Impact of Vermicomposting products in soil fertility of degraded Brazilian Cerrado and the perspective to minimize water pollutants release

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Abstract

Household wastes vary in composition but generally have high organic matter concentrations. Landfills are commonly used for disposing of these wastes, but the degradation of the organic fraction produces leachates that, in combination with rainwater percolation, significantly threaten surface and ground waters. Composting – breaking down of organic material by organisms that feed on wastes, converts it to a soil-like mass (compost) and liquid (leachate) – is an alternative to reduce inappropriate waste into the environment. These composting outputs can be used as a soil conditioner.

The Brazilian Cerrado is a biome characterized by acid soils with low essential nutrient availability, high aluminum saturation, and low water-holding capacity. The study site was an area of degraded Cerrado used for over 30 years for pasture. The study evaluated the use of vermicomposting byproducts performed by red wiggler worms (*Eisenia fetida*) on plant development (*Agapanthus africanus* and aromatic herbs). Basic characterizations of the waste material were performed and the viability of the systems was evaluated in terms of compost and leachate yields in relation to organic matter mass inputs - providing an indirect estimative of the amount of pollutants that would otherwise be released into the environment in unsustainable manner.

Keywords: leachete; plant development, vermecomposting, waste management, water pollution.

1. Introduction

Wastes generation in Brazil increased 29% from 2003 to 2014, five times its population growth rate in the period (6%). The amounts of properly treated waste, however, did not accompany waste generation and only 58.4% was directed to landfills. More than 41% of solid waste (78.6 million tons) generated in that country in 2014 was disposed of in dumps and controlled landfills. These sites are inadequate and provide risks to the environment and health. Each Brazilian citizen generates an average of 1.062 kg of waste per day, but more than 38.5% of the Brazilian population has no access to proper services for the disposal of solid wastes. Additionally, more than 20 million people do not have any access to regular garbage collection, and approximately 10% of the material generated is not collected at all. The volume of waste produced grew by 2.9% between 2013 and 2014; waste collection, in turn, increased by 3.2% [1].

Detailed information concerning waste composition in Brazil is not readily available. Ribeiro [2] estimated that solid municipal waste (SMW) generated in Brazil has an average of organic material of 54.9%. Similar results were reported for the city of Varginha (Minas Gerais, Brazil), having SMW with 55.89% organic content [3]. Varginha is located in Southeastern Brazil, has a population of 124,000 inhabitants, and is considered to have a high growth rate. It is economy was previously based on agriculture and livestock breeding (coffee and milk production), but industrial growth has changed the lifestyle of its citizens. The garbage generated in Varginha was disposed of in dumps until 2011. In 2012 that area was converted to a landfill that is now operating at overcapacity. There is an expectation that controlled landfills will begin to operate at the end of 2016, together with the selective collection of waste in another area [4].

Sanitary landfills have been the most popular means of solid waste disposal in many countries. Most of the landfills are basically open dumping grounds, and pose serious environmental and social risks [5]. A major concern associated with this disposal method is the leachate it generates. Leachate production is principally caused by percolation of precipitation through waste deposited in a landfill [6]. Landfill leachate mainly consists of organic matter mixture with inorganic compounds, with high level of ammoniacal nitrogen [7, 8, 9]. The characteristics of the leachate will vary with regard to its composition and volume, the biodegradable matter present over time, soil characteristics, weather conditions, and operating and downstream processes [10, 11]. The complexity of these factors makes leachate difficult to manage. The treatment of landfill leachate constituents prior to its discharge is order to avoid pollution of bodies of water and to prevent severe and continual toxicity is therefore a legal necessity [11].

A viable option for decreasing the volume of leachates produced in landfills (and reducing water pollution) is to stimulate household vermicomposting. Vermicomposting is a simple biotechnological composting process in which earthworms are used to enhance waste conversion processes and generate better end-product. Vermicomposting differs from composting in several ways [12]. It is a mesophilic process, utilizing microorganisms and earthworms that are active between 10 and 32°C. The process is faster than composting because the material passes through the earthworm gut, where significant (but not yet fully understood) transformations takes place, and the resulting earthworm castings (worm manure) are rich in microbial activity and plant growth regulators, and fortified with pest-repellent attributes [13].

