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Suitability of Treated Secondary Sewage Effluent for Irrigation of Horticultural Crops in Botswana

V.E. Emongor, E.B. Khonga, G.M. Ramolemana, K. Marumo, S. Machacha and T. Motsamai
Department of Crop Science and Production, Botswana College of Agriculture,
Private Bag, 0027, Gaborone, Botswana

Abstract: The objective of this study was to evaluate the suitability of treated secondary sewage effluent for irrigation of horticultural crops in Botswana. Secondary effluent water was sampled every month for one year, from a breather pipe on the pivot irrigation system at the Botswana College of Agriculture, Notwane Farm, Gaborone, using USEPA procedures and guidelines. The results of the study showed that the secondary sewage effluent from the activated sewage treatment plant in Gaborone had the following physico-chemical properties: Electrical Conductivity (EC) of 0.51 dS m^{-1}, pH 9.08, total dissolved solids of 358 mg L^{-1}, total alkalinity of 234 mg L^{-1} as $CaCO_3$, Cl^- 70 mg L^{-1}, NaCl 115 mg L^{-1}, Sodium Adsorption Ratio (SAR) of 2.26, NO_3^- 5.56 mg L^{-1}, NH_4^+ 0.3 mg L^{-1}, NO_2^- 0.0184 mg L^{-1}, total Fe 0.623 mg L^{-1} and faecal coliforms of 5/100 mL. The current results suggest that the Gaborone secondary sewage effluent is suitable for unrestricted irrigation of horticultural crops based on the EC, SAR, Cl^-, NaCl, faecal coliforms, available plant nutrients and the low concentration of heavy metals (Pb, Cr, Cu, Co, Cd, As and Se all present in parts per billion).

Key words: Secondary sewage effluent, SAR, EC, faecal coliforms, horticulture, Botswana

INTRODUCTION

Botswana's location in the sub-tropical high pressure belt of southern hemisphere in the interior of Southern Africa and away from oceanic influence, makes it to experience low rainfall and high temperatures in summer. There is high inter-annual variability of rainfall and drought is a recurring element of Botswana's climate. Drought adversely affects the already fragile food and agricultural situation in the country and seriously impairs the rural economy and socio-cultural structures. Due to the erratic, unreliable and poorly distributed rainfall, plus high temperatures, water becomes the most limiting factor to agricultural production in Botswana. Measures that can augment the available sources of water or measures that can reduce the demand on potable water should be given serious consideration. Using treated sewage effluent is a viable option for increasing horticultural production in Botswana.

In irrigated agriculture, the hazard of salt water is a constant threat. Poor quality irrigation water is of concern in arid climatic conditions. In Botswana, perhaps the most critical factor in predicting, managing and reducing salt-affected soils is the quality of irrigation water being used. Besides affecting crop yield and soil physical conditions, irrigation water quality affects fertility needs, irrigation system performance and longevity and how the water can be applied[1]. Therefore, knowledge of the quality of treated secondary sewage effluent would be of importance before it's used for irrigation in Botswana. The Botswana government is building several activated sewage treatment plants in major towns and municipalities. The treated secondary sewage effluents from these plants could be used for irrigation purposes, provided its quality is known. The Gaborone sewage treatment plant is the activated type, in which alternate aerobic and anaerobic cycles in an oxidation pond to oxidize organic matter, reduce nitrogen content and separate effluent from sludge and 21 days ponding in shallow ponds to permit partial UV disinfection. It has a capacity of 40,000 m^3 day^{-1}. The Gaborone sewage water is what drains from sinks, washing machines, bathtubs and toilets, combined with industrial wastewater. The objective of this study was to evaluate the quality of treated secondary sewage effluent from Gaborone sewage treatment plant to be used for irrigation water in order to improve horticultural crop production in Botswana.

MATERIALS AND METHODS

Secondary effluent water samples were collected every month for a period of 12 months from a breather

Corresponding Author: Dr. V.E. Emongor, Department of Crop Science and Production, Botswana College of Agriculture, Private Bag, 0027, Gaborone, Botswana E-mail: vemongor@temo.bca.bw or gramolem@temo.bca.bw

pipe on the central pivot irrigation system at Notwane Farm, Botswana College of Agriculture, using USEPA procedures and guidelines. The water samples were analysed for physico-chemical variables [pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), suspended solids, turbidity, alkalinity], anion and cation content.

