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Minerals in Soils and Forages Irrigated with Secondary Treated Sewage Water in Sebele, Botswana

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Abstract: Production of forage using treated sewage water is a viable practice internationally. However, there is not much information on the heavy metal content of such forages. This study was conducted to determine the effect of sewage water on soils and forages irrigated with treated sewage water at Botswana College of Agriculture 's farm. The study was conducted for a period of 120 days using established forage pastures of rye grass (*Lolium multiflorum*) and lucerne (*Medicago sativa*). Heavy metals determined were Fe, Mn, Cu, Zn, Ni, Pb and Cd. Generally the treated sewage water contained relatively low levels of heavy metals. Zn, Ni and Mn concentration were below the detectable levels. In the sewage water while soils and plants had low levels of heavy metals. Comparatively the soil and plants heavy metal levels were much higher than those in the water and the difference was significant ($p<0.05$). There was some low correlation between trace element contents in the water and soil. In addition there was some significant difference ($p<0.05$) in heavy metal concentration in sewage water between the months during which the analyses were done. However, the sewage water, soils and forage mineral concentrations were within the internationally allowable heavy metal concentration with respect to irrigation, soil loadings and animal feeds.

Key words: Heavy metals, treated sewage water, forages

INTRODUCTION

Agriculture forms the basis of the rural economy in Botswana and a lot of Batswana still depend on it for subsistence. However, this sector's contribution to the Gross Domestic Product (GDP) has declined considerable from 40% before independence to only 4% today[1]. This poor performance is largely attributed to low and variable rainfall as well as the occurrence of successive droughts. This calls for exploitation of other means of water sources to sustain the sector as underground water from boreholes, damming of rivers and sewage water. The latter being the most sustainable as it minimizes the cost of procuring portable or fresh water for agricultural use. Concern for water quality denotes it's suitability and is related to it's effect on the soil and plants and the management that may be necessary to control or compensate for a water quality related problem is the most limiting factor in the use of sewage water for agricultural purposes. The principle for evaluating the quality of irrigation water deals with the total concentration and composition of soluble salts in water[2]. Soluble salts commonly found in sewage water may have an undesirable effect on the physical properties of the soil and may also be toxic to plants. Therefore, the use of sewage effluent as a water source in irrigation requires that its quality be assured, in terms of its possible effects on soils, plants, animals and human.

As Botswana's population grow and water usage also grows thereby generating huge volumes of effluent water, discarded as sewage water throughout the country. An average of approximately 20 million cubic meters of effluent is generated per annum and discarded in Gaborone alone as sewage[3]. The use of sewage water for irrigation is a positive way to dispose off sewage. Such huge volumes of water in a country with persistent droughts and unreliable rainfall can be of great agronomic and economic importance. Irrigation with sewage water can increase available water supply or release water for alternative use. The utilization of sewage water also contributes to cleaning of the environment, as the water is not discharged into water bodies that could otherwise get polluted. In addition to these direct economic benefits that conserve natural resources, this water contains a lot of nutrients and can serve as an alternative source to expensive chemical fertilizers. FAO[4] estimated that typical wastewater from domestic sources could supply all of the nitrogen and much of the phosphorus and potassium that are normally required for agricultural crop production. Additionally, micronutrients and organic matter from

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sewage water also provides additional benefits. There are many successful wastewater schemes throughout the world where nutrient recycling is a major benefit to the project[4]. In the United States of America and in Europe, sewage effluents have been applied to land for decades in selected sites. Some cities operate sewage farms on which they produce crops for animal feeds and forages, which offset part of the expense of effluent disposal[5]. In a carefully planned and managed effluent irrigation system, the combination of nutrient uptake by plants, adsorption of inorganic and organic constituents by soil colloids and degradation of organic compounds by soil micro organisms results in the purification of waste water. Percolation of the purified water eventually replenishes the ground water supply[5]. However, sewage water contains a wide spectrum of contaminants that are hazardous to the environment and human health. Contaminants of sewage water may be categorized into disease causing microorganism and toxic chemicals (heavy metals, pesticides residues). Pathogens in domestic wastewater are subject to adverse environmental condition once they are introduced into the soil and are not expected to survive for extended periods of time or, to multiply because they are unable to survive outside the host for lengthy periods. While the pathogenic organisms are undergoing the decaying process, the hygienic risk of wastewater in land application diminishes[6].