This alternative waste treatment method is in agreement with the concept of reverse logistics, and consists of using red wiggler worms (*Eisenia fetida*) that break down organic wastes and convert them to soil-like masses (compost) and liquid (leachate). These composting outputs can be used as a soil conditioner. The present work evaluated the effects of vermicomposting byproducts performed by red wiggler worms on plant development (*Agapanthus africanus* and aromatic herbs) in degraded Cerrado soil that have been used as pasture for over 30 years. The Brazilian Cerrado is a biome characterized by acid soils with low essential nutrient availability, high aluminum saturation, and low water-retention capacity. Basic characterizations of the waste material were performed and the viability of the systems was evaluated in terms of compost and leachate yields in relation to organic matter mass inputs - therefore providing an indirect estimative of the amount of pollutants that would otherwise be released in unsustainable manner into the environment.

2. Methodology

2.1. Study area

The city of Varginha is located in southeastern Brazil and has a mesothermal climate (CWB on the Köppen scale) and a well-defined dry season. The rainy season occurs from October to March. The mean annual temperature is 22°C, with temperature varying from 17 °C to 24°C. The main vegetation type surrounding Varginha is Cerrado '*sensu stricto*'. The experiments were carried out in the gardens of the Centro Federal de Educação Tecnológica de Minas Gerais, located in Varginha, Minas Gerais State. Historical records indicate that the land at the study site was used as pasture for more than 30 years. This practice was discontinued in 2007, and the area was protected by a wall in 2008 (blocking the entrance of cattle from adjacent farms). The soil in experimental area is composed approximately 42% sandy, 38% clay and 20% silt [14], slightly acid and has low total organic carbon, nitrogen and essential minerals contents and high levels of aluminum (unpublished data). The gardens of the school were planted in 2014 and some plant species have not flourished yet.

2.2. Plants species

During celebrations of Environment Week (June, 2015) each one of the nine high school classes were asked to design projects and built (and take care of) beds of aromatic herbs to work the concepts of biodiversity, native versus invasive and commercial plant species, and soil management. The species plated and their origins are listed in Table 1.

The school has a garden of *Agapanthus africanus* was first planted in February/2014, but it has never flowered. This species usually flowers in the Austral spring through the end of summer (September until March) but requires high organic matter soil content and was used for that reason in the experimental design (Figure 1).

2.3. Experimental design and field experiments

The aromatic herbs beds were randomly irrigated with raw leachate; three negative control beds received no organic matter addition. Irrigation was performed once a month. Once differences between irrigated gardens and negative control were noted (by the end of 2015), we decided to perform more detailed series of experiments.

The *Agapanthus africanus* garden was divided into sixteen 2.5 m length x 2.5 m plots (6.25 m^2) (Figure 1). Leachate application was performed in triplicate, with three plots, per leachate dilution. The leachates were diluted in concentration of 0.5:10; 1:10; 2:10 (liter/liter) with tap water and applied to the gardens monthly. Raw leachate was applied to one plot to evaluate its toxicity. A positive control plot received commercial organic matter appropriate for gardening at the same frequency of leachate. The commercial gardening organic material was composed of a mixture of vermiculite, vegetable charcoal, peat (turf) and *Pinus sp.* bark. Three of the plots were irrigated with tap water as negative control. The experimental design is outlined in Figure 3.