The water samples used for analysis of physico-chemical properties had a temperature of 25°C. Water sample measurements were determined in triplicate. The water pH was measured using a pH meter (Hach, USA). The EC was measured using a conductivity meter (Hanna Instruments, USA). While the TDS was determined using TDS meter (Hanna instruments, USA). Suspended solids were determined using the photometric method[2]. Turbidity was determined using the absorptometric method[2]. Total and phenolphthalein alkalinity were determined using the buret titration method. A 50 mL water sample was transferred to a 250 mL Erlenmeyer flask. Six drops of 1% phenolphthalein indicator was added to the sample. Then the water sample was titrated using 0.02 N H_2SO_4 while swirling the flask until the solution changed colour from pink to colourless (pH 8.3). Thereafter, six drops of a mixture of 1% bromcresol green-methyl red indicator (1:1) were added to the titrated water sample. The mixture was swirled to mix. The mixture was then titrated with 0.02 N H_2SO_4 until a light pink colour developed. Then phenolphthalein and total alkalinity were calculated as mg L^{-1} $CaCO_3$[2].

The cations Na^+, K^+, Li^+, Ca^{2+} and Mg^{2+} were determined using undigested water samples. While the other cations were determined using digested water samples. The water samples were digested as follows. The samples were acidified with concentrated nitric acid (55%) at the time of collection by adding 5 mL of acid per litre of sample. Then 100 mL of well-mixed sample was transferred to 250 mL beaker. Then 5 mL of distilled water 1:1 hydrochloric acid was added. The samples were then heated in a water bath maintained at 80°C until the volume reduced to 20 mL. The samples were then filtered to remove any insoluble material. The sample pH was adjusted to a pH of 4 by adding 5.0 N NaOH a drop at a time while mixing and checking the pH after each drop of NaOH. Then the samples were quantitatively transferred to a 100 mL volumetric flasks and diluted with deionized water.

The alkali metals, Na, K and Li were determined using a flame photometer (Corning 410). While Ca and Mg were determined using flame atomic absorption spectrometer (GBC 908AA). The anions (NO_3^-, NO_2^-, NH_4^+, PO_4^-, SO_4^{2-}, Cl^-, F^-, Br^- and MnO_4^{2-}) and the trace elements (Al, Mn, Zn, Mo, Fe and P) were determined using a microprocessor-controlled, LED-sourced filter photometer (Hach DR/850, USA). The faecal coliforms were determined using the membrane (0.45 microns) filtration method on Hach's EC medium (44.5±0.2°C).

Data collected was subjected to analysis of variance using the general linear models (Proc GLM) procedure of the statistical analysis system program package. Proc Univariate procedure was carried out on residuals to support the assumptions of normality made by the researchers.

RESULTS AND DISCUSSION

Irrigated agriculture is dependent upon adequate good quality irrigation water. Poor quality irrigation water is of concern in semi-arid and arid conditions. The most important criteria for evaluating irrigation water quality are: salinity hazard (total amount of dissolved salts in the water), sodium hazard (the relative proportion of Na^+ to Ca^{2+} and Mg^{2+} ions), pH, alkalinity (total amount of carbonates and bicarbonates in the water), specific ions (Cl^-, SO_4^{2-}, NO_3^-, B), heavy metals and microbial contaminants.

The results of the current study showed that the treated secondary sewage effluent (water) had an average EC, TDS and Sodium Adsorption Ratio (SAR) of 0.51 dS m^{-1}, 357.5 mg L^{-1} and 2.26, respectively (Table 1). The EC, TDS and SAR values were all within the recommended limits by FAO and Botswana government guidelines for irrigation water quality. Classification of irrigation water quality based on EC, SAR and TDS, the water under study could be classified as class 2, which is good for irrigation[1,3]. The main effect of high EC and TDS water on crop productivity is the inability of the plant to compete with ions in the soil solution for water (physiological drought). The higher the EC and TDS, the less water is available to plants, even though a field may appear wet. Irrigation water with a high SAR value is detrimental to the soil physical properties. Calcium flocculates, while sodium disperses the soil particles. Dispersed soils crust and have poor infiltration and permeability. Classification of irrigation water based on SAR values, the Gaborone secondary effluent could be classified as low sodium hazard water since the SAR value is 2.26 which is within 1-9[1]. The mean sodium content in the Gaborone secondary sewage effluent is 55.52 mg L^{-1} (Table 1), which is within the recommended limits for irrigation water and sodium would not cause toxicity problems[1].