Concentrations of heavy metal contaminants in wastewater from different sources vary widely. They depend upon the chemical composition of the source of water, the storage and conveyance system before and after use and inputs associated with domestic and industrial use. Corrosion of waste storage and conveyance facilities, contaminants introduced through domestic inputs from consumer goods and foods as well as industrial input, all significantly contribute to heavy metal concentrations of wastewaters, which enter and leave treatment plants[7]. However, an effective primary-secondary treatment removes 85 to 90% of the major impurities in raw sewage. Metals such as cadmium, chromium, copper, mercury, lead and zinc can be reduced substantially, with percent reduction greater than 70%[8]. The magnitude of the bioavailability of the heavy metals and phytotoxicity depends on the interrelationships of a number of factors, such as the rate and frequency of application, soil characteristics and plant species[9]. However, additional plant and soil factors further modify the uptake and the concentration of elements in crops. The plant-soil system has three protective mechanisms that can limit the potentially toxic trace elements in the aerial portions of a plant and so minimize health problems to human or animals. The soil plant barrier, which includes elements that are insoluble in soil and do not accumulate in plants (Pb, Hg); elements that are absorbed into the root but are insoluble in the root or have limited translocation to shoot (Fe, Al and occasionally Hg and Pb) and elements which when applied in excess cause phytotoxicity (Zn, Cu, Ni, Co and Mn). The allowable levels of some metals in irrigation water by FAO[4], in soils and in animal feeds are used as controls or standards when using treated sewage water in irrigation.

Cadmium represents the livestock dietary poison of principal concern in relation to the utilization of sewage on agricultural land[11]. This is because Cd is readily bio-available for plant uptake in contaminated soils[11]. Cadmium can accumulate in the edible portions of crop plants to levels, which could be injurious to animals if consumed for long periods of time in large quantities, whilst having no apparent detrimental effects on crops themselves[11]. Pb is of concern, principally due to its potential zootoxic effects[11]. However, this element is held tightly in soils and there is generally no direct relationship between the amounts in soil and concentrations in crops[12]. Vigerast and Selmer-Olsen[13] summarized 117 sludge trials which showed no crop uptake of this element. Most field experiments have failed to demonstrate any significant increase in the Pb content in the food chain[14]. Chumbley and Unwin[15] found no correlation between soil and plant concentration of Pb for commercially grown crops taken from fields with long histories of sludge spreading and containing up to 496 mg Pb kg^{-1} in soil. In contrast, investigation on urban soils contaminated with lead arising from aerial deposition, probably originating from domestic chimney ash and smoke, industrial emissions, vehicle exhaust have shown some relationship may exist between soil and plant levels of Pb[16].

The use of sewage water for irrigation is becoming common around urban centres in Botswana. Sewage water quality is a concern as it contains a wide spectrum of contaminants that may be hazardous to the environment, animals and human health depending on its treatment. Therefore, the use of sewage effluent as a water source in irrigation requires that its quality be assured, in terms of its possible effects on soils, plants, animals and human. Presently, the knowledge about the actual environmental and health risks of irrigating with sewage water in Botswana is limited. Therefore, this study will determine heavy metal contamination in forage produced through irrigating with sewage water. The objective of the study was to determine heavy metal contents of soils and forages in this case, grass (ryegrass) and leguminous forage (lucerne) irrigated with sewage water.

MATERIALS AND METHODS

The study was conducted at the Botswana College of Agriculture farm in Sebele. The samples of forages collected and analyzed for heavy metals were ryegrass (*Lolium multiflorum*) and lucerne (*Medicago sativa*), soils and irrigation water (treated sewage water). Minerals determined were Fe, Cu, Pb, Zn, Cd, Mn and Ni. Soil and forage samples were collected under the boom (irrigated land) while water samples was collected from the pivot sprinkler. The fields sampled for soils and forage are approximately 6 and 2 ha for lucerne and ryegrass, respectively. Forage, soil and water sampling was conducted every two weeks during the months of September, October, November and December in 2003.

Sampling: The transect method was adopted for soil and forage sampling. The transect accounts for the possibility of large variability in soils that may be encountered. This helped to collect samples that represent the whole forage fields. The lucerne (*Medicago sativa*) field was divided into two areas of 3 ha for sampling purposes while the ryegrass (*Lolium multiflorum*) field, was treated as one field[17]. The lucerne field was divided according to uniformity with respect to soil colour, texture and slope. Soil and plant samples were collected at predetermined intervals of 20 paces along transects on the area demarcated by means of a 25x25 cm quadrate and the sample consisted of 20 sub samples per field.

The soil samples were collected at 20 cm depth using an auger in the center of the quadrate after clipping off forage samples[18]. The primary interest was to assess the accumulation of metals in the root zone of plants. The soil samples were thoroughly mixed, breaking up all lumps or clods to make composite samples for each crop field before analysis. Thus two composite samples were collected for laboratory analysis from the Lucerne field and one from the ryegrass field. The forage samples were also taken at regular intervals of 20 paces and were clipped at mowing height and sampling was restricted to the marked transect. Samples were obtained from each field in four replicates then analyzed for heavy metals.