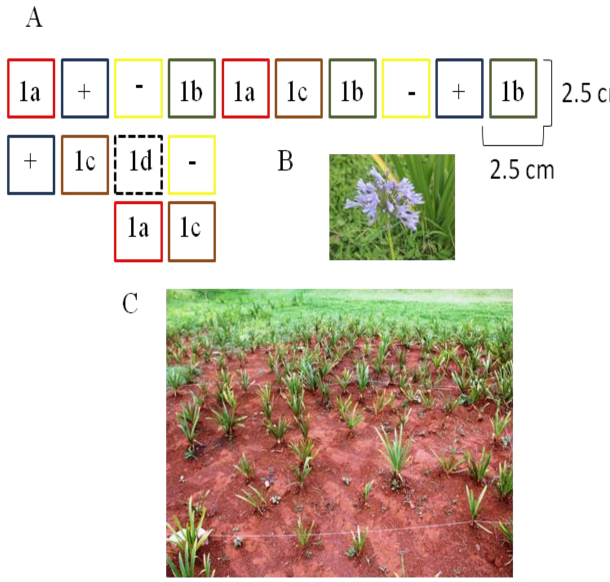

Figure 1: Experimental design. A: *Agapanthus africanus* garden were divided into 16 plots of 6.25 m^2. Plots were irrigated with leachate indicated as follows. Plot 1a: 10 liters of diluted leachate at concentration 0.5:10; Plot 1b: 10 liters of diluted leachate at concentration 1:10; 1c: 10 liters of diluted leachate at concentration 2:10; 1d: 10 liters of undiluted leachate; Plot +: commercial gardening organic matter (positive control); Plot - :10 liters of water (negative control). B: *A. africanus*; C: Overview *A. africanus* garden.

2.4. Vermicomposting and leachate recovery

Vermicomposting was performed using household system. The first apparatus used had only two trays (Figure 2). Leachate produced in this system was insufficient to be applied in all sixteen plots in the experimental design, and was primarily used to irrigate aromatic herbs beds. A second apparatus (Figure 3) was acquired that allowed better quantification of the volume of leachate production in relation of biomass input and is certified by Brazilian Ministry of the Environment (purchased from Morada da Floresta, Brazil); its specifications are available in website [15]. The food wastes were obtained from school restaurant. Skin of fruits and vegetables were chopped in small pieces and mixture with sawdust. Sometimes was added coffee powder, green leafs (i.e. spoiled lettuce, cabbage steam), egg shells, etc. Eventually was added in feeding tray wastes of citric fruits, napkin, papers and spices. All organic wastes before being mixture with sawdust were weight and results recorded. After each week collection tray was drained and the volume of leachate was determined. The decomposing process was considered finished when less than 10 ml of leachate was drained from holding tray in the week. At the end of process calculation of amount of leachate produced per gram of biomass was determined and a new cycle of production started with addition of organic matter mixture with sawdust. Red wiggler worms (*Eisenia fetida*) (Figure 4) was purchase from Morada da Floresta (Brazil). About 300 animals were added in the feeding tray.

Figure 2: First system 1: A: Processing tray - worms bedding and organic matter content. B: Holding leachate tray. C: Tap to drain leachate to be diluted in different concentration and use in field.

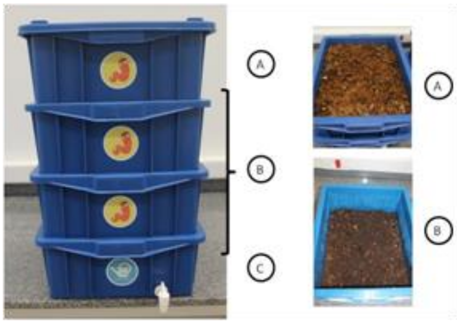

Figure 3: System 2. A: Processing and feeding tray n° 1 (worms bedding, around 300 red wriggler worms, organic waste plus 1.5 kg of sawdust. C: Processing tray n° 2 and n° 3 organic compost and sawdust. D: Holding leachate tray. E: Tap to drain leachate to be diluted in different concentration and to be used in field.

Figure 4: Red wiggler worms *(Eisenia fetida)*

2.4. Characterization of leachate

The leachate samples were collected from holding tray weekly. When leachate ceased flowing into the holding tray a new cycle with input of food begins. The collected volumes were stored at room temperature in plastic bottles to experimental use. Analysis where normally performed at time of collection to minimize biological and chemical reactions. The samples were characterized in terms of pH, electrical conductivity, and absorbance (660 nm and 445 nm). Measurements of these parameters were conducted in triplicate, means are presented.

2.5. Measurement of pH in Soil

A spoon was used to weigh out about 10 g of soil into the 100 ml Becker, distilled water 50ml was added to soil sample (1:5 diluted). Container was shaken for about 2-3 minutes and then it was allowed the soil to settle for 2 minutes. Measurements was performed with pHmeter and data recorded.