The pH, total alkalinity, CO_3^{2-}, HCO_3^-, Ca^{2+} and Mg^{2+} of the Gaborone secondary sewage effluent was 9.08, 234

Table 1: Properties of treated secondary effluent from Gaborone (Botswana) sewage treatment plant and irrigation water quality guidelines

Property (mg L^{-1})	Secondary effluent mean±SD[Y]	Botswana irrigation water quality	FAO[Z] irrigation water quality
PH	9.08± 0.19	6.5-9.0	6.5-8.4
EC (dSm^{-1})	0.51±0.06	<2.0	0.25-3.0
Turbidity (NTU)	48.11±35.8	-	-
Total dissolved solids	357.5±48.2	<2000	<2000
Suspended solids	56.0± 8.04	<100	<100
Faecal coliforms per 100 mL	4.67±4.11	<100	<100
Calcium	23.59±3.55	-	<400
Magnesium	13.41±4.61	-	<61
Sodium	55.52±9.30	<100	<460
SAR	2.26±0.82	<10	<9
Chlorides	70.0±5.5	<500	<350
Sodium chloride	115.0±9.08	<500	<500
Potassium	25.79±4.67	-	<2.0
Ammonium-N	0.3±0.02	<5.0	<5.0
Nitrate-N	5.56±2.87	<10.0	<10.0
Nitrite-N	0.0184±0.007	-	
Phosphate (PO_4^-)	8.12±1.64	-	<2.0
Orthophosphate (P_2O_5)	6.08±1.23	-	-
Total phosphorus	2.63±0.52	<1.5	-
Sulphate	26.0±3.0	<500	-
Fluoride	0.33±0.17	1.0-15	<1.0
Bromine	1.17±0.05	-	
Iron	0.623±0.29	5.0-20	<5.0
Molybdenum	0.044±0.005	<0.05	<0.01
Molybdate (MoO_4^{2-})	0.11±0.01	-	-
Manganese	0.28±0.16	<0.2	<0.2
Zinc	0.25±0.07	2.0-10	<2.0
Aluminum	0.073±0.006	<5.0	<5.0
Lithium	0.038±0.004	-	-
Total Alkalinity	234.0±62		-
Carbonate	128.0±84		-
Bicarbonate	105.0±21	<500	<610

[Y]SD Standard deviation, [Z]FAO Ayers and Westcot[1], Dash means no standard developed

as $CaCO_3$, 128, 105, 23.59 and 13.41 mg L^{-1} (Table 1), respectively. These water variables are all within the acceptable limits for irrigation quality. The medium alkalinity, CO_3^{2-} and HCO_3^- plus the relative high Ca^{2+} and Mg^{2+} ions in the water lowers the sodium hazard because calcium and magnesium will not all form insoluble minerals hence Na^+ ions will not be dominant in the soil solution. The desirable alkalinity in irrigation water should be between 40-100 mg L^{-1}[4,5]. Water pH determines if medium pH will change after planting or potting while water alkalinity determines how quickly media pH will change. Based on the Gaborone secondary effluent (water) pH and total alkalinity farmers should use acidifying fertilizers in order to lower the soil pH during production. The pH of 9.08 is partially contributed by the pH of Gaborone potable water (8.63), CO_3^{2-} and HCO_3^- levels in the water. However, the water pH is within the recommended limit of the Botswana guidelines for irrigation water.

The Cl^-, NaCl, SO_4^{2-}, PO_4^-, NO_3^-, NH_4^+, NO_2^- and K contents in the Gaborone secondary effluent was 70, 115, 26, 8.12, 5.56, 0.3, 0.0184 and 25.79 mg L^{-1}, respectively (Table 1) and are within the limits of Botswana and FAO guidelines for irrigation water with exception of K. The Cl^- and NaCl content was low and may not cause toxicity problems in most crops except in very sensitive crops when sprinkler irrigation is used. Chloride concentration of below 70 mg L^{-1} is considered safe for all plants[1]. The high PO_4^- and NO_3^- levels in the water may cause eutrophication of the Notwane river where the water is discharged. Nitrogen in irrigation water is largely a fertilizer issue. The nitrate ion was 18.5x higher in concentration than NH_4^+ ion in Gaborone secondary effluent. Water high in N (> 10 mg L^{-1}) can cause quality problems in some crops such as barley and sugar beet and excessive vegetative growth in some vegetables. However, these problems can be overcome by good fertilizer and irrigation management. Nitrate should be credited toward the fertilizer rate especially when the concentration exceeds 10 mg L^{-1}.The SO_4^{2-}, PO_4^-, NO_3^-, NH_4^+, NO_2^-, K, Zn, MoO_4^{2-}, Mn and Fe at the concentrations available in the water, makes Gaborone secondary sewage effluent a very good source of plant nutrients (fertilizer). Toxicity is not an issue with SO_4^{2-}, except at very high concentrations when SO_4^{2-} can interfere with uptake of other nutrients. The faecal coliform content in the Gaborone secondary sewage effluent was 5 colonies per 100 mL of water which is far below the recommended limit of 100 colonies per 100 mL of water by Botswana and FAO guidelines for irrigation water. In conclusion, the Gaborone treated secondary effluent is suitable for irrigation water purposes and can improve horticultural production in a semi-arid and arid country like Botswana.

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