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Economic viability of the agricultural recycling of sewage sludge in Brazil

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The sewage sludge can be used for agricultural recycling as biosolids, since all the legal requirements are fulfilled, in plantations whose edible part does not have contact with the ground, thus its use is not allowed with the oleraceous, tubers, roots and flooded cultures. Considering that, from data collected by the Sanitation Company of Paraná (SANEPAR), the agronomic analysis reports of 10 lots of biosolids processed at Ouro Verde Sludge Management Unit, in the city of Foz do Iguaçu, Brazilian state of Paraná, were checked, relating the concentration of nutrients N, P, K, Ca and Mg. Assuming the biosolids are given to farmers, responsible for transportation costs, the material becomes attractive only when equivalent to mineral fertilizers cost. By determining the price of fertilizers by the lot of biosolids, the distance that justifies its utilization was established. The main results found allow the conclusion that biosolids have from R$30.83 to R$167.32 of fertilizers per ton, considering the worst and best case scenario, respectively. The compensatory distance has exceeded 1500 km, increasing the possible use by producers from other cities or states. The reduction of the humidity content in the material is directly proportional to economy granted to the producer.

Key words: Biosolids, fertilizer, cost.

INTRODUCTION

The investments in the sector of sanitation increased significantly, mainly after the announcement of the Plan of Growth Acceleration, which fulfilled the gap in the sanitary treatment in the Brazilian scenario. Data of the federal government show that in the year of 2012 the volume of sewage collected exceeded 5 trillion meter cube for the volume of sewage treated around 3.5 trillion meter cube, with the addition of 8.9 and 10.5%, respectively, compared to the year of 2011 (Brasil, 2014). Consequently, the concern about the residue generated by this process becomes significant, taking into account the environmental impact that can still be created, even

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with the proper destination. The agricultural use, the destination to places of residue elimination, the recuperation and restoration of blighted áreas, and the incineration, stand out among others (Fytili and Zabaniotou, 2008).

In general, in Brazil, the effluent treatment plants (ETEs) are designed to remove settleable solids and carbonaceous organic matter, with deficiency to remove the nitrogen and phosphorus, which cause the deterioration of the water resources and accelerators of eutrophication of the bodies of water which are recipient from the effluents (Lamego Neto and Costa, 2011).

The biosolids, originating from the sewage sludge, is the organic product of the sewage treatment system, rich in organic matter and nutrients, especially nitrogen and phosphorus, with agricultural potential for isolated use or in combination with mineral compost (Lemainski and Silva, 2006a). Thus, the agricultural recycling of biosolids is a viable alternative for the final destination, since besides the acknowledged presence of several nutrients in its composition; there is equivalence of performance when substituting the chemical fertilizers (Backes et al., 2009; Adair et al., 2014). Studies show that biossolid aplication on no-till dryland agroecosystem is an efficient method of recycling for this source of nutrients (Barbarick et al., 2012). However, the availability of potentially toxic metals, several times, restrains its use (Singh and Agrawal, 2008), when the limits required by law are not.

In a long-term study, the application of sewage sludge for agricultural lands changed the physical properties of the soil (Maria et al., 2010); the same happened on experiments in vases (Song and Lee, 2010). Besides, there are reports of increase of productivity from certain cultures, such as the sunflower, when used instead of the mineral fertilizer (Lamb et al., 2012; Figueiredo and Grassi Filho, 2007).

Teixeira et. al. (2005) estimated the average energy added to the nitrogen-based fertilizer at 59.46 $MJkg^{-1}$, for the phosphate at 11.96 $MJkg^{-1}$ and for the potassium at 5.89 $MJkg^{-1}$. This demonstrates that the acquisition of mineral or industrialized fertilizers, available at the market, is strongly dependent on fossil fuel. According to Pracucho et al. (2007), when the energy balance of corn plantation is analyzed, the part regarding the energy consumption of fertilizers stands out from the other variables.

The Brazilian regulation defines, through the Resolution number 375/2006 of the National Environmental Council (Conama, 2006), the criteria for the agricultural recycling of biosolids, considering the macronutrients and other variables of agronomic interest existent in each lot of the product. The document also defines the cultures able to use biosolids, whose edible part doesn't have contact with the soil, thus it is not allowed to be used with the oleraceous, tubers, roots and flooded cultures. In spite of that, some producers are still afraid of the use of biosolids in the food production. One alternative that eliminates the drawback in the possibility of food chain contamination is its use as indirect alternative energy, such as the energetic cultures, for the production of biogas, bioethanol and biodiesel, or in cultures of fibers as the combustion feedstock (Wang et al., 2008).

