban Brazil (CARVALHO et al., 2006). Although this topic is frequently discussed in the field of urban sanitation, the underlying issue is that an appropriate solution requires many resources. Currently, waste management is based on collection, removal, and disposal, as has been true historically, mostly in technically and environmentally inappropriate sites. Most Brazilian municipalities dispose of their waste in improper sites without any type of environmental protection, exacerbating the environmental degradation (air, water, and soil pollution), which highlights the need to promote the adequate management of disposal sites for solid waste in an effort to prevent or reduce possible negative effects on the environment or public health.

According to Alberte, Carneiro and Kan (2005), the search for solutions has mainly involved the technical, social, and environmental remediation of inadequate solid waste landfills. Methods of remediation of dumps and landfills are developed based on the need to implement mechanisms of inerting waste mass with the intention of closing the dumps and/or landfills or extending their lifespan. Furthermore, the transfer of knowledge on that subject, in the Brazilian context, has become essential, according to those authors. The application of remediation methods enables the most efficient treatment of waste mass and of liquid and gas effluents and promotes a better use of sites available for the final destination of solid waste.

Currently, agricultural use is an alternative to solid waste (leachate, biosolid) disposal, considering the hypothesis that the agricultural use of waste is promising for reducing treatment costs, promoting nutrient reuse, and improving the physical and chemical conditions of soil. Thus, this literature review, based on previously published data, seeks to confirm or disprove the hypothesis regarding the promising use of solid waste in agriculture to decrease the environmental liability challenging public administrators in the development of efficient management.

Current solid waste disposal and environmental issues

The final destination of solid waste is a problem that affects all cities and piques the public interest in the search for economically and environmentally sustainable alternatives. According to Alberte, Carneiro and Kan (2005) and IBGE (2008), 50.8% of cities dispose of their waste in sites termed dumps and 20.7% in sanitary landfills, with the latter being the best method of waste disposal.

Sanitary landfills for final solid waste disposal continue to be widely accepted and used because of their economic advantages. In comparative studies of several possible means of municipal solid waste disposal (landfilling, composting and incineration, among others), Renou et al. (2008) showed that landfilling is the cheapest alternative in terms of operating costs. In addition to their economic advantages, sanitary landfills minimize environmental effects and other inconveniences and enable the decomposition of waste under controlled conditions until the waste has transformed and stabilized because the sanitary landfill avoids exposing solid waste on the soil surface (ABNT, 1984).

Recycling is the most technically, economically, and environmentally appropriate method in which to dispose of anthropogenic waste and is an economical method of recycling organic matter and nutrients that may fertilize the soil, according to Matthews (1998) and Tsutiya (1999).

Conversely, open-air solid waste disposal is frequently used even though it is environmentally inappropriate, given the possibility of environmental contamination associated with large areas of solid waste disposal (SOUZA; ROESER; MATOS, 2002). However, cities worldwide dispose of their waste in landfills. Taiwan disposes of approximately 95% of its waste in sanitary landfills, Poland 90%, and Korea 52% (RENOU et al., 2008). That form of waste disposal causes environmental (air, soil, and water pollution and visual pollution), social (the landfill becomes an alternative job for the low-income population seeking to market recyclable materials, despite the unsanitary conditions and the inhumane activity), and economic (depreciation of the site and its surroundings) problems.

The environmental problems are prominent among those issues because the disposal sites may not be considered the endpoint of substances contained in or generated by municipal solid waste, given the continuous production of wastewater that occurs in waste disposal (MORAIS; SITORI; ZAMORA, 2004). This wastewater results from the solubilization and degradation of organic matter from solid waste by the water filtered into the landfill. The wastewater has a dark color, a strong odor, and high concentrations of organic and inorganic matter and is termed leachate, leach water, or percolate (SEGATO, 2000; MORAIS; SITORI; ZAMORA, 2004; RENOU et al., 2008). This wastewater may reach surface water resources, infiltrate the soil and reach groundwater, compromising its use. Therefore, treatment of leachate captured by drainage networks remains a great obstacle in drafting sanitary landfill projects because the characteristics of leachate treatment change according to the amount of water incorporated into the leachate, the characteristics of the waste disposed in the landfill, and, particularly, the age of the landfill (FERREIRA et al., 2001). The relatively low efficiency of the conventional treatment system (anaerobic lagoons followed by facultative lagoons) and the existing demand for large areas have led technicians and researchers to seek technical alternatives enabling the treatment and final disposal of waste at reduced economic and environmental costs (MATOS et al., 2007).

Leachate composition and quality

The composition and quality of leachate depends on several factors, including the waste quantity and quality (type of waste and composition, which depends on the standard of living of the population), compaction and age of the landfill, rainfall, and seasonal variation. Leachates may be then characterized as an aqueous solution with four groups of pollutants: dissolved organic matter (volatile fatty acids and more refractory organic compounds, including humic and fulvic acids), inorganic macro components (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, $NH4^{+}$, Fe^{2+}, Mn^{2+}, Cl^{-}, $SO_4^{\ 2-}$, and $HCO_3^{\ -}$), heavy metals (Cd^{2+}, Cr^{3+}, Cu^{2+}, Pb^{2+}, Ni^{2+}, and Zn^{2+}), and xenobiotic organic compounds originating from domestic waste and chemicals present at low concentrations (aromatic hydrocarbons, phenols and pesticides, among others) (KJELDSEN et al., 2002). Leachates derived from waste disposal on land basically consist of a mixture of organic and inorganic substances, compounds in solution and in colloidal form, and various species of microorganisms (ANDRADE, 2002).

The chemical and microbiological composition of leachate is quite complex and variable because it depends on the characteristics of the waste deposited and is affected by the environmental conditions, the landfill operating conditions, and, especially, the dynamics of the decomposition processes that occur intracellularly (EL-FADEL et al., 2002; KJELDSEN et al., 2002). A rapid anaerobic fermentation occurs in new landfills that contain large quantities of biodegradable organic matter, resulting in volatile acids (WELANDER; WELANDER, 1997). The fermentation of the acid is enhanced by the high levels of moisture or water in the solid waste (WANG; SMITH; EL-DIN, 2003). The initial phase of the lifespan of a landfill, termed the acidogenic phase, leads to the release of large amounts of free volatile acids and has a 95% organic matter content, according to Harsen (1983). The methanogenic phase occurs when the landfill matures. Methanogenic microorganisms develop in waste, and the volatile acids are converted into biogas. The organic fraction of the leachate becomes dominated by (non-biodegradable) refractory compounds, including humic acids (CHIAN; DEWALLE, 1976).

Thus, leachates from recent landfills tend to show high levels of organic matter, ammonia nitrogen, and concentrations of iron, manganese, calcium, zinc, and other metals (HOILIJOKO; KETTUNEN; RINTALA, 1999). The pollution potential decreases over the life of the landfill because the amount of chemical substances in the waste is finite. Thus, the leachate quality reaches a limit of diversity of its components after approximately two to three years, followed by a gradual decline in the ensuing years (PAES, 2003).

Gomes et al. (2004) evaluated the movement of nitrate (N-NO−3) derived from slaughterhouse wastewater in soil columns. The results showed an increase in the rate of nitrate above the initial concentration C0 in all effluents percolated into the soils, and those values were more pronounced for the column of sandy soil with limestone. Liming induced a predisposition to nitrate leaching and showed a smaller decrease in leachate pH. The sandy soil showed a greater leaching of total salts and nitrate, regardless of the limestone application.

Use of solid waste in agriculture: effect on soil physical and chemical properties and organic matter

The sustainable use of natural resources, especially soil and water, has become relevant given the increase in anthropogenic activities. Agricultural use has become an alternative for the disposal of sewage sludge (biosolids) and leachate (wastewater) (BARBOSA; TAVARES FILHO, 2006), considering the hypothesis that their agricultural use is promising for reducing waste treatment costs, prompting nutrient reuse, and improving the physical and chemical conditions of soil. Such improvements occur because the soil and plants act as living filters, absorbing and retaining pollutants and pathogenic organisms present in anthropogenic waste and wastewater. However, according to Matos et al. (1997), recycled materials should be used carefully to avoid contributing to surface water, groundwater, and plant contamination and to prevent negative effects on soil quality. According to Doran and Parking (1994), soil quality may be conceptualized as the capacity of that resource to perform various functions within the limits of land and ecosystem use; to sustain biological productivity; to maintain or enhance environmental quality; and to contribute to plant, animal, and human health.

