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USE OF BREWERY WASTEWATER AND ITS EFFECTS ON SOIL PHYSICAL AND CHEMICAL PROPERTIES UNDER GREENHOUSE CONDITIONS

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Abstract: Brewing industry in Peru has increased markedly during the last eight years, subsequently increasing the production of solid and liquid organic wastes. Due to its organic nature, most of those wastes can be used in agriculture as sources of organic matter for soil. A pot experiment was set up to evaluate the effect of fractionated application of brewery wastewater (BW) at increasing levels (0.125, 0.25, 0.5 and 1.0 L kg^{-1}) on physical and chemical properties of two different-textured soils: Sandy Loam and Fine Sand, collected from the central coast of Peru. Pots were irrigated with BW was applied twice a week during eight weeks and then soils were incubated for two months. Soil pH, electrical conductivity, bulk density, water holding capacity and the contents of total and labile organic carbon, total nitrogen and lead were evaluated. Bulk density was not affected by BW application in any soil but water holding capacity was increased both in Sandy Loam and Fine Sand. Soil pH gradually decreased as the rate of application of BW increased but the electrical conductivity was not affected by application rate. Total organic carbon and total nitrogen contents in the Sandy Loam soil were significantly increased by the application of 0.5 and 1.0 L kg^{-1} while labile organic carbon was increased by 1.0 L kg^{-1}. In the Fine Sand the content of total organic carbon was significantly increased by the application of 0.5 and 1.0 L kg^{-1}. Total nitrogen and active organic carbon contents were increased by all rates higher than 0.125 L kg^{-1}. The relative increase in total carbon was higher for the Fine Sand than for the Sandy Loam. The application of BW did not affect Pb content on the soils. Our results showed that the use of brewery wastewater as organic source can be suitable for arid soils of the Peruvian coast.
Key words: Brewery wastewater, Soil organic carbon, Soil properties

1. INTRODUCTION

The production *per capita* of beer in Peru has increased from 20 L in 2000 to approximately 41 L in 2008 (La República, 2009). This fact has generated concern as brewing industries are characterized by high indices of water use and waste, and generate solid residues and effluents during different stages (Fillaudeau et al., 2006). Some effluents can be highly polluting as they may contain ethanol (Pant et al., 2007) and can not be directly discharged into rivers or land (Nandy et al., 2002) but they are also rich in organic carbon and contain variable levels of nitrogen, phosphorus, potassium and micronutrients (Mohana et al., 2009) and thus can become useful. Effluents from breweries and distilleries have been extensively tested as sources of organic matter for the soil and nutrients for crops (Ajmal and Khan, 1984; Pathak et al., 1999; Ramana et al., 2002a, 2002c; Hati et al., 2007) and as chemical amendments for sodium affected soils (Kaushik et al., 2005).

The application of effluents to the soil usually decreases bulk density and increases porosity and water holding capacity (Pathak et al., 1999; Hati et al., 2007). Effects on soil pH can vary from decrease (Ajmal and Khan, 1984) to slight increases (Hati et al., 2007). Several beneficial effects of the application of wastewaters and effluents have been reported, including significant increases in the contents of organic carbon (Pathak et al., 1999; Kaushik et al., 2005; Hati et al., 2007), available nitrogen, phosphorus (Ajmal and Khan, 1984) and potassium (Hati et al., 2007) in the soil. Increases in growth and yield have been reported for groundnut (Ramana et al., 2002a) and maize (Ramana et al., 2002c). On the other hand, continuous application of brewery and distillery effluents can increase soil electrical conductivity and the level of sodium (Pathak et al., 1999; Hati et al., 2007) and high rates of application have shown to affect seed germination in several crops (Ajmal and Khan, 1984; Ramana et al., 2002b).

As external experiences need to be validated under local conditions, a pot experiment was set to evaluate the quality of a brewery effluent as source of organic matter and nutrients for two soils from the arid coast of Peru.

2. MATERIAL AND METHODS

2.1. Wastewater and Soil Collection

The wastewater tested corresponded to an effluent generated at the fermentation tank bottom and was obtained from an industrial brewery situated in Lima, Peru. Some chemical characteristics of the effluent are shown in Table 1.

Two Entisols from the central coastal area of Peru: an alluvial pale brown soil (*Typic Ustifluvents*) and an eolic pale yellowish brown sand (*Typic Torripsamments*), were collected from the furrow slices (0 – 20 cm) of two close farms. After collection,

Table 1. Chemical characterization of the brewery effluent

pH	3.44 – 5.50
EC (dS m^{-1})	0.65 – 0.77
Total organic C (g L^{-1})	3.05
Total N (mg L^{-1})	280.0
Total P (mg L^{-1})	28.2
Total K (mg L^{-1})	80.8
Ca (mg L^{-1})	76.8
Mg (mg L^{-1})	18.4
Na (mg L^{-1})	32.4
Fe (mg L^{-1})	4.08
Pb (mg L^{-1})	0.52

the soils were air-dried, sieved through a 2 mm mesh, mixed thoroughly and sampled for chemical analysis (Table 2). Both soils were filled in plastic pots (4 kg pot^{-1}) and moistened to approximately 20% of soil volume.

2.2. Pot Experiment

Brewery effluent was applied at rates of 0.00, 0.125, 0.25, 0.50 and 1.00 L kg^{-1} of soil, equivalent to 0, 35, 70, 140 and 280 mg N kg^{-1} of soil. Wastewater application was divided in 16 portions (twice a week during eight weeks), and the application volume was uniformized with water avoiding percolation in the pots. After completing the applications, the pots were incubated in a greenhouse with no active climatic control. Air temperature ranged within 23 °C (day) to 17 °C (night). Pots were irrigated when needed with lead-free tap water.

2.3. Soils Analysis

After the incubation period, soil in the pots was sampled, air-dried, ground and sieved through a 2 mm mesh. Soil pH was measured in a 1:1 (soil: water) suspension (Thomas, 1996) and electrical conductivity (EC) in the saturated paste extract (Richards, 1954). The content of total organic carbon was measured by sulphuric acid-potassium dichromate digestion (method of Walkey and Black), and spectrocolorimetry (Nelson and Sommers, 1996). Active organic carbon was measured by potassium permanganate digestion (Blair et al., 1995) according to the method modified by Weil et al. (2003). Nitrogen content was analyzed by Kjeldahl method (Bremner, 1996). Total Pb was extracted by open vessel digestion in aqua regia and measured by atomic absorption spectrometry (Pansu and Gautheyrou, 2006).

After sampling, the pots were heavily irrigated and allowed to drain for 72 h. Soil bulk density and water holding capacity were measured by the methods of the cylinder and gravimetry, respectively.

2.4. Statistical Analysis

Treatments were distributed in a complete randomized design with ten replicates. The effects of brewery effluent on soil physical properties and on the contents of C, N and Pb were tested using analysis of variance, and the means were compared by using the Duncan's multiple range test ($p<0.05$). Data were analyzed using R software (R Development Core Team, 2009).

3. RESULTS AND DISCUSSION

3.1. Soil Physical and Chemical Characteristics

Initial bulk densities were similar between both experimental soils. The use of brewery effluent did not affect bulk density in the alluvial soil, but slightly increased that for the eolic sand (Table 3). The application of 0.5 L kg^{-1} resulted in a significant increase of sand bulk density compared with the control and with the dose of 0.125 L kg^{-1} ($p<0.05$), but was not different form the other doses. The increase of bulk density in the sand can be related with the presence of suspended silt-like silica particles in the brewery effluent (not shown in the analysis), which can partially occupy air pores resulting in reduced porosity. This effect was not observed in the alluvial soil, as most of suspended particles remained in the surface after brewery effluent application.

Brewery wastewater increased water holding capacity (WHC) in both soils. In the alluvial soil, WHC increases gradually as the dose of brewery effluent increased. The rate of 1.0 L kg^{-1} resulted in the highest WHC, but all rates between 0.25 and 1.0 L kg^{-1} were significantly higher than the control. In the eolic sand, all rates applied were similar and significantly higher than the control. The increase in WHC ranged from 23.6 to 33.9%.

The incubation period slightly increased the pH in the untreated soils. This effect can be related to the equilibrium within the soil solution and the exchangeable cations (Curtin y Smillie, 1995). Soil and sand pH were significantly reduced by the application of brewery effluent. In the alluvial soil, the rate of 1.0 L kg^{-1} resulted in significantly lower pH compared with the other treatments. Sand pH decreased gradually as the rate of application increased. All rates between 0.25 and 1.0 L kg^{-1} resulted in significantly lower pH than the control. The rate of 1.0 L kg^{-1} was lower than 0.5 L kg^{-1} and this was lower than 0.25 L kg^{-1}. Both soil and sand pH were similar when 1.0 L kg^{-1} was applied. The gradual decrease in soil pH using brewery effluent has been found previously (Ajmal and Khan, 1984; Kütük et al., 2003) and can be related to the production of organic acids due to the fermentation of sugars and the mineralization of N contained in the effluent (Erdem and Ok, 2002). Soil electrical conductivity (EC) was not significantly affected by the application of wastewater although slight decreases were appreciated in both soils.

3.2. Soil Carbon and Nitrogen Contents

The application of BW significantly increased the contents of total organic carbon, labile organic carbon and total nitrogen ($p<0.05$), both in the alluvial soil and in the eolic sand (Table 4). The relative increases were correlated with the amount of BW applied in both soils and were higher for sand due to the very low content of organic matter. The rates of 0.5 and 1.0 L kg^{-1} were significantly different than control for total organic carbon in both soils and for total nitrogen in the alluvial sandy loam. The rate of 1.0 L kg^{-1} was also different than control in this soil for labile carbon. Under the eolic sand, all rates within 0.25 to 1.0 L kg^{-1} were significantly different than control for the contents of labile carbon and total nitrogen. In the alluvial soil, the relative increases observed for total organic carbon were higher than those for labile carbon. The opposite was observed for the eolic sand, indicating that microbial activity was higher in the first, and sugars and other low molecular weight compounds were more easily metabolized in it.

Table 2. Physical and chemicals characteristics of soils used in the experiment

Characteristics	Alluvial soil	Eolic sand
Sand (%)	62	96
Silt (%)	30	2
Clay (%)	8	2
Texture class	Sandy Loam	Sand
pH	7.19	7.70
EC (dS m^{-1})	2.55	2.39
$CaCO_3$ (%)	2.40	2.28
Organic matter (%)	2.0	0.2
Total N (mg kg^{-1})	1200	100
Available P (mg kg^{-1})	1.0	0.3
Available K (mg kg^{-1})	326	131
CEC (cmol kg^{-1})	12.00	2.72
Exchangeable Ca	9.05	1.69
Exchangeable Mg	1.70	0.48
Exchangeable K	0.96	0.21
Exchangeable Na	0.29	0.34
Total Pb (mg kg^{-1})	102.87	4.60

3.3. Soil Lead Contents

The content of Pb in the soils was not affected by the application of the effluent tested (Table 4). The higher Pb content in the alluvial soil can be related to the higher contents of silt and clay and to the pollution associated to proximity to urban area of Lima. The contents of cadmium (Cd) and chromium (Cr) in the wastewater were below the detection limits of AAS, indicating low risk of heavy metals accumulation, although long-term monitoring is recommendable.

4. CONCLUSION

Application of brewery wastewater and solid residues generated by brewing industries to agricultural soils is not a common practice in Peru, but results shown in the present work indicate that continuous application of brewery wastewater can improve soil physical and chemical characteristics and increase the contents of organic carbon and nitrogen. Beneficial effects on soil quality are more evident in poorly developed soils sandy soils. The application of brewery wastewaters can supply nitrogen, phosphorus and other nutrients for crops, although mineralization could take some months to increase their availability for plants. The wastewater tested in this experiment showed low content of Pb, indicating that can be used for agriculture with low environmental risk although further research is required to evaluate the cumulative effects in long-term application experiments.

Table 3. Effect of application of brewery wastewater on physical and chemical characteristics of two soils

Application of BW (L kg^{-1})	BD (g cm^{-3})	WHC (%)	pH	EC (dS m^{-1})
		Soil		
0.00	1.48 a	19.69 c	7.66 a	3.47 a
0.125	1.46 a	21.58 bc	7.65 a	3.01 a
0.25	1.44 a	22.81 ab	7.60 a	2.78 a
0.50	1.46 a	23.06 ab	7.58 a	3.16 a
1.00	1.44 a	24.61 a	7.46 b	3.22 a
		Sand		
0.00	1.44 b	8.72 b	8.01 a	1.57 a
0.125	1.45 b	10.91 a	7.97 ab	1.26 ab
0.25	1.46 ab	10.78 a	7.85 b	1.04 b
0.50	1.49 a	11.18 a	7.61 c	1.16 ab
1.00	1.46 ab	11.67 a	7.46 d	1.07 b

Values are means of ten replicates; treatment means within a column followed by the same letter are not significantly different at $P<0.05$, according to Duncan's grouping. BD = bulk density, WHC = water holding capacity. EC = electrical conductivity

Table 4. Effect of application of brewery wastewater on the contents of total organic carbon, labile organic carbon, total nitrogen and lead of two soils

Application of BW (L kg^{-1})	Organic C Total (g kg^{-1})	Organic C Labile (mg kg^{-1})	N (mg kg^{-1})	Pb (mg kg^{-1})
	Soil			
0.00	11.25 c	504.44 b	1250.0 b	121.98 a
0.125	11.08 c	500.68 b	1225.0 b	119.35 a
0.25	11.95 bc	529.36 ab	1325.0 ab	124.87 a
0.50	12.73 ab	538.14 ab	1475.0 a	123.20 a
1.00	13.58 a	551.79 a	1500.0 a	126.44 a
	Sand			
0.00	1.35 c	24.07 d	100.0 c	4.40 a
0.125	1.75 bc	44.09 cd	125.0 c	5.07 a
0.25	1.83 bc	65.92 c	225.0 b	4.43 a
0.50	2.45ab	113.20 b	225.0 b	4.09 a
1.00	2.85 a	141.86 a	325.0 a	5.45 a

Values are means of ten replicates; treatment means within a column followed by the same letter are not significantly different at P<0.05, according to Duncan's grouping

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6. REFERENCES

Ajmal, M., Khan, A.U. 1984. Effects of brewery effluent on agricultural soil and crop plants. Environmental Pollution (Series A) 33: 341-351.

Blair, G.J., Lefroy, R., Whitbread, A., Blair, N., Conteh, A. 2001. The development of the $KMnO_4$ oxidation technique to determine labile carbon in soil and its use in a carbon management index, in: Lal, R. Kimble, J. Follet, R., Stewart, B. (Eds). Assessment Methods for Soil Carbon. Lewis Publishers, Boca Raton, FL. 323-337.

Curtin, D., Smillie, G.W. 1995. Effects of incubation and pH on soil solution and exchangeable cation ratios. Soil Sci. Soc. Am. J. 59: 1006–1011.

Erdem, N., Ok, S.S. 2002. Effect of brewery sludge amendments on some chemical properties of acid soil in pot experiments. Bioresource Technology 84: 271-273.

Fillaudeau, L., Blanpain-Avet, P., Daufin, G. 2006. Water, wastewater and waste management in brewing industries. Journal of Cleaner Production 14: 463-471.

Hati, K.M., Biswas, A.K., Bandyopadhyay, K.K., Misra, A.K. 2007. Soil properties and crop yields on a vertisol in India with application of distillery effluent. Soil and Tillage Research 92: 60-68.

Kaushik, A., Nisha, R., Jagjeeta, K., Kaushik, C.P. 2005. Impact of long and short term irrigation of a sodic soil with distillery effluent in combination with bioamendments. Bioresource Technology 96: 1860-1866.

Kütük, C., Çayci, G., Baran, A., Başkan, O., Hartmann, R., 2003. Effects of beer factory sludge on soil properties and growth of sugar beet (*Beta vulgaris saccharifera* L.). Bioresource Technology 90: 75–80.

La República. 2009. Consumo de cerveza se ha duplicado en últimos tres años. Section Economy. 19th January, 2009. On line edition: http://www.larepublica.pe.

Mohana, S., Acharya, B.K., Madamwar D. 2009. Distillery spent wash: Treatment technologies and potential applications. Journal of Hazardous Materials 163: 12–25.

Nandy, T., Shastry, S., Kaul, S. N. 2002. Wastewater management in a cane molasses distillery involving bioresource recovery. Journal of Environmental Management 65: 25-38

Nelson, D.W., Sommers, L.E. 1996. Total carbon, Organic Carbon and Organic Matter. In Methods of Soil Analysis. Part 3. Chemical Methods, 961-1009. Sparks, D.L., ed: SSSA – ASA.

Pansu, M., Gautheyrou, J. 2006. Handbook of soil analysis. Mineralogical, organic and inorganic methods. Springer-Verlag. Berlin. 993 pp.

Pant, D., Adholeya. A. 2007 Biological approaches for treatment of distillery wastewater. Bioresource Technology 98: 2321-2334.

Pathak, H., Joshi, H.C., Chaudhary, A., Kalra, N., Dwivedi, M.K., 1999. Soil amendment with distillery effluent for wheat and rice cultivation. Water, Air and Soil Pollution 113: 133–140.

R Development Core Team. 2009. A Language and Environment for Statistical Computing. Ver 2.9.2. Vienna, Austria. R Foundation for Statistical Computing.

Ramana, S., Biswas, A.K., Singh, A.B., Yadava, R.B.R. 2002a. Relative efficacy of different distillery effluents on growth, nitrogen fixation and yield of groundnut. Bioresource Technology 81: 117-121.

Ramana, S., Biswas, A.K., Kundu, S. Saha, R.B. Yadava, R.B.R. 2002b. Effect of distillery effluent on seed germination in some vegetable crops. Bioresource Technology 82: 273-275.

Ramana, S., Biswas, A.K., Singh A.B. 2002c. Effect of distillery effluents on some physiological aspects in maize. Bioresource Technology 84: 295-297.

Richards, L.A. 1954. Diagnosis and improvement of saline and alkali soils. USDA Agric. Handbook 60. Washington D. C.

Thomas, G.W. (1996) Soil pH and soil acidity, in: Sparks D.L. (Ed.), Methods of Soil Analysis, Part 3: Chemical Methods. ASA-SSSA, Madison, WI, USA, pp 475–490.

Weil, R.R., Islam, K.R., Stine, M.A., Gruver, J.B., Samson-Liebig, S.E. 2003. Estimating active carbon for soil quality assessment. A simplified method for laboratory and field use. American Journal of Alternative Agriculture 18: 3 – 17.