Independent on the culture that will be planted, the attractiveness for the rural producers opting for the biosolids is increased when the cost-effect relationship is considered favorable.

This way, this work aims to relate, from a historical series of data, the agronomic parameters of ten lots of biosolids processed in a Sludge Management Unit (UGL), determining the quantity and the correspondent price of nitrogen, phosphorus, potassium, calcium and magnesium inserted in the biosolids, as well as the distance of economic viability that justifies the substitution of chemical fertilizers by the use of biosolids, considering that the cargo dues will be paid by the farmer.

MATERIALS AND METHODS

The study was based on data from the Sludge Management Unit (UGL) Ouro Verde, located on Idalina Correa Gradela Street, no address number, in the city of Foz do Iguaçu, in the Brazilian State of Paraná, with geographic coordinates S 25°33'36" W 54° 34'48", kept by the Sanitation Company of Paraná (SANEPAR). The sludge processed is predominantly domestic, originating from the sewage treatment system in the region, which use the process of anaerobic digestion. The dewatering of the material was obtained through natural bed dryers; the sanitation was done through extended alkaline stabilization for 30 days, with addition of lime to 30% of the total solids according to procedures standardized by SANEPAR.

After the period of stabilization, the lots were sampled in order to characterize the agronomic features determined by Conama (2006). However, for the periods prior to 2006, there is not a standardization of methodology, due to the lack of regulation. In spite of that, the techniques used were considered adequate for the aimed study, since all the lots were allocated to agricultural recycling, with the authorization from the responsible environmental agencies.

From the analysis history, 10 (ten) lots were considered within the period from 2002 to 2012, from which the agronomic parameters of the biosolids on dry basis referred to the concentrations of nitrogen, phosphorus, potassium, calcium and magnesium.

For the data shown in this study, from the original reports of chemical characterization, it was performed the calculation adjustment of nitrogen available for the plants, considering the fraction of mineralization (FM) determined by Conama (2006). The other parameters, which refer to the the concentrations of phosphorus, potassium, calcium and magnesium, did not need calculation adjustment, taking into account the initial analysis' values. The Kolmogorov-Smirnov method was used for the normality statistical test.

From the concentration of nutrients contained in the biosolids, it was possible to establish the equivalence of chemical fertilizers NPK and of limestone, due to the presence of Ca and Mg, inserted individually in each lot, considering, at first, the dry basis, in order to establish the best and the worst case scenario.

Nevertheless, the influence of humidity in the lots of biosolids was considered, since it alters the concentration of nutrients, besides affecting directly the cost of transport and capability of cargo in the vehicle , regarding volume and mass. Hence, the

Table 1. Concentration of nitrogen, phosphorus, potassium, calcium and magnesium per lot of biosolids on dry basis (mg kg^{-1}).

Lot	Date	N	P	K	Ca	Mg
I	jul/02	1820	4400	450	63000	226700
II	apr/03	3000	2300	400	31030	48000
II	feb/05	3040	6900	626	77600	85100
IV	sep/05	2740	6900	2400	46000	2300
V	may/06	3420	2100	280	37241	1800
VI	mar/07	3220	7800	612	120700	1600
VII	mar/09	2432	5728	755	168600	4798
VIII	aug/10	4666	4526	410	161700	12075
IX	jul/11	8220	5298	940	168300	1450
X	apr/12	4873	2276	1600	72000	1250
Average		5048	4823	847	94617	38507

Source: report analyses SANEPAR (2002 - 2012).

concentration of nutrients in the lots of biosolids in the wet basis was recalculated, according to the indication of the samples collected, which is the valid condition for transport.

The costs were extracted from the site of the National Supply Company (Conab, 2013), regarding the average price of industrialized fertilizers charged within the period from November 2012 to October 2013, in the State of Paraná, namely: Ammonium nitrate, simple superphosphate and potassium chloride. Regarding the calcium content, under direct comparison, dolomite lime was chosen over the calcium lime, due to a bigger concentration of Mg, identified in the analysis of the biosolids.

Relating the values about the costs of chemical fertilizers by the concentration of nutrients contained in the lots analyzed, the costs of nutrients inserted in a ton of biosolids on dry basis were obtained.

Assuming that there are some advantages for the use by the farmer when the total value of the nutrients contained in a definite mass of the material is equal or above the cargo dues, the maximum efficient distance of transport of the sewage sludge was calculated according to the methodology presented by Silva et al. (2002), in Equation 1.

$$d \leq \frac{CN}{CT} \quad (1)$$

Where: d, distance in kilometers (km); CN, cost of nutrients inserted in 1 ton of biosolids (R$ t^{-1}); CT, cost of transport per ton - kilometer (R$ $t^{-1}km^{-1}$).

The CT was obtained in the System of Cargo Information (Sifreca, 2013), and the maximum distance with economic viability for the use of biosolids was determined, simulated for the scenarios of nutrient concentration in each lot.

RESULTS AND DISCUSSION

The concentration of nutrients for 10 lots of biosolids on dry basis is related on Table 1. The concentration of nitrogen was adjusted, from the original data, for the nitrogen available for the plants in the superficial application.

The data showed normality, as $p_{value} > 0.05$, for the Kolmogorov-Smirnov test. However, it is perceptible the large variability in the chemical composition among the lots of biosolids, meeting the data behavior from Martins et al. (2003), which reported difficulties conducting long term experiments. The same way, Silva et al. (2002), reported the occurrence of daily variations in the nutrient composition of the sludge. Thus, it was not possible to establish a tendency in the concentration of different nutrients of the biosolids. Other attributes must also be observed, as in other heavy metals and other composts, which also have variation in their concentration, due to the places, time and seasonality (García-Delgado et al., 2007). This way, it is necessary to adjust the calculation for the quantities of the material in every application, of the individualized evaluation per lot or according to the monitoring time based on the quantity of sludge processed at UGL, in order to elaborate the agronomic project, as defined by Conama (2006).

For Vesilind and Hsu (1997), the water in the sewage sludge can be presented in four ways: free, adsorbed, capillary and cellular. For the first form, the portion can be separated by simple gravity process. For the rest, there is a need of mechanical forces or a change in the physical state of water sample evaporation or freezing.

In the samples analyzed, the humidity to 0% occurred only under lab conditions, due to the greenhouse drying process for determining the dry mass. Under environmental conditions the data demonstrate great humidity variation in the sludge obtained after draining in natural bed. This implicates that for each ton of humid biosolids transported, from 122.20 to 461.40 kg of water are included. By contrast, the concentration of nutrients per ton of biosolids decreases, as observed on Table 2.

The cost of industrialized fertilizers according to Conab (2013), are shown on Table 3, with the adjustment for the nutrient content.

Relating Tables 2 and 3, the total cost of nutrients inserted in a ton of biosolids was obtained, under the conditions of dry and humid basis, resulting in Table 4.

Table 2. Concentration of nutrients NPK, Ca e Mg per ton biosolids on humid basis.

Lot	Humidity %	Biosolids dry basis (kg)	N (mg kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})
I	26.32	736.80	1341	3242	332	46418	167033
II	25.18	748.20	2245	1721	299	23217	35914
II	13.70	863.00	2624	5955	540	66969	73441
IV	21.60	784.00	2148	5410	1882	36064	1803
V	16.06	839.40	2871	1763	235	31260	1511
VI	23.80	762.00	2454	5944	466	91973	1219
VII	38.50	615.00	1496	3523	464	103689	2951
VIII	46.14	538.60	2513	2438	221	87092	6504
IX	32.46	675.40	5552	3578	635	113670	979
X	12.22	877.80	4278	1998	1404	63202	1097
Average	25.60	744.02	2752	3557	648	66355	29245

Table 3. Average cost of nutrient adjusted by R$ t^{-1} of nitrogenous, phosphate, potassic and dolomite lime, in the Brazilian State of Paraná, within November/2012 and October/2013.

Product	Average cost of product (R$ t^{-1})	Nutrient content (%)	Adjusted cost nutrient (R$ t^{-1})
Ammonium nitrate	1075.58	34.00	3163.47
Simple superphosphate	916.77	18.00	5093.18
Potassium chloride	1399.24	60.00	2332.06
Dolomitic limestone	111.37		
CaO		30.00	366.36
MgO		21.95	507.39

It is possible to observe that there are from R$ 30.83 to R$ 167.32 of nutrients inserted in a ton of biosolids, considering the worst and the best scenario, respectively. The difference on dry and humid basis was up to R$ 48.05, which demonstrates the considerable advantage in the reduction of humidity. Silva et al. (2002), says that one of the possibilities to increase the area range for the use of biosolids is to remove the excess of water.

According to Sifreca (2013), the average cost of national bulk cargo for the transport of fertilizers was R$ 0.1091 t^{-1} km^{-1}. Applying the Equation (1), the maximum distance of economic viability for the use of biosolids was simulated on Table 5.

The lower the water content is, the bigger the compensatory distance for the farmer to use biosolids, reaching 1521.12 km. Even for the worst case scenario, the distance was 280.24 km. The average distance was between 841.66 and 613.47 km, for dry and humid basis, respectively. The last column shows the proportion of increased attractiveness of the product distance for dry basis, which we can observe the significant difference for lot VIII.

As mentioned by Quintana et al. (2012), considering only the substitution of NPK, the added value to sewage sludge was R$ 102.47 per ton. For the distance of 25 km, the cargo cost R$ 11.84, almost 10 (ten) times less than the price of fertilizers, therefore, compensating. When compared to other possible destinations, the agricultural application of sewage sludge has the lowest cost (Lundin et al., 2004), which highlights the economic advantage of its utilization.

For Kimberley et al. (2004), the application of biosolids can increase significantly the economic benefit and compensate its transportation and application costs. It demonstrates that, the less distant from the UGL the rural property is, the bigger the profit for the farmer, who could use the resources which would be used to purchase industrialized fertilizers on other investments on their property.

Lemainski and Silva (2006b), in an experiment on the production of corn, biosolids were on average 21% more efficient than mineral fertilizers. Considering the transport distance of 100 km, the best cost-benefit ratio in productivity (1.90) was obtained with the application of 30 t ha^{-1} of humid biosolids.

The use of sewage sludge as fertilizer may be the best option from an economic and environmental point of view, it has the lowest cost for final disposal, allowing a

Table 4. Comparison of total cost of nutrients per ton of biosolids on dry and humid basis (R$ t^{-1}).

Lot	Dry basis	Humid basis	Difference
I	167.32	123.28	44.04
II	57.86	43.29	14.57
II	117.83	101.69	16.14
IV	67.43	52.86	14.56
V	36.72	30.83	5.90
VI	96.37	73.44	22.94
VII	102.83	63.24	39.59
VIII	104.14	56.09	48.05
IX	117.57	79.41	38.16
X	57.75	50.69	7.06
Average	92.58	67.48	25.10

Table 5. Maximum distance (km) of economic viability for the use of biosolids at UGL Ouro Verde.

Lot	Distance (km) dry basis	Distance (km) humid basis	Difference (%)
I	1521.12	1120.76	35.72
II	526.00	393.56	33.65
II	1071.17	924.42	15.87
IV	612.98	480.57	27.55
V	333.86	280.24	19.13
VI	876.11	667.59	31.23
VII	934.82	574.91	62.60
VIII	946.69	509.89	85.67
IX	1068.86	721.91	48.06
X	525.02	460.86	13.92
Average	841.66	613.47	37.20

reduction in the use of mineral fertilizers and recycling of organic matter, with essential nutrients to plants (Santos et al., 2011). This demonstrates its importance in agricultural recycling, especially when considering the scarcity of mineral resources in certain regions.

Conclusion

The biosolids processed at UGL Ouro Verde showed economic viability for agricultural use. In a ton of biosolids at UGL Ouro Verde there are from R$ 30.83 to R$ 167.32 of fertilizers, considering the worst and best case scenario, respectively, at a distance of viability that reaches 1500 km. This way, the use of biosolids is not restrained to rural producers close to the UGL, whereas it is also viable to make the material available to producers from other cities, and even other states, considering the geographic localization. The humidity content in the biosolids is directly proportional to the transportation cost for the producer. Thus, the economy generated is related to the decreased humidity, since this way more nutrients are transported. So, future studies about technology aimed at the reduction of humidity are advisable, from which it is possible to highlight the use of thermal energy from biogas produced in the sewage treatment plant.

Conflict of Interest

The authors have not declared any conflict of interest.

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REFERENCES

Adair KI, Wratten S, Barnes AM, Waterhouse BR, Smith M, Lear G, Weber P, Pizey M, Boyer S (2014). Effects of biosolidss on biodiesel crop yield and belowground communities. Ecol. Eng. 68:270-278.

Backes C, Büll LT, Godoy LJG, Bôas RLV, Lima CP, Pires EC (2009). Uso de lodo de esgoto na produção de tapetes de grama esmeralda. Cienc. Rural 39:1045-1050.

Barbarick KA, Ippolito JA, McDaniel J, Hansen NC, Peterson GA (2012). Biosolidss application to no-till dryland agroecosystems. Agric. Ecosyst. Environ. 150:72-81.

Brasil (2014). Diagnóstico dos Serviços de Água e Esgotos – 2012. Brasília, DF. SNSA/MCIDADES. Accessed November 16, available in: http://www.snis.gov.br/PaginaCarrega.php?EWRErterterTERTer=103

Conama – Conselho Nacional do Meio Ambiente (2006). Resolução n.º 375 de 29 de agosto de 2006. Diário Oficial da União, Brasília, 30 de agosto de 2006, 1:141-146.

Conab – Companhia Nacional de Abastecimento (2013). Consulta de preços – insumos agropecuários (2013). Accessed December 07, available in: http://consultaweb.conab.gov.br/consultas/consultaInsumo.do;jsessionid=A25DFCD3F711AF054FD7B36FFB33151E?method=acaoListarConsulta

Figueiredo TL, Grassi Filho H (2007). Níveis de lodo na produtividade de girassol. R.C. Suelo Nutr. Veg. 7(3):16-25.

Fytili D, Zabaniotou A. (2008). Utilization of sewage sludge in EU application of old and new methods - A review. Renew. Sust. Energ. Rev. 12:116-140.

García-Delgado M, Rodríguez-Cruz MS, Lorenzo LF, Arienzo M, Sánchez-Martín, MJ (2007). Seasonal and time variability of heavy metal content and of its chemical forms in sewage sludges from different wastewater treatment plants. Sci. Total Environ. 382(1):82-92.

Kimberley MO, Wang H, Wilks PJ, Fisher CR, Magesan GN (2004). Economic analysis of growth response from a pine plantation forest applied with biosolids. Forest Ecol. Manage. 189:345-351.

Lamb DT, Heading S, Bolan N, Naidu R (2012). Use of biosolids for phytocapping of landfill soil. Water Air Soil Poll. 223:2695-2705.

Lamego Neto LG, Costa RHR (2011). Tratamento de esgoto sanitário em reator híbrido em bateladas sequenciais: eficiência e estabilidade na remoção de matéria orgânica e nutrientes (N, P). Eng. Sanit. Ambient. 16(4):411-420.

Lemainski J, Silva JE da (2006a). Avaliação agronômica e econômica da aplicação de biossólido na produção de soja. Pesqui Agropecu Bras 41(10):1477-1484.

Lemainski J, Silva JE da (2006b). Utilização do biossólido da CAESB na produção de milho no Distrito Federal. Rev. Bras. Ciênc. Solo 30(4):741-750.

Lundin M, Olofsson M, Petterson GJ, Zetterlund H (2004). Environmental and economic assessment of sewage sludge handling options. Resour. Conserv. Recy. 41:255–278.

Maria IC de, Chiba MK, Costa A, Berton RS (2010). Sewage sludge application to agricultural land as soil physical conditioner. Rev. Bras. Ciênc. Solo 34(3):967-974.

Martins ALC, Bataglia OC, Camargo OA, Cantarella H (2003). Produção de grãos e absorção de Cu, Fe, Mn e Zn pelo milho em solo adubado com lodo de esgoto, com e sem calcário. Rev. Bras. Ciênc. Solo 27:563-574.

Pracucho TTGM, Esperancine MST, Bueno OC (2007). Análise energética e econômica da produção de milho (Zea mays) em sistema de plantio direto em propriedades familiares no município de Pratânia - SP. Energ. Agric. 22(2):94-109.

Quintana NRG, Bueno OC, Melo WJ (2012). Custo de transporte do lodo de esgoto para viabilidade no uso agrícola. Energ. Agric. 27(3):90-96.

Santos LM dos, Leite WC, Luz F de MM, Saab S da C (2011). Determinação do potencial agrícola do lodo de esgoto por meio de análises físico-químicas e microbiológicas. Synergismus scyentifica UTFPR 06(1).

Sifreca – Sistema de Informações de Fretes (2013). Anuário 2012. São Paulo, SP: USP, 2013. Available in: http://esalqlog.esalq.usp.br/files/biblioteca/606.pdf.

Silva JE, Resck DVS, Sharma RD (2002). Alternativa agronômica para o biossólido produzido no Distrito Federal. II - Aspectos qualitativos, econômicos e práticos de seu uso. Ver. Bras. Ciênc. Solo 26:497-503.

Singh RP, Agrawal M (2008). Potential benefits and risks of land application of sewage sludge. Waste Manage. 28:347–358.

Song U, Lee EJ (2010). Environmental and economical assessment of sewage sludge compost application on soil and plants in a landfill. Resour. Conserv. Recy. 54:1109-1116.

Teixeira CA, Lacerda Filho AF de, Pereira S, Souza LH de, Russo JR (2005). Balanço energético de uma cultura de tomate. Ver. Bras. Eng. Agríc. Ambient. 9(3):429-432.

Vesilind PA, Hsu CC (1997). Limits of sludge dewaterability. Water Sci. Technol. 36(11):87-91.

Wang H, Brown SL, Magesan GN, Slade AH, Quintern M, Clinton PW, Payn TW (2008). Technological options for the management of biosolidss. Environ. Sci. Pollut. R. 15:308-317.