Effect on soil physical properties

Understanding and quantifying the effect of leachate use on the physical quality of soil is key for the development of sustainable agricultural systems. The leachate from solid waste contains a considerable percentage of organic matter and elements essential to plants and may play a key role in the physical properties of soil and in maintaining soil fertility. The addition of waste to soils is expected to trigger numerous physical, chemical, and biological processes that are strongly interrelated and are often synergistic, as occurs in processes that lead to the increased stability of soil aggregates and organic matter stocks; a greater amount of organic matter causes greater aggregate stability and thus improves soil quality. Therefore, a cause-and-effect relation between aggregation and organic matter is established (SIX; ELLIOT; PAUSTIAN, 1999, 2000) in which aggregate stability increases with the increase in soil organic matter content.

Changes in the physical properties of soil may limit nutrient adsorption and/or absorption, water infiltration and redistribution, gas exchange, and root system development (BICKI; SIEMENS, 1991; LLANILLO et al., 2006; BARBOSA; TAVARES FILHO; FONSECA, 2007), resulting in decreased agricultural production. Furthermore, the physical and chemical properties of clays and, consequently, clay soils, may vary depending on environmental changes, given clay's high affinity for water. For example, groundwater contamination may alter the Atterberg limits, hydraulic conductivity, compressibility, and shear strength of clay soils (ÖREN; KAYA, 2003).

Water-dispersible clay

The soil as a dispersed system has electrochemical charges that are responsible for the mechanisms of the dispersion and flocculation of colloids and the cation and anion exchange capacity, among other processes. Those charges derive from the mineral fraction, especially the clay fraction and the organic fraction (BENITES; MENDONÇA, 1998).

The dispersion of soil colloidal particles is related to the surface interaction with electric charges and may be generated by isomorphous substitution (permanent) or dissociation of radicals (variable). The predominant variables in Oxisols depend on the soil chemical properties, pH, and soil solution electrolyte concentration (AZEVEDO; BONUMA, 2004). Therefore, the addition of organic matter (present in solid waste) to a system in equilibrium promotes changes in the charges resulting from direct and indirect factors. The adsorption of organic acids by mineral colloids causes an increase in the negative charges of the system and a decrease in the point of zero charge (PZC) (OADES, 1984). Conversely, the addition of organic matter may promote soil pH changes, favoring the expression of variable charges. These effects are compounded in electropositive soils, leading to electronegativity. This causes the electropositive environment of subsurface horizons to become electronegative near the surface because of the effect of organic matter (COLEMAN; OADES; UEHARA, 1989). The relation between the soil electrochemical potential and clay dispersion remains a seldom-studied phenomenon. The magnitude of that potential is related to clay dispersion in most cases. However, under some conditions, the dispersion mechanisms are not directly related to the soil electrostatic status because of interactions between inorganic colloids and humic substances (OADES, 1989; KRETZCHMAR; ROBARGE; WEED, 1993).

The neutralization of exchangeable Al, which is an ion that stabilizes the soil structure, and the elevation of soil pH, which has dispersing action in the range of pH lower than 7 (PAVAN; ROTH, 1992), contribute to soil dispersion into single particles. The stability of soil aggregates depends on the texture (oxides and silicates), levels, and type of cations and organic matter pH (FERREIRA; ANDREOLI; JÜRGENSEN, 1999; MEURER, 2006). These are determining factors of the diffuse double layer thickness that affect particle dispersion and flocculation (MEURER, 2006).

Cañasveras et al. (2010) report that the ratio of water-stable aggregates, aggregate weighted mean diameter, and water-dispersible clay are three valuable indicators of the risk for surface impermeabilization, runoff generation, and soil erosion by water. These aggregation rates are affected by the levels of clay, iron oxide, calcium carbonate, and organic matter in addition to other soil properties.

Nguetnkam and Sultz (2011) assessed the relations between the aggregation rate and the soil physical and chemical properties, finding a positive correlation between water-dispersible clay and the clay dispersion ratio when studying water-dispersible clay in Cameroonian soils. The same authors noted that full flocculation is observed at pH 3 and 4, the pH at which the point of zero charge is reached for the clay fractions of horizons A and B, respectively.

Karathanasis and Johnson (2006) evaluated the stability of water-suspended biosolid colloids from urban and agricultural waste and their transportability through undisturbed soils to assess the potential risks of those colloidal particles carrying contaminants associated with changes in organic waste applied to soils. The authors previously observed that biosolid colloids showed stability over a wide range of pH conditions and that lime-stabilized biosolid colloids were more stable than poultry manure, in which the pH and organic matter (OM) levels were the dominant factors affecting this stability. The authors concluded that the increase in colloidal stability does not always result in greater transportability, most likely because of carbonate dissolution and increasing ionic interaction with the soil matrix.

Effect on soil physical and chemical properties

According to Van Raij (1998), the benefits from waste application may match or exceed the benefits of a mineral fertilizer, particularly regarding yield and savings on fertilizers, especially nitrogen-based ones. However, given waste's high moisture levels, applications of large amounts of waste are required to reach the nutritional equivalence of mineral fertilizers.

Solid waste application has demonstrated good results as fertilizer for various crops, including soybean, maize, and wheat (BROWN; ANGLE; CHANEY, 1997; SILVA; RESCK; SHARMA, 2002a; GALDOS; MARIA; CAMARGO, 2004; GOMES; NASCIMENTO; BIONDI, 2007; QUINTANA; CARMO; MELO, 2009); beans and sunflowers (DESCHAMPS; FAVARETTO, 1997; LOBO; GRASSI FILHO, 2007; NASCIMENTO et al., 2004); and eucalyptus and pine trees (TRIGUEIRO, 2002; ROCHA GONÇALVES; MOURA, 2004). Thus, solid waste is a potential fertilizer in various soil and climate conditions.

Barros et al. (2002) noted the occurrence of increased plant nitrogen levels, which were proportional to the increase in the doses of sewage sludge added, whereas Silva, Resck and Sharma (2002a) showed that the biosolid used was 25% more efficient than triple superphosphate as a source of phosphorus for maize. Potassium has been the element of greatest need for supplementation with mineral fertilizers when using sludge as fertilizer, given the low levels of potassium in sludge resulting from potassium's high water solubility (ROSS et al., 1990; MELO et al., 1997). Galdos, Maria and Camargo (2004), when applying sewage sludge to maize crops, observed up to 25% higher production levels compared with plots without sludge and receiving nitrogen, phosphorus, and potassium (NPK) fertilization. Anjos and Mattiazzo (2000) observed no significant differences between the yield of treatments with biosolids and conventional fertilization in an experiment with maize grown in pots. Silva, Resck and Sharma (2002a) reported greater grain production compared with the absolute control and NPK fertilization for three years following a single sludge application, which demonstrates sludge's residual effect.

Malta (2001) stated that waste (sewage sludge) changes the soil physical properties, improving soil density, porosity, and water-holding capacity, and improves soil fertility levels, decreasing the exchangeable aluminum levels and increasing the pH, the cation exchange capacity (CEC) and the soil's ability to provide nutrients to plants. Furthermore, because of the high levels of organic matter and other nutrients in its composition, waste promotes the growth of soil organisms, which are critical to nutrient cycling.

Studies on the viability of the agricultural use of biosolids from industrial sources are scarce and have been conducted with various types of waste, including waste derived from the tannery and coal industries (KONRAD; CASTILHOS, 2002; FERREIRA et al., 2003). However, because of the high diversity of industrial biosolids with characteristics that vary depending on the raw material used, the manufacturing process employed, and the treatment system applied (FERREIRA; ANDREOLI; JÜRGENSEN, 1999), agronomic studies are required to define the rates of application, technical feasibility, and environmental safety levels specific to each waste (TRANNIN; SIQUEIRA; MOREIRA, 2005).

The presence of nutrients in treated wastewater, for example, is beneficial to plants when irrigating agricultural and forest crops and undesirable when releasing that waste into bodies of water (SANTOS, 2004). The use of sewage sludge and wastewater in soil as an alternative to the disposal of this waste and as a method of enriching soils (adding organic matter, increasing the pH, and increasing nutrient availability) has been considered and is currently being studied. Similar to swine wastewater and sewage sludge, the agricultural use of leachate as a means of the final disposal of this product and how this disposal affects soil properties should be evaluated because leachate comprises organic and inorganic substances.

Barbosa and Tavares Filho (2006), when studying waste resulting from urban sewage treatment, noted that this product has characteristics that enable rational and environmentally safe agricultural use because this waste has some essential nutrients (N, P, and micronutrients), is rich in organic matter, and acts as a soil conditioner, improving soil structure (aggregation of soil particles). The application of organic waste (sewage sludge, solid waste, and leachate) to agricultural soils as organic fertilizer or soil conditioner should grow over the next several years in Brazil, following a worldwide trend and the demand generated by a marked increase in the volume of waste produced in Brazil (TSUTIYA, 2001).

Tsutiya (2001) and Silva, Resck and Sharma (2002a) claim that some crops are more appropriate for receiving fertilization with this type of material because these crops better utilize the chemical composition of organic waste and minimize the risks of contamination with pathogens. These crops include those whose edible parts do not come into contact with the residue in pastures and reforestations (BETTIOL; CAMARGO, 2000; BARBOSA; TAVARES FILHO, 2006; BARBOSA; TAVARES FILHO; FONSECA, 2007) and crops that are used in the remediation of degraded areas. However, caution is required because the exclusive use of sewage sludge as fertilizer may cause nutritional deficiencies in crops, given the imbalance in the nutrient levels provided (SOUZA, 2004).

According to Haruvy (1997), the use of wastewater in irrigation may reduce crop fertilization costs and the required level of purification of the effluent and, therefore, the cost of treatment because wastewaters contain nutrients and the soil and crops act as natural biofilters. Thus, the use of wastewaters rich in organic matter may be an appropriate method for the final disposal of that waste, contributing to an improvement in soil quality and enabling an increase in the yield of many agricultural crops (MATOS; BRASIL; FONSECA, 2003).

Considering that the leachate produced in landfills shows potential for use in agricultural crop fertigation, Loher (1984) recommended the application of up to 750 kg ha^{-1} d^{-1} BOD (biological oxygen demand) in the case of disposal of wastewaters rich in organic material. Queiroz et al. (2004) noted positive effects and little environmental risk with the application of swine wastewater at the rate of 800 kg ha^{-1} d^{-1} BOD in soil planted with grasses. Approximately 3.3 and 2.6 ha of land are required for leachate disposal, with recently collected garbage cells 2.47-m high for each hectare of sanitary landfill, based on the leachate production data reported by Carvalho et al. (2006) for solid waste columns with and without building a demolition waste (“*resíduos de construção civil”* – RCC) layer and on the initial BOD of the leachate, respectively.

Matos, Carvalho and Azevedo (2008) analyzed the viability of the agricultural use of leachate from municipal solid waste and concluded that the use of leachate from sanitary landfills should be regarded as a viable alternative for the final disposal of that wastewater, given its relatively high pH values and concentrations of organic matter and macronutrients (N, Ca, Mg) and its low concentrations of heavy metals.

Matos, Carvalho and Azevedo (2008), when evaluating the viability of the agricultural use of leachate from solid waste, also noted that the concentration of macronutrients (N, Ca, and Mg) in the leachate decreased over the life of the solid waste landfill. The concentrations present are an indication that leachate has significant fertilizer value, which could enable its use in soil fertilization for agro-forestry-pastoral production if properly applied to the soil. The authors also report that cadmium, copper, chromium, lead, nickel, and zinc concentrations are generally lower than the detection limits of the device used. With regard to those heavy metals, the leachate meets the conditions for release in receiving water bodies, according to the standards established in the National Council for the Environment Resolution (CONAMA, 2005), indicating a small risk of its disposal on soil. Furthermore, fertigation should be regarded as an alternative for the final disposal of sanitary landfill leachate based on its high pH values and concentrations of organic material and macronutrients (N, Ca, Mg) and its low concentrations of heavy metals.

Gutierrez, Matos and Rossmann (2010) evaluated the capacity of solid waste to remove heavy metals present in the leachate of recently collected solid waste and concluded that all variables evaluated in the wastewater (Co, Pb, BOD, pH), except Cd and Zn, were below the standards established in the State Council for Environmental Policy/Board of Water Resources Normative Ruling (Deliberação Normativa do Conselho Estadual de Política Ambiental/ Câmara de Recursos Hídricos, COPAM/ CRH) regarding the release of leachates into water bodies (thus, with potential use for fertigation).

Silva et al. (2010) evaluated the changes in the concentration and saturation of the sodium exchange complex in a soil planted with Tifton 85 submitted to municipal solid waste leachate application at different rates and concluded that solid waste leachate application enabled sodium accumulation in all soil layers evaluated, albeit without impairing its quality. Application rates less than 1000 kg ha^{-1} d^{-1} BOD$_5$ of solid waste leachate cause no problems in the soil during the experimental period and therefore should be used for the disposal of those wastewaters.

Erthal et al. (2010) evaluated the effects of cattle farm wastewater (*água residuária de bovinocultura* – ARB) on the physiological and nutritional properties (photosynthetic rate, transpiration rate, stomatal conductance, leaf chlorophyll levels, forage yield, and crude protein [CP] and dry matter nutrient levels [P, K, Ca, Mg, Na, Zn and Cu]), as well as on the yield, of Tifton 85 (*Cynodon spp*.) and black oat (*Avena strigosa* Schreb) and concluded that using ARB caused no osmotic stress or toxicity by the chemical elements analyzed while enabling nutrient absorption and forage yield at levels similar to those recommended. Therefore, this wastewater may partially replace mineral fertilization in the growth of those forage plants.

Silva Neto et al. (2010) evaluated the effect of applying liquid slaughterhouse effluent (LSE) on the total dry mass values, leaf area index, crop growth rate, total number and mean weight of tillers, plant height, and plant tissue levels of N, P, and K^+ of Marandu grass pasture in Entisol. The authors concluded that the total dry mass production, leaf area index, crop growth rate, total number and mean weight of tillers, and plant height increased linearly ($p<0.05$) with increasing doses of LSE. The levels of N, P, and K^+ showed a response according to a linear regression model ($p<0.05$) upon LSE application. The N concentration remained in the appropriate range for Marandu grass. The levels of P and K were lower than the normal rate of variation in the plant tissue of Marandu grass, despite the positive response to LSE doses.

Silva et al. (2011) evaluated the chemical characteristics of soil planted with Tifton 85 grass (*Cynodon* spp.) following the application of different rates of solid waste leachate and noted that the leachate application caused an increase in the soil concentration of total N, K, P, NO_3- and Mn. The use of solid waste leachate at rates less than 750 kg ha^{-1} day^{-1} BOD caused no increase in the concentrations of contaminants to critical levels during the experimental period and, therefore, may be used. However, the authors recommended a long-term monitoring of the soil and groundwater chemical characteristics to assess the risks of environmental contamination associated with disposal in an area outside the sanitary landfill.

Coelho (2013) analyzed the effect of applying solid waste leachate on the quality of an argisol and elephant grass production (*Pennisetum purpureum* Schum.), and the results indicated that only the pH, Na, and exchangeable sodium percentage increased, suggesting that the soil studied salinized and subsequently sodified. In contrast, the Fe concentrations decreased significantly over time throughout the soil profile. Moreover, no significant differences were identified between the treatments applied regarding the wet plant mass, wet leaf mass, and dry leaf mass of the crop. The treatment that showed the best performance regarding the vegetative characteristics of elephant grass was treatment T2 (28.0 kg day^{-1} ha^{-1}), and high solid waste leachate concentrations applied to the soil caused a decrease in soil quality and, therefore, in the biomass production of that crop.

Matos et al. (2013) evaluated the effect of applying different rates of solid waste leachate on the yield and chemical composition of Tifton 85 grass (*Cynodon* spp) shoots and observed an increase in dry matter yield, crude protein levels and N, K, Na, Ca, Mg, Mn, Cd, Pb, and Fe concentrations in shoots with an increase in the leachate application rates. The concentrations of N, P, and Mn tended to decrease with the number of grass cuts, the Cd, Pb, and Fe concentrations tended to stabilize after the 2nd or 3rd cuts, and the Na concentrations tended to increase after the 3rd cut. The concentrations of K, Ca, and Mg remained unstable.

Effect on organic matter in soil

The importance of organic matter with regard to chemical, physical, and biological soil characteristics is widely recognized. Organic matter's effect on soil properties and sensitivity to management practices dictate that organic matter is a key parameter in the evaluation of soil quality (DORAN; PARKIN, 1994).

Among the effects of organic solid waste on the soil physical properties, mainly conditioned by the presence of organic matter, is the improvement in the state of the aggregation of soil particles, with a consequent decrease in density; increased porosity, aeration, infiltration, and soil water retention (MELO; MARQUES, 2000; BARBOSA; TAVARES FILHO; FONSECA, 2002); and an influence on the Atterberg limits (SMITH et al., 1985), optimal compaction moisture (DÌAZ-ZORITA; GROSSO, 2000), and stability of aggregates (MUNEER; OADES, 1989).

With regard to the chemical aspects, the application of organic solid waste has produced increases in the levels of phosphorus (SILVA; RESCK; SHARMA, 2002a), organic carbon

(CAVALLARO; PADILHA; VILLARRUBIA, 1993), humin fraction of soil organic matter (MELO et al., 1994), pH, electrical conductivity, cation exchange capacity (OLIVEIRA et al., 2002), soil CEC (TESTA; TEIXEIRA; MIELNICZUK, 1992; BAYER; MIELNICZUK, 1997; CIOTTA et al., 2002), and nutrient availability, especially N (TEIXEIRA; TESTA; MIELNICZUK, 1994; BURLE; MIELNICZUK; FOCCHI, 1997), among other elements, and decreases in Al toxicity (SALET, 1994).

It is important to remember that some of the effects caused by applying organic waste to agricultural soils are directly related to the persistence of the waste organic charge in these soils. The soil C levels will increase over successive applications and may cause significant changes in some of the soil physical and chemical properties if part of the organic carbon present in the waste is resistant to degradation (CLAPP et al., 1986; METZER; YARON, 1987). The mere increase in organic C levels may not benefit the soil-plant system, as shown by Hohla, Jones and Hinesly (1978) in a soil that received successive applications of anaerobic sewage sludge for six years, wherein the organic C levels increased from 9.5 to 22.9 g kg^{-1}. However, fractionation studies show that 10.9% of the organic C present in the treated soil corresponded to carbohydrates and 11.9% to oils and fats, whereas in the control soil, those fractions were 18.9% and 1.67%, respectively. Those percentages indicate that the quality of the persisting organic carbon, particularly its long-term effects on the soil chemical and physical characteristics, must be known (CALEGARI, 2006).

According to Bayer (1996), combinations with soil organic carbon (SOC) occur in tropical and subtropical soils, in which the mineral fractions show a high degree of variable charges and concentration of Fe and Al oxides, contributing to a strong physical protection of SOC compared with temperate soils. The following mechanisms are involved in the physical protection of organic carbon, according to Balesdent, Chenu and Balabane (2000): a) SOC sorption to solid surfaces – in which the organic compounds adsorbed to the surfaces of minerals may not be used by the microorganisms and, in the case of polymeric substrates, require the action of extracellular enzymes, and b) sequestration in small pores – the pores inaccessible to microorganisms or their enzymes will prevent the attack of microorganisms, according to microscopic observations (KILBERTUS, 1980; FOSTER, 1981).

Six, Elliot and Paustian (1999, 2000) noted that the binding of microaggregates to form macroaggregates is crucial for the long-term SOC sequestration because microaggregates have a greater capacity to protect the SOC against decomposition compared with macroaggregates (BALESDENT; CHENU; BALABANE, 2000). The interaction between organic matter and minerals may promote protection against microbial attachment, delaying the SOC mineralization and affecting the chemical composition of soils with variable charges (BALDOCK; SKJEMSTAD, 2000). The organic matter polysaccharides associated with kaolinite and iron are apparently preserved, primarily by SOC adsorption to minerals with variable charges (CALEGARI et al., 2006). The organo-mineral interactions affect the dynamics of SOC accumulation in Oxisols (SIX; ELLIOT; PAUSTIAN, 1999, 2000), and the high levels of clay (> 800 g kg^{-1}), oxides and hydroxides of an Oxisol most likely contribute to the protection of SOC against decomposition (ROSCOE; BUURMAN; VELTHORST, 2000; ROSCOE et al., 2001).

Some studies have shown that sewage sludge application may result in increased organic matter in the soil and increased stability of soil aggregates. Garcia-Orenes et al. (2005) observed an increase in the organic carbon and percentage of stable aggregates upon sewage sludge application to saline and non-saline soils. Tsadilas et al. (1995) noted an increase in organic matter and aggregate stability and an improvement of other physical properties of soil when applying 0 to 50 t/ha sludge, positively affecting the production of cotton. Souza et al. (2005) observed an increase in the average diameter of the aggregates when applying approximately 50 t/ha sewage sludge over five years in medium-texture and clayey-texture Oxisols. Lindsay and Logan (1998) observed an increase in the average diameter of aggregates when applying from 0 to 300 t/ha sewage sludge to the soil, albeit with maximum effect at the dose of 60 t/ha.

Sort and Alcañiz (1999), in the experimental remediation of a degraded area, observed that the main effect of sewage sludge was the increased stability of aggregates upon the impact of raindrops following sewage sludge application. However, that effect had substantially decreased after one year. Furthermore, these authors failed to assess a lasting effect of sewage sludge application, similar to other studies that observed no sludge effect on soil organic matter and aggregation.

Andrade, Oliveira and Cerri (2005) noted no difference in carbon stocks between control treatments and treatments with the application of sludge doses ranging from 10 to 40 t/ha after five years of eucalyptus inter-row topdressing with alkaline sewage sludge (with carbonates). Barbosa, Mitsios and Golia (2004) observed no significant difference in soil aggregation upon lime-treated sewage sludge application for two years from 0 to 36 t/ha. This study also showed surface water repellency at the highest doses.

Several authors (CARVALHO-PUPPATTO; BULL; CRUSCIOL, 2004; LOVATO et al., 2004; SOUZA et al., 2005) report that using steel slag, lime mud, and sewage sludge and adopting the no-tillage system are practices that elevate the soil levels of Ca and organic matter. The combination of those agricultural practices may improve the soil physical properties because these factors are responsible for the greater aggregation and stability of soil particles. Some studies, including those by Melo et al. (2004) and Souza et al. (2005), report that the results of physical changes in soil involving sewage sludge are associated with the conventional tillage system and with the incorporation of this waste. Melo et al. (2004) showed that sewage sludge application to tropical soils results in increased macroporosity. Conversely, Camilotti et al. (2006) observed no effect of sewage sludge application on soil physical properties, considering the lack of association between this waste and organic matter.

Final Considerations

Brito et al. (2007) reported that the excessive use of fertilizers and leachate, one of the main causes of groundwater contamination, worries consumers, who are showing a growing interest in agricultural production methods. The use of biosolids is a recent practice in agriculture, generating doubts regarding product costs compared with conventional fertilizers and requiring further study of the economic evaluation of their implementation (SILVA; RESCK; SHARMA, 2002b).

Thus, studies on the use of waste in agricultural areas are necessary to confirm the safety of using waste on the environment and human health. The characteristics of waste and soils presumably undergo changes when they are in contact with one another, and the levels of organic matter, Na, Ca, and Mg decrease over time after contact with soil. In turn, the cation exchange capacity (CEC), Al, water-dispersible clay, density, macro- and microporosity, and Atterberg limits undergo a significant change over time when in contact with the waste. Waste disposal in agricultural soils presumably benefits the soils, given the most likely increase in the organic matter levels and pH rise. However, waste may consequently cause soil disruption, given its dispersion, affecting porosity.

However, data published in the literature indicate that the agricultural soil-waste contact is apparently rather complex, thus requiring further studies in other soils and on different scales to reach more definitive conclusions regarding the effect of the use of solid waste on agricultural properties.

Studies analyzing the production of specific crops (cost/benefit) using different types of waste are lacking. Further characterization of waste organic matter and discussion of its molecular mass and its long-term effect on the physical, chemical and biological soil properties (more than 5 years of data collection in different weather conditions and soils) are necessary.

References

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS – ABNT. *NBR 8.419:* apresentação de projetos de aterros sanitários de resíduos sólidos urbanos: Procedimento. Rio de Janeiro: ABNT, 1984. 7 p.

AGENCE DE L'ENVIRONNEMENT ET DE MAITRISE DE L'ENERGIE – ADEME. Enquêete sur les installations de traitement des d´echets menagers et assimilés. France: ADEME, 2002. 52 p.

ALBERTE, E. P. V.; CARNEIRO, A. P.; KAN, L. Recuperação de áreas degradadas por disposição de resíduos sólidos urbanos. Diálogos & Ciência: *Revista Eletrônica da Faculdade de Tecnologia e Ciências de Feira de Santana*, Feira de Santana, Ano III, n. 5, p. 1-15, 2005.

ANDRADE, C. A.; OLIVEIRA, C.; CERRI, C. C. Qualidade da matéria orgânica e estoques de carbono e nitrogênio em latossolo tratado com biossólido e cultivado com eucalipto. *Revista Brasileira de Ciência do Solo*, Campinas, v. 29, n. 5 p. 803-816, 2005.

ANDRADE, S. M. A. *Caracterização físico-química e tratabilidade por coagulação-floculação dos líquidos percolados gerados no aterro sanitário de Uberlândia-MG*. 2002. Dissertação (Mestrado em Engenharia Química) – Faculdade de Engenharia Química, Universidade Federal de Uberlândia, Uberlândia.

ANJOS, A. R. M.; MATTIAZZO, M. E. Lixiviação de íons inorgânicos em solos repetidamente tratados com biossólido. *Revista Brasileira de Ciência do Solo*, Campinas, v. 24, n. 4, p. 927-938, 2000.

AZEVEDO, A. C.; BONUMÁ, A. S. Partículas coloidais, dispersão e agregação em latossolos. *Revista Brasileira de Ciência do Solo,* Campinas, v. 34, n. 2, p. 609-617, 2004.

BALDOCK, J. A.; SKJEMSTAD, J. O. Role of the soil matrix and minerals in protecting natural organic material against biological attack. *Organic Geochemistry*, Oxford, v. 31, n. 7, p. 697-710, 2000.

BALESDENT, J.; CHENU, C.; BALABANE, M. Relationship of soil organic matter dynamics to physical protection and tillage. *Soil and Tillage Research*, Amsterdam, v. 53, n. 3-4, p. 215-230, 2000.

BARBOSA, G. M. C.; MITSIOS, I. K.; GOLIA, E. Condutividade hidráulica saturada e não saturada de latossolo vermelho eutroférrico tratado com lodo de esgoto. *Revista Brasileira de Ciência do Solo*, Campinas, v. 28, n. 2, p. 403-407, 2004.

BARBOSA, G. M. C.; TAVARES FILHO, J. Uso agrícola do lodo de esgoto: influência nas propriedades químicas e físicas do solo, produtividade e recuperação de áreas degradadas. *Semina: Ciências Agrárias*, Londrina, v. 27, n. 4, p. 565-580, 2006.

BARBOSA, G. M. C.; TAVARES FILHO, J.; FONSECA, I. C. B. Efeito do lodo de esgoto em propriedades físicas de um Latossolo Vermelho eutroférrico. *Semina: Ciências Agrárias, Londrina,* v. 28, n. 1, p. 65-70, 2007.

______. Propriedades químicas de um Latossolo Vermelho eutroférrico após aplicação por dois anos consecutivos de lodo de esgoto. *Acta Scientiariun,* Maringá, v. 24, n. 5, p. 1501-1505, 2002.

BARROS, D. A. S.; PEIXOTO, J. S.; NASCIMENTO, C. W. A.; MELO, E. E. C. Conteúdo de nitrogênio e produção de biomassa em milho e feijoeiro em solos submetidos a doses de lodo de esgoto. In: FERTBIO, 3., Rio de Janeiro, 2002. *Anais*... Rio de Janeiro: Sociedade Brasileira de Ciência do Solo, 2002. CD-ROM.

BAYER, C. *Dinâmica da matéria orgânica em sistemas conservacionistas de manejo de solos*. 1996. Tese (Doutorado em Ciência do Solo Faculdade de Agronomia) – Universidade Federal do Rio Grande do Sul, Porto Alegre.

BAYER, C.; MIELNICZUK, J. *C*aracterísticas químicas do solo afetadas por métodos de preparo e sistemas de cultura. *Revista Brasileira de Ciência do Solo*, Campinas, v. 21, n. 1, p. 105-112, 1997.

BENITES, V. M.; MENDONÇA, E. S. Propriedades eletroquímicas de um solo eletropositivo inflluenciadas pela adição de diferentes fontes de matéria orgânica. *Revista Brasileira de Ciência do Solo*, Campinas, v. 22, n. 2, p. 215-221, 1998.

BETTIOL, W.; CAMARGO, O. A. *Impacto ambiental do uso agrícola do lodo de esgoto*. Jaguariúna: Embrapa Meio Ambiente, 2000. 312 p.

BICKI, T. J.; SIEMENS, J. C. Crop response to wheel traffic soil compaction. *Transactions of the American Society of Agricultural Engineers*, Philadelphia, v. 34, n. 3, p. 909-913, 1991.

BRITO, L. M.; FERNANDES, A. S.; TORRES, A. M.; AMARO, A. L. Influencia da dose de um composto de sólidos de chorume na produção de milho silagem. *Pastagens e Forragens*, Elvas, v. 28, p. 169-180, 2007.

BROWN, S.; ANGLE, J. S.; CHANEY, R. L. Correction of limed biosolid induced manganese deficiency on a long term field experiment. *Journal Environmental Quality***,** Madison, v. 26, n. 5, p. 1375-1384, 1997.

BURLE, M. L.; MIELNICZUK, J.; FOCCHI, S. Effect of cropping systems on soil chemical characteristics, with emphasis on soil acidification. *Plant Soil*, The Hague, v. 190, n. 2, p. 309-316, 1997.

CALEGARI, A. *Sequestro de carbono, atributos físicos e químicos em diferentes sistemas de manejo em um latossolo argiloso do sul do Brasil.* 2006. Tese (Doutorado em Agronomia) – Universidade Estadual de Londrina, Londrina.

CALEGARI, A.; CASTRO FILHO, C.; TAVARES FILHO, J.; RALISCH, R.; GUIMARÃES, M. F. Melhoria da agregação do solo através do sistema plantio direto. *Semina: Ciências Agrárias,* Londrina, v. 27, n. 2, p. 147-158, 2006.

CAMILOTTI, F.; ANDRIOLI, I.; MARQUES, M. O.; SILVA, A. R.; TASSO JUNIOR, L. C.; NOBILE, F. O. Atributos físicos de um Latossolo cultivado com cana-de-açúcar após aplicação de lodo de esgoto e vinhaça. *Engenharia Agricola*, Sorocaba, v. 26, n. 3, p. 738- 747, 2006.

CAÑASVERAS, J. C.; BARRÓN, V.; DEL CAMPILLO, M. C.; TORRENT, J.; GÓMEZ, J. A. Estimation of aggregate stability indices in Mediterranean soils by diffuse reflectance spectroscopy. *Geoderma*, Amsterdam, v. 158, n. 1-2, p. 78-84, 2010. Available at: <http://www.sciencedirect.com/science/article/pii/S001670610900281X>. Accessed at: 25 jan. 20012.

CARVALHO, A. L.; MATOS, A. T.; HAMAKAWA, P. J.; AZEVEDO, R. F. *P*rodução de percolado por resíduos sólidos urbanos de diferentes idades, na presença de resíduos da construção civil e sob recirculação. *Engenharia na Agricultura*, Viçosa, v. 14, n. 2, p. 131-138, 2006.

CARVALHO-PUPPATTO, J. G.; BÜLL, L. T.; CRUSCIOL, C. A. C. Atributos químicos do solo, crescimento radicular e produtividade do arroz com a aplicação de escórias. *Pesquisa Agropecuária Brasileira*, Brasília, v. 39, n. 12, p. 1213-1218, 2004.

CAVALLARO, N.; PADILLA, N.; VILLARRUBIA, J. Sewage sludge effects on chemical properties of acid soils. *Soil Science*, Baltimore, v. 156, n. 2, p. 63-70, 1993.

CHIAN, E. S. K.; DEWALLE, F. B. Sanitary landfill leachates and their treatment. *Journal Environmental Engineering Division*, New York, v. 102, n. 2, p. 411-431, 1976.

CIOTTA, M. N.; BAYER, C.; ERNANI, P. R.; FONTOURA, S. M. V.; ALBUQUERQUE, J. A.; WOBETO, C. Acidificação de um Latossolo sob plantio direto. *Revista Brasileira de Ciência do Solo*, Campinas, v. 26, n. 4, p. 1055-1064, 2002.

CLAPP, C. E.; SATARCK, S. A.; CLAY, D. E.; CARSO, H. E. Sewage sludge organic matter and soil properties. In: CHEN, Y. E.; ARNI MELEICH, Y. (Ed.). *The role of organic matter in modern agriculture.* Dorchecht: Kluwer, 1986. p. 209-248.

COELHO, D. C. L. *Atributos químicos de um argissolo e produção de capim elefante decorrentes da aplicação de percolado de aterro sanitário*. 2013. Dissertação (Mestrado em Ciência do Solo) – Universidade Federal Rural do Semi-Árido, Mossoró.

COLEMAN, D. C.; OADES, J. M.; UEHARA, G. *Dynamics of soil organic matter in tropical ecosystems*. Honolulu: University of Hawaii, 1989. 249 p.

CONSELHO NACIONAL DO MEIO AMBIENTE – CONAMA. Resolução n. 357/05. *Estabelece a classificação das águas doces, salobras e salinas do Território Nacional*. Brasília: SEMA, 2005.

DESCHAMPS, C.; FAVARETTO, N. Efeito do lodo complementado com fertilizante mineral na produtividade e desenvolvimento da cultura do feijoeiro e do girassol. *Sanare: Revista Técnica da Sanepar*, Curitiba, v. 8, n. 8, p. 33-38, 1997.

DÌAZ-ZORITA, M.; GROSSO, G. A. Effect of texture, organic carbon and water retention on the compactability of soil from Argentinean pampas. *Soil & Tillage Research*, Amsterdam, v. 54, n. 1, p. 121-126, 2000.

DORAN, J. W.; PARKIN, T. B. Defining and assessing soil quality. In: DORAN, J. C.; COLEMAN, D. C.; BEZDICEK, D. F.; STEWART, B. A. (Ed.). *Defining soil quality for a sustainable environment*. Madison: Soil Science Society of America, 1994. p. 3-21.

EL-FADEL, M.; BOU-ZEID, E.; CHAHINE, W.; ALAYLI, B. Temporal variation of leachate quality from pre-sorted and baled municipal solid waste with high organic and moisture content. *Waste Management*, Oxford, v. 22, n. 3, p. 269-282, 2002.

ERTHAL, V. J. T.; FERREIRA, P. A.; MATOS, A. T. de; PEREIRA, O. G. Alterações físicas e químicas de um Argissolo pela aplicação de água residuária de bovinocultura. *Revista Brasileira de Engenharia Agrícola e Ambiental,* Campina Grande, v. 14, n. 5, p. 467-477, 2010.

FERREIRA, A. C.; ANDREOLI, C. V.; JÜRGENSEN, D. I- Produção e características dos biossólidos. In: PROGRAMA DE PESQUISA EM SANEAMENTO BÁSICO. *Uso e manejo do lodo de esgoto na agricultura*. Rio de Janeiro: Prosab, 1999. p. 16-25.

FERREIRA, A. S.; CAMARGO, F. A. O.; TEDESCO, M. J.; BISSANI, C. A. Alterações de atributos químicos e biológicos de solo e rendimento de milho e soja pela utilização de resíduo de curtume e carbonífero. *Revista Brasileira de Ciência do Solo*, Campinas, v. 27, n. 4, p. 755-763, 2003.

FERREIRA, J. A.; GIORDANO, G.; RITTER, E.; ROSSO, T. C. A.; CAMPOS, J. C.; LIMA, P. Z. M. Uma revisão das técnicas de tratamento de chorume e a realidade do Estado do Rio de Janeiro. In: CONGRESSO BRASILEIRO DE ENGENHARIA SANITÁRIA E AMBIENTAL, 21., João Pessoa, 2001. *Anais*... Rio de Janeiro: ABES, 2001. p. 26-34.

FOSTER, R. C. Localization of organic materials in situ in ultrathin sections of natural soil fabrics using cytochemical techniques. In: BISDOM, E. B. A. (Ed.). *International working group on submicroscopy*. Wageningen: The Netherlands, 1981. p. 309-319.

GALDOS, M. V.; MARIA, I. C. de; CAMARGO, O. A. Atributos químicos e produção do milho em um Latossolo Vermelho eutroférrico tratado com lodo de esgoto. *Revista Brasileira de Ciência do Solo*, Campinas, v. 28, n. 8, p. 569-577, 2004.

GARCIA-ORENES, F.; GUERREIRO, C.; MATAIX-SOLERA, J.; NAVARRO-PEDRENO, J.; COMEZ, I.; MATAIX-BENEYTO, J. Factors controlling the aggregate stability and bulk density in two different soils amended with biosolids. *Soils & Tillage Research*, Amsterdam, v. 82, n. 1, p. 65-76, 2005.

GOMES, E. R. S.; SAMPAIO, S. C.; CORRÊA, M. M.; VILAS BOAS, M. A.; ALVES, L. F. A.; SOBRINHO, T. A. Movimento de nitrato proveniente de água residuária em colunas de solos. *Engenharia Agrícola,* Jaboticabal, v. 24, n. 3, p. 557-568, 2004.

GOMES, S. B. V.; NASCIMENTO, C. W. A.; BIONDI, C. M. Produtividade e composição mineral de plantas de milho em solo adubado com lodo de esgoto. *Revista Brasileira de Engenharia Agrícola e Ambiental*, Campina Grande, v. 11, n. 5, p. 459-465, 2007.

GUTIERREZ, K, G.; MATOS, A. T.; ROSSMANN, M. Influência da presença da camada de resíduos de construção civil na remoção de metais pesados em percolado recirculado em aterro sanitário. *Revista Ambiente & Água*, Taubaté, v. 5, n. 2, p. 1-12, 2010.

HARSEN, J. Identification of organic compounds in leachate from a waste tip. *Water Research*, New York, v. 17, n. 6, p. 699-705, 1983.

HARUVY, N. Agricultural reuse of wastewater: nation-wide cost-benefit analysis. *Agriculture, Ecosystems and Environment*, Amsterdam, v. 66, n. 2, p. 133-119, 1997.

HOHLA, G. N.; JONES, R. L.; HINESLY, T. D. The effect of anaerobically digested sewage sludge on organic fractions of blount silt loam. *Journal Environmental Quality*, Madison, v. 7, n. 4, p. 559-563, 1978.

HOILIJOKO, T. H.; KETTUNEN, R. H.; RINTALA, J. A. Nitrification of anaerobically pretreated municipal landfill leachate at low temperature. *Water Research*, New York, v. 34, n. 5, p. 1435-1446, 1999.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA – IBGE. Pesquisa Nacional de Saneamento Básico. Rio de Janeiro, 2008. Available at: <http://www.ibge.gov.br/home/presidencia/noticias/noticia_ visualiza.php?id_noticia=1691&id_pagina=1>. Accessed at: 18 feb. 2012.

KARATHANASIS, A. D.; JOHNSON, D. M. C. Stability and transportability of biosolid colloids through undisturbed soil monoliths. *Geoderma*, Amsterdam, v. 130, n. 3-4, p. 334-345, feb. 2006.

KILBERTUS, G. Etude des microhabitats contenus dans les agrégats de sol, leur relation avec la biomasse bactérienne et la taille des procaryotes. *Revue D'Ecologie et de Biologie du Sol*, Montrouge, v. 17, n. 4, p. 543-557, 1980.

KJELDSEN, P.; BARTAZ, M. A.; ROOKER, A. P.; BAUN, A.; LEDIN, A.; CHRISTENSEN, T. H. Present and long term composition of MSW landfill leachate: a review. *Critical Reviews in Environmental Science and Technology,* Boca Raton, v. 32, n. 4, p. 297-336, 2002.

KONRAD, E. E.; CASTILHOS, D. D. Alterações químicas do solo e crescimento do milho decorrentes da adição de lodos de curtume. *Revista Brasileira de Ciência do Solo*, Campinas, v. 26, n. 1, p. 257-265, 2002.

KRETZCHMAR, R.; ROBARGE, W. P.; WEED, S. B. Flocculation of kaolinitic soil clays: effect of humic substances and iron oxides. *Soil Science Society of America Journal*, Madison, v. 57, n. 5, p. 1277-1283, 1993.

LINDSAY, B. J.; LOGAN, T. J. Field response of soil physical properties to sewage sludge. *Journal of Enviromental Quality,* Madison, v. 27, n. 3, p. 534-542, 1998.

LLANILLO, R. F.; RICHART, A.; TAVARES FILHO, J.; GUIMARÃES, M. F.; FERREIRA, R. R. M. Evolução de propriedades físicas do solo em função dos sistemas de manejo em culturas anuais. *Semina: Ciências Agrárias*, Londrina, v. 27, n. 2, p. 205-220, abr./jun. 2006.

LOBO, F. T.; GRASSI FILHO, H. Níveis de lodo de esgoto na produtividade do girassol. *Revista de la Ciência del Suelo Nutrición Vegetal*, Botucatu, v. 7, n. 3, p. 16-25, 2007.

LOHER, R. A. *Pollution control for agriculture*. New York: Academic Press, 1984. 464 p.

LOVATO, T.; MIELNICZUK, J.; BAYER, C.; VEZZANI, F. Adição de carbono e nitrogênio e sua relação com os estoques no solo e com o rendimento do milho em sistemas de manejo. *Revista Brasileira de Ciência do Solo*, Campinas, v. 28, n. 1, p. 175-187, 2004.

MALTA, T. S. *Aplicação de lodos de estações de tratamento de esgotos na agricultura: estudo do caso do município de Rio das Ostras – RJ.* 2001. Dissertação (Mestrado em Engenharia Sanitária e Saúde Pública) – Fundação Oswaldo Cruz. Escola Nacional de Saúde Pública, Rio de Janeiro.

MATOS, A. T.; BRASIL, M. S.; FONSECA, S. P. P. Aproveitamento de efluentes líquidos domésticos e agroindustriais na agricultura. In: ENCONTRO DE PRESERVAÇÃO DE MANANCIAIS DA ZONA DA MATA MINEIRA, 3., 2003, Viçosa. *Anais*... Viçosa: ABES-MG, 2003. p. 25-79.

MATOS, A. T.; CARVALHO, A. L.; AZEVEDO, I. C. D, D. A. Viabilidade do aprovietamento agrícola de percolados de resíduos sólidos urbanos. *Revista Brasileira de Engenharia Agrícola e Ambiental*, Campina Grande, v. 12, n. 4, p. 435-440, 2008.

MATOS, A.T.; EUSTÁQUIO JÚNIOR, V.; PEREIRA, P. A.; MATOS, M. P. Tratamento de água para reuso no descascamento/despolpa dos frutos do cafeeiro. *Engenharia na Agricultura*, Viçosa, MG, v. 15, n. 2, p. 173-178, 2007.

MATOS, A. T.; SEDIYAMA, M. A. N.; FREITAS, S. P.; VIDIGAL, S. M.; GARCIA, N. C. P. Características químicas e microbiológicas do solo influenciadas pela aplicação de dejeto líquido de suínos. *Revista Ceres*, Viçosa, v. 44, n. 254, p. 399-410, 1997.

MATOS, A. T. de; SILVA, D. de F.; LO MONACO, P. A. V.; PEREIRA, O. G. Produtividade e composição química do capim-Tifton 85 submetido a diferentes taxas de aplicação do percolado de resíduo sólido urbano. *Engenharia Agrícola*, Jaboticabal, v. 33, n. 1, p. 188-200, 2013.

MATTHEWS, P. Sustainability in biosolids management. *Water Science Technology*, Oxford, v. 38, n. 2, p. 97-102, 1998.

MELO, V. P.; BEUTLER, A. N.; SOUZA, Z. M.; CENTURION, J. F.; MELO, W. J. Atributos físicos de Latossolos adubados durante cinco anos com biossólido. *Pesquisa Agropecuária Brasileira*, Brasília, v. 39, n. 1, p. 67-72, 2004.

MELO, W. J.; MARQUES, M. O. Potencial do lodo de esgoto como fonte de nutrientes para as plantas. In: BETTIOL, W.; CAMARGO, O. A. (Ed.). *Impacto ambiental do uso agrícola do lodo de esgoto.* Jaguariúna: Embrapa Meio Ambiente, 2000. p. 109-141.

MELO, W. J.; MARQUES, M. O.; SANTIAGO, G.; CHELLI, R. A. Efeito de doses crescentes de lodo de esgoto sobre frações da matéria orgânica e CTC de um Latossolo cultivado com cana-de-açúcar. *Revista Brasileira de Ciência do Solo*, Campinas, v. 18, n. 3, p. 449-455, 1994.

MELO, W. J.; MARQUES, M. O.; SILVA, F. C.; BOARETTO, A. E. Uso de resíduos sólidos urbanos na agricultura e impactos ambientais. In: CONGRESSO BRASILEIRO DE CIÊNCIA DO SOLO, 26., 1997, Rio de Janeiro. *Anais*... Rio de Janeiro: Sociedade Brasileira de Ciência do Solo, 1997. CD-ROM.

METZER, L.; YARON, B. Influence of sludge organic matter on soil physical properties. *Advances in Soil Science*, Baltimore, v. 7, p. 141-163, 1987.

MEURER, E. J. *Fundamentos de química do solo*. 3. ed. Porto Alegre: Evangraf, 2006. 285 p.

MORAIS, J. L.; SITORI, C.; ZAMORA, P. G. Emprego de processos oxidativos avançados visando o aumento da biodegradabilidade de chorume de aterro sanitário. In: CONGRESSO BRASILERIO DE CIÊNCIA E TECNOLOGIA EM RESÍDUOS E DESENVOLVIMENTO SUSTENTÁVEL – ICTR, 1., 2004, Florianópolis. *Anais*... Florianópolis: ICTR, 2004. p. 1-8.

MUNEER, M.; OADES, J. M. The role of Ca-organic interactions in soil aggregate stability. III. Mechanisms and models. *Australian Journal of Soil Research*, Melbourne, v. 29, n. 2, p. 411-423, 1989.

NASCIMENTO, C. W. A.; BARROS, D. A. S.; MELO, E. E. C.; OLIVEIRA, A. B. Alterações químicas em solos e crescimento de milho e feijoeiro após aplicação de lodo de esgoto. *Revista Brasileira de Ciência do Solo*, Campinas, v. 28, n. 2, p. 385-392, 2004.

NGUETNKAM, J. P.; SULTZ, S. Soil degradation in Central North Cameroon: water-dispersible clay in relation to surface charge in Oxisol A and B horizons. *Soil and Tillage Research*, Amsterdam, v. 113, n. 1, p. 38-47, 2011.

OADES, J. M. Soil organic matter and structural stability: mechanisms and implications for management. *Plant Soil*, The Hague, v. 76, n. 1-3, p. 319-337, 1984.

______. An introduction to organic matter in mineral soils. In: DIXON, J. B. E.; WEED, S. B. (Ed.). *Minerals in soil environments*. 2. ed. Madison: Soil Science Society of America, 1989. p. 89-160.

OLIVEIRA, F. C.; MATTIAZZO, M. E.; MARCIANO, C. R.; ROSSETO, R. Efeitos de aplicações sucessivas de lodo de esgoto em Latossolo Amarelo distrófico cultivado com cana-de-açucar: carbono orgânico, condutividade elétrica, pH e CTC. *Revista Brasileira de Ciência do Solo,* Campinas, v. 26, n. 3, p. 505-519, 2002.

ÖREN, A. H.; KAYA, A. Some engineering aspects of homoionized mixed clay minerals. *Environmental Monitoring and Assessment*, Geneva, v.87, n. 1-2, p. 85-98, 2003.

PAES, R. F. C. *Caracterização do chorume produzido no Aterro de Muribeca – PE*. 2003. Dissertação (Mestrado em Engenharia Civil e Ambiental) – Universidade Federal de Campina Grande, Campina Grande**.**

PAVAN, M. A.; ROTH, C. H. Effect of lime and gypsum on chemical composition of runoff and leachate from samples of a Brazilian Oxisol. *Ciência e Cultura*, São Paulo, v. 44, n. 6, p. 391-394, 1992.

QUEIROZ, F. M.; MATOS, A. T.; PEREIRA, O. G.; OLIVEIRA, R. A.; LEMOS, A. F. Características químicas do solo e absorção de nutrientes por gramíneas forrageiras em rampas de tratamento de águas residuárias da suinocultura. *Revista Engenharia na Agricultura*, Viçosa, v. 12, n. 2, p. 77-90, 2004.

QUINTANA, N. R. G.; CARMO, M. S.; MELO, W. J. Valor agregado ao lodo de esgoto. *Energia na Agricultura*, Botucatu, v. 24, n. 1, p. 121-129, 2009.

RENOU, S.; GIVAUDAN, J. G.; POULAIN, S.; DIRASSOUYAN, F.; MOULIN, P. Landfill leachate treatment: review and opportunity. *Journal of Hazardous Materials,* Amsterdam, v. 150, n. 3, p. 468-93, 2008.

ROCHA, G. N.; GONÇALVES, J. L. M.; MOURA, I. M. Mudanças da fertilidade do solo e crescimento de um povoamento de *Eucalyptus grandis* fertilizado com biosólido. *Revista Brasileira de Ciência do Solo*, Campinas, v. 28, n. 4, p. 623-639, 2004.

ROSCOE, R.; BUURMAN, P.; VELTHORST, E. J. Disruption of soil aggregates by varied amounts of ultrasonic energy in fractionation of organic matter of a clay Latosol: carbon, nitrogen, and S ^{13}C distribution in particle-size fractions. *European Journal of Soil Science*, Oxford, v. 51, n. 3, p. 445-454, 2000.

ROSCOE, R.; BUURMAN, P.; VELTHORST, E. J.; VASCONCELLOS, C. A. Soil organic matter dynamics in density and particle-size fractions as revealed by ^{13}C/^{12}C isotope ratio in a cerrado Oxisol. *Geoderma*, Amsterdam, v. 104, n. 3-4, p. 185-202, 2001.

ROSS, C. A.; AITA, C.; CERETTA, C. A.; FRIES, M. R. Utilização de lodo de esgoto como fertilizante: efeito imediato no milheto e residual na associação de aveia + ervilhaca. In: REUNIÃO BRASILEIRA DE FERTILIDADE DO SOLO E NUTRIÇÃO DE PLANTAS, 23., Santa Maria, 1990. *Resumos.* Santa Maria: Sociedade Brasileira de Ciência do Solo, 1990. p. 20.

SALET, R. L. *Dinâmica de íons na solução de um solo submetido ao sistema plantio-direto*. 1994. Dissertação (Mestrado em Ciência do solo Faculdade de Agronomia) – Universidade Federal do Rio Grande do Sul, Porto Alegre.

SANTOS, A. P. *Efeito da irrigação do efluente de esgoto tratado, rico em sódio, em propriedades químicas e físicas de um argissolo vermelho distrófico cultivado com capim-Tifton 85.* 2004. Dissertação (Mestrado em Agronomia) – Universidade de São Paulo. Escola Superior de Agricultura Luiz de Queiroz, Piracicaba.

SEGATO, L. M. Caracterização do chorume do aterro sanitário de Bauru. In: CONGRESSO INTERAMERICANO DE ENGENHARIA SANITÁRIA E AMBIENTAL – ABES, 27., 2000, Porto Alegre. *Anais...* Porto Alegre: ABES, 2000. p. 1-9.

SILVA, D. F.; MATOS, A. T.; PEREIRA, O. G.; CECON, P. R.; BATISTA, R. O.; MOREIRA, D. A. Alteração química de solo cultivado com capim Tifton 85 (Cynodon spp.) e fertirrigado com percolado de resíduo sólido urbano. *Acta Scientiarum. Technology*, Maringá, v. 33, n. 3, p. 243-251, 2011

SILVA, D. F.; MATOS, A. T.; PEREIRA, O. G.; CECON, P. R.; MOREIRA, D. A. Disponibilidade de sódio em solo com capim tifton e aplicação de percolado de resíduo sólido. *Revista Brasileira de Engenharia Agrícola e Ambiental*, v. 14, n. 10, p. 1094-1100, 2010.

SILVA, J. E.; RESCK, D. V. S.; SHARMA, R. D. Alternativa agronômica para o biossólido produzido no Distrito Federal: I. Efeito na produção de milho e na adição de metais pesados em latossolo no Cerrado. *Revista Brasileira de Ciência do Solo*, Campinas, v. 26, n. 2, p. 487-495, 2002a.

______. Alternativa agronômica para o biossólido produzido no Distrito Federal: II. Aspectos qualitativos, econômicos e práticos de seu uso. *Revista Brasileira de Ciência do Solo*, Campinas, v. 26, n. 2, p. 497-503, 2002b.

SILVA NETO; S. P. da; SILVA, J. E. C.; SANTOS, A. C.; CASTRO, J. G. D.; DIM, V. P.; ARAÚJO, A. S. Características agronômicas e nutricionais do capim-Marandu em função da aplicação de resíduo líquido de frigorífico. *Acta Scientiarum. Animal Sciences*, Maringá, v. 32, n. 1, p. 9-17, 2010.

SIX, J.; ELLIOT, E. T.; PAUSTIAN, K. Aggregation and soil organic matter dynamics under conventional and no-tillage systems. *Soil Science Society of America Journal*, Madison, v. 63, n. 5, p. 1350-1358, 1999.

______. Soil macroaggregate turn-over and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. *Soil Biology and Biochemistry*, Elmsford, v. 32, n. 14, p. 2099-2103, 2000.

SMITH, C. W.; HADAS, A.; DAN, J.; KOYUMDJISKY, H. Shrinkage and Atterberg limits in relation to other properties of principal soil types in Israel. *Geoderma*, Amsterdam, v. 35, n. 1, p. 47-65, 1985.

SORT, X.; ALCAÑIZ, J. M. Effects of sewage sludge amendment on soil aggregation. *Land Degradation & Development,* Oxford, v. 10, n. 1, p. 3-12, 1999.

SOUZA, H. A.; ROESER, H. M. P.; MATOS, A. T. Métodos e técnicas aplicados a avaliação ambiental do aterro da BR – 040 da Prefeitura Municipal de Belo Horizonte – MG. *REM: Revista da Escola de Minas*, Ouro Preto, v. 55, n. 4, p. 291-300, 2002.

SOUZA, W. J. O. *Fósforo em solo tratado com biossólido e cultivado com milho*. 2004. Tese (Doutorado em Agronomia/Produção Vegetal) – Faculdade de Ciências Agrárias e Veterinárias. Universidade Estadual Paulista, Jaboticabal.

SOUZA, Z. M.; BEUTLER, A. N.; MELO, V. P.; MELO, W. J. Estabilidade de agregados e resistência à penetração em latossolos adubados por cinco anos por biossolidos. *Revista Brasileira de Ciência do Solo*, Campinas, v. 29, n. 1, p. 117-127, 2005.

TEIXEIRA, L. A. J.; TESTA, V. M.; MIELNICZUK, J. Nitrogênio do solo, nutrição e rendimento de milho afetados por sistemas de cultura. *Revista Brasileira de Ciência do Solo*, Campinas, v. 18, n. 2, p. 207-214, 1994.

TESTA, V. M.; TEIXEIRA, L. A. J.; MIELNICZUK, J. Características químicas de um podzólico vermelho-escuro afetadas por sistemas de culturas. *Revista Brasileira de Ciência do Solo*, Campinas, v. 16, n. 1, p. 107-114, 1992.

TRANNIN, I. C. B.; SIQUEIRA, J. O.; MOREIRA, F. M. S. Avaliação agronômica de um biossólido industrial para a cultura do milho. *Pesquisa Agropecuária Brasileira,* Brasília, v. 40, n. 3, p. 261-269, 2005.

TRIGUEIRO, R. M. *Uso de biossólidos como substrato para produção de mudas de pinus e eucalipto*. 2002. Dissertação (Mestrado em Agronomia/Energia na Agricultura) – Faculdade de Ciências Agronômicas. Universidade Estadual Paulista, Botucatu.

TSADILAS, C. D.; MATSI, T.; BARBAYIANNIS, N.; DIMOYIANNIS, D. Influence of sewage sludge application on soil properties and on the distribution and availability of heavy metal fractions. *Communications in Soil Science and Plant Analysis*, New York, v. 26, n. 15-16, p. 2603-2619, 1995.

TSUTIYA, M. T. Alternativas de disposição final de biossólidos. In: TSUTIYA, M. T.; COMPARINI, J. B.; SOBRINHO, P. A.; HESPANHOL, I.; CARVALHO, P. C. T.; MELFI, A. J.; MELO, W. J.; MARQUES, M. O. (Ed.). *Biossólidos na agricultura*. São Paulo: SABESP, 2001. p. 133-180.

TSUTIYA, M. T. Metais pesados: o principal fator limitante para o uso agrícola de biossólidos das estações de tratamento de esgotos. In: CONGRESSO BRASILEIRO DE ENGENHARIA SANITÁRIA E AMBIENTAL, 20., 1999, Rio de Janeiro. *Anais...* Rio de Janeiro: ABES, 1999. p. 753-761.

VAN RAIJ, B. Uso agrícola de biossólidos. In: SEMINÁRIO SOBRE GERENCIAMENTO DE BIOSSÓLIDOS NO MERCOSUL, 1., Curitiba, 1998. Anais... Curitiba: ABES, 1998. p. 147-151.

WANG, F.; SMITH, D. W.; EL-DIN, M. G. *Application* of advanced oxidation methods for landfill leachate treatment. *Journal of Environmental Engeenering Science*, Canadá, v. 2, n. 6, p. 413-427, 2003.

WARAH, R. United nations centre for human settlements (Habitat) – UNCHS. In: AUCLAIR, C.; BAZAGLU, N.; BIAU, D.; MASELAND, J.; MOOR, J.; TUREL, A.; Ken WORPOLE, K. (Ed.). *The state of the world's cities*. Nairobi: Urban Waste**,** 2001. cap. 4, p. 60-61.

WELANDER, U. T.; WELANDER, H. T. Nitrification of landfill leachate using suspended-carrier biofilm technology. *Water Research, New York*, v. 31, n. 9, p. 2351-2355, 1997.