3. Results and Discussion

3.1. Leachate production

Leachate volumes produced varied among the different decomposition cycles, most likely due to the nature of organic wastes used and other factors such as temperature. Decomposition cycles normally last from two to four weeks and usually produce about two liters of leachate per week at the beginning of the process, with decreasing volume with time (data not shown). Preliminary data indicated an average of 600 ml of leachate was produced per kilogram of organic matter. Assuming then that each citizen in Varginha city produces approximately 0.8 kg of solid waste material per day, that 55.9% is organic matter [3], that only half of this organic matter would be used in vermicomposting processes (some materials, like acidic and cooked foods in high quantities, are undesirable), and that 1% of the Varginha citizens would adopted the vermicomposting methodology – approximately 5400 liters of leachate could be recovered and used in sustainable manners – and this high-valuable organic material could be used to promote plant growth, support biodiversity, and minimize the release of chemicals and pollutants into the environment. MSW in closed landfill cells is slowly converted into gases, liquids, and inert solids over periods of 20–30 years. Landfill leachate is one of the main sources of groundwater and surface water pollution if not properly collected, treated, and safely disposed of, as it can percolate through the soil and reach aquifers [16].

Household vermicomposting is therefore a viable alternative for reducing leachate release and reutilization organic material. In Vermicomposting, the ingestion, digestion, and absorption of organic wastes is performed by earthworms, followed by the excretion of castings, thus enhancing the levels of nutrients available to plants through the biological activities of decomposers. Vermicompost byproducts provide higher levels and more soluble forms of important nutrients - nitrogen, phosphorus, potassium, calcium and magnesium – as compared to the substrate, the underlying soil, or normal compost. During the recycling processes in the worm's gut, the nutrients locked in the organic wastes are transformed into more simple and more readily available (and absorbable) forms such as nitrates and ammonium nitrogen, exchangeable phosphorus and soluble potassium, calcium, magnesium. Vermicompost is often considered a supplement to fertilizers, releasing major and minor nutrients slowly with significant reductions in C/N ratios and in synchrony with plant requirements [17].

The leachate was collected on a weekly basis for analysis. Table 2 lists the characteristics of leachate produced by vermicomposting. The moderate alkalinity of this liquid makes it suitable for application on the slightly acidic degraded Cerrado soil sin the study plots (Figure 5). Historical reports of the study area indicate that the land was used as pasture for more than 30 years. This practice is common in the Cerrado and results in soils with varying levels of degradation and low productivity [18]. This low fertility condition is mainly the result of reduced biological activity and the lack of essential elements such as nitrogen, phosphorus, potassium, calcium, and magnesium. Low levels of exchangeable bases lead to soil acidification and increases in the level of exchangeable aluminum. The phytotoxicity of aluminum in these soils has been demonstrated by different researchers [19]. The use of vermicomposting leachate therefore seems appropriate for minimizing acidity and restoring degraded Cerrado soils. Conductivity is a measure of the ability of aqueous solutions to carry an electric current, and depends on the presence of ions (their total concentration, mobility, and valence). Solutions of most inorganic compounds are relatively good conductors. Conversely, organic molecules that do not dissociate in aqueous solutions will conduct current very poorly. The electrical conductivity was very low compared to previous work, probably because leachate was fresh and there was not enough time for degradation of organic matter releasing minerals such as exchangeable Ca, Mg, K, and P in the available forms [17].

Table 2: Basic leachate characterization

Parameters				
Sample	pH*	Electrical conductivity**	Absorbance***	
			660 nm	445nm
1	8,68	10,83	0.049	0.763
2	8,74	10,64	0.005	0.666
3	8,73	10,45	0.009	0.644
4	8,31	10,86	0.051	0.679
5	8,72	10,61	0.002	0.665
6	8,62	7,63	1.312	2.834

* pHmeter (Micronal, Brazil)