Laboratory analysis

Soils: The soil samples were air-dried, mixed and passed through a 2 mm mesh stainless steel sieve before analysis. Soil samples were analyzed for pH using a Soil: $CaCl_2$ suspension and organic carbon by the Walkley-Black Procedure[19]. A 1:2 soil/solution ratio was used to extract available heavy metals, Zn, Fe, Cu, Mn, Pb, Cd and Ni. The DTPA solution contained 0.005 M DTPA, 0.01 M $CaCl_2$ and 0.1 M TEA adjusted to pH 7.3[20] and analyzed by Atomic Absorption Spectrophotometry (AAS) except graphite furnace that was used to analyze Cd and Pb.

Forage: Forage samples were oven dried at 60°C for 72 h, ground in stainless steel mill and stored in plastic vials prior to analysis. Mineral levels in forage tissue (Fe, Cu, Pb, Zn, Cd, Mn and Ni) were determined by H_2SO_4 and H_2O_2 wet digestion procedure[21]. Fe, Cu, Zn, Mn and Ni were analyzed by Atomic Absorption Spectrophotometry (AAS) while graphite furnace was used for Cd and Pb.

Sewage water: The water samples were filtered through a 0.45 mm membrane to remove suspended solids. The minerals in water were analyzed according to the American Public Health Association, 1976 modified by Lewis[22]. Atomic Absorption Spectrometry (AAS) was used to determine heavy metal levels in sewage water, while graphite furnace was used for Cd and Pb.

Data analysis: Heavy metal concentrations in the plants, water and soil samples were subjected to analysis of variance (ANOVA). Correlation analysis of metal concentration between water and soils, soils and plants and water and plants was determined. A significance level of 0.05 was set[23].

RESULTS

Treated sewage water: The results showed that the water contained Fe, Cu, Zn, Pb and Cd. The concentration of Mn and Ni were below levels detected by the Atomic Absorption Spectrophotometer (AAS) procedure. There was no variation in heavy metal concentration with months except for Fe increased with respect to months (Table 2). The decline was significantly different at $p<0.05$ and similarly the increase in Fe were significantly different at $p<0.05$. The mineral concentrations were within the typical and allowable concentrations required for irrigation water compared to levels in Table 1.

Table 1: Typical and allowable levels of some heavy metals for irrigation water, soil and in animal feeds

Elements	Fe	Mn	Zn	Cu	Cd	Pb
Recommended maximum concentration for Irrigation ($mg\ L^{-1}$) in water	5.00	0.20	2.00	0.20	0.01	5.00
Maximum allowable concentration (ppm) in soil	1500	600	1500	775	20	20
Typical concentration (ppm) in soil	0.01-21000	1-18300	10-300	2-250	0.01-24	2-300
Toxicity level ($mg\ kg^{-1}$) in animal feeds	1000	1000	1000	40	10	40

Source: FAO[10]

Table 2: Mean±SEM mineral composition (ppm) of treated sewage water

Months	Fe	Cu	Pb	Cd
September	0.163±0.084*	0.045±0.004	0.011±0.0006	0.006±0.0008
October	0.170±0.084	0.042±0.004	0.007±0.0006	0.008±0.0008
November	0.490±0.084	0.043±0.004	0.010±0.0006	0.008±0.0008
December	0.620±0.084	0.055±0.004	0.008±0.0006	0.001±0.0008

Mean followed by the (*) within a column are significantly different at $p<0.05$

Table 3: Mean±SEM mineral concentration in the soils of the ryegrass and lucerne fields

		Mineral concentration in ppm (mg kg^{-1})						
Months		Mn	Fe	Cu	Zn	Ni	Pb	Cd
September	Rye field	11.344	4.471	0.120	0.367	0.293	0.180	0.030
	Lucerne field	12.019	5.127	0.216	0.233	0.280	0.260	0.035
October	Rye field	11.344	4.471	0.120	0.367	0.293	0.180	0.030
	Lucerne field	12.019	5.127	0.216	0.233	0.280	0.260	0.035
November	Rye field	12.442	5.896	0.109	0.188	0.203	0.244	0.040
	Lucerne field	10.849	6.149	1.163	0.206	0.206	0.244	0.040
December	Rye field	13.037	2.929	0.112	0.291	0.325	0.330	0.035
	Lucerne field	9.7465	3.498	0.180	0.333	0.241	0.366	0.040
SEM	Rye field	0.2053	0.0506	0.0014	0.0207	0.0164	0.0134	0.0014
	Lucerne field	1.139	0.7228	0.5024	0.0239	0.0222	0.0522	0.0020