** electrical conductivity (mS/cm) (conductivimeter Ionlab, Bazil)

*** Turbidity at 660 nm and Color (uH) 445nm (Spectrophotometer, Mapada shanghai)

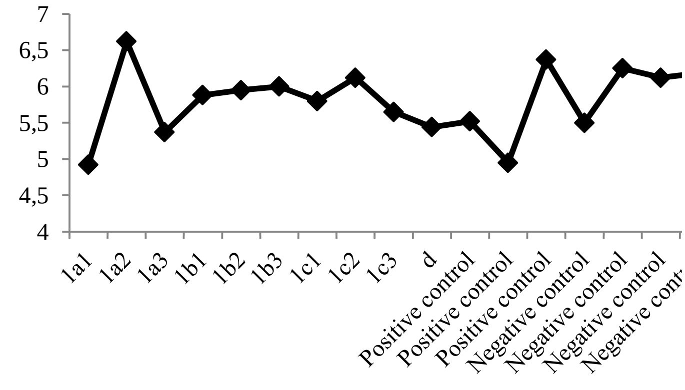

Figure 5: Variation of soil pH in different plots of experimental design before leachate application

3.2. Aromatic herbs beds

The principal herbs planted in the student gardens are listed in Table 1. Only one of them (*Solidago microglossa*) seems to be of South America origin. Independent of their origins, however, aromatic herbs were easily cultivated in the gardens when organic matter was added (Figure 6A). Clear differences were observed in gardens with no added organic matter (Figure 6B), especially in terms of chive and basil (which were planted in sites with or without organic matter). Herb beds without added organic matter showed very little growth, indicating that the soils were deficient in essential nutrients. The chives have not yet produced flowers and are very weak in relation to commercial demands (medium height) [20]. Despite the fact that Cerrado soils were long considered to have low productivity, the Cerrado region has been the focus of intense agricultural expansion since the 1970s –a commercial use detrimental, to biodiversity maintenance. Therefore the characterization of plant development in Cerrado soils will be important for understanding the physiology of that biome.

Table 1: Main species of aromatic herbs planted in the study site

Common name	Specie	Origin
Aloe	*Aloe vera*	Africa
Basil	*Ocimum basilicum*	India
Boldo	*Peumus boldus*	Chile central
Chive	*Allium schoenoprasum*	Unknown, Central Asia
Fennel	*Foeniculum vulgare*	Southern Europe and the Mediterranean area
Arnica	*Solidago microglossa*	South America
Lemon grass	*Cymbopogon citrates*	Southeast Asia
Mint	*Mentha*	Unknown, probably Eurasia
Oregano	*Origanum vulgare*	Greece
Chili Pepper	*Capiscum sp.*	America
Parsley	*Petroselinum crispum*	Unknown, probably Mediterranean region
Purple basil	*Ocimum basilicum purpurescens*	India
Rue	*Ruta graveolens*	Probably Mediterranean region or Western Asia
Rosemary	*Rosmarinus officinalis*	Mediterranean region
Sage	*Salvia officinalis*	Mediterranean region
Sedum	*Sedum dendroideum*	Mexico
Thyme	*Thymus spp.*	Mediterranean region

Figure 6: An aromatic herb bed. A: An aromatic herb bed with plants that were cultivated with added organic matter. B: An aromatic herb bed with plants those were cultivated without the addition of organic matter. Clear differences can be seen between the plants growing in beds with and without added organic matter.

3.3. Experimental design

Ten liters of leachate raw and in different dilutions were used to irrigate *A. africanus* gardens; this irrigation was performed only once. No toxicity of the leachate was noted among the plants in plot d. Improvements in plant development were noted in plot 1a, now with budding plants (Figure 7). No budding was observed among plants growing in the other plots. No differences in plant stem length, presence or absence of root hairs, and leaf size were noted. Inflorescences will be quantified at the end of the year during the flowering season.

Figure 7: New buds (black arrow) were observed on several A. africanus individuals in plot 1a, where leachate (0.5:10 dilution) was added. All triplicate plots of 1a had plants in propagation.

4. Conclusions

The technique of vermicomposting using red wiggler worms (*Eisenia fetida*) is suitable for situations of reverse logistics, converting organic material into valuable byproducts that can be used for agriculture or garden soil recuperation and avoid its unnecessary release into the environment. In addition to municipal wastes, Varginha generates large amounts of agriculture (corn and coffee hulls) and livestock (manure) wastes that can be processed by vermicomposting to minimize inappropriate environmental releases and water pollution.

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