Table 4: Mean±SME of mineral concentration in ryegrass and lucerne

	Mineral concentration in ppm							
Months	Forage	Mn	Fe	Cu	Zn	Ni	Pb	Cd
September	Ryegrass	75.64	411.67	16.75	38.43	0.755	1.66	0.103
	Lucerne	46.54	368.50*	12.35	47.50*	0.66	1.680	0.115
October	Ryegrass	83.54	385.86	13.21	45.23	0.645	1.430	0.105
	Lucerne	38.64	348.02*	9.86	49.09*	0.64	1.530	0.045
November	Ryegrass	106.78	484.48	11.30	39.59	0.695	1.415	0.115
	Lucerne	53.38	370.82*	15.24	44.72*	0.68	1.250	0.115
December	Ryegrass	81.02	258.25	7.18	41.13	0.725	1.469	0.146
	Lucerne	50.65	358.58*	11.09	47.80*	0.69	1.644	0.388
SEM	Ryegrass	1.569	15.271	0.832	4.711	0.011	0.101	0.040
	Lucerne	4.067	17.743	0.557	3.249	0.029	0.111	0.0129

Means followed by (*) within a column are significantly different at $p<0.05$

Soils: Soil analysis (Table 3) exhibited relatively high levels of heavy metals compared to the treated sewage water (Table 2). There were no significant differences observed with respect to soil concentration with months. Nevertheless, the levels were within the typical and allowable levels in soil as shown in Table 1.

Forage: The results showed that both forages contained some heavy metals including non-essential trace elements such as Pb and Cd. There were some significant differences ($p<0.05$) in concentrations of most constituents determined for lucerne and rye grass except for Cu (Table 4).

Seasonal variations in heavy metal concentration (wet and dry season): In this study the months of September and October were treated as the dry season while November and December were treated as the wet season. Some variation in heavy metals detected in water, soils and forages as a result of fluctuations between dry and wet seasons. Comparatively high concentrations of heavy metals were detected in the dry season than the wet season. In water some fluctuations were observed in Fe and Zn concentrations. Fe increased from 0.167 to 0.560 ppm, while Zn was not detected during the wet season. Similarly some fluctuations were observed in the soils, in which there was some significant difference between seasons in Mn, Zn, Cu and Cd for the rye field and Cd for the lucerne field . The Mn and Cu increased while the concentration of Zn and Cd decreased. This was also the case with Cd in the lucerne field. Seasonal variations in heavy metal content in the rye, with mean fluctuations of Mn ranging from 76.40 in the dry season to 106.78 ppm in the wet season. In contrast Cu decreased significantly from 16.75 to 7.18 ppm in the wet season. Lucerne seasonal contrast showed some significant variation in some heavy metal concentrations. The heavy metals involved include Mn, Cu, Pb and Cd. Like in the ryegrass, Mn concentration increased significantly in the wet season while Cu, Pb and Cd decreased during the wet season Correlations between the irrigation water, soil and forages (lucerne and ryegrass). The correlation between most elements in water and in the soil was very low (Table 5). Therefore, there was no multi co linearity effect.

Table 5: Correlation coefficients of sewage water and soils

	Fe in water	Cu in water	Pb in water	Cd in water
Fe soils	-0.0893 (L) -0.19289 (R)			
Cu soils		0.1515 (L) -0.3465 (R)		
Pb soils			-0.4885 (L) (P=0.0549) -0.31424 (R)	
Cd soils				-0.1444 (L) -0.00923 (R)

DISCUSSION

Treated sewage water: The data (Table 2) showed that the water contained some heavy metals of concern especially Pb and Cd. The results further indicated that the heavy metal concentrations were low, thus they were within the acceptable levels of irrigation water (Table 1). Some fluctuations in water were observed for Fe and Zn concentrations. The low levels may imply that the sewage was not heavily contaminated as inputs in the sewage are introduced through domestic inputs from consumer goods and foods as well as industrial input that enter and leave the treatment plants. These results agree with the findings of Chang[6], in which they concluded that metals such as Cd, Cu, Pb and Zn are removed substantially, during treatment to percentage reduction greater than 70%. D'ltril *et al.*[7] also observed that, an effective primary-secondary treatment removes 85 to 90% of the major impurities in raw sewage water. Similarly, Strauss[24] reported that the major portions of toxic chemicals are removed from the liquid fraction during treatment, adsorbing on particular matter and ending up in sludge hence only traces of chemicals being found in wastewater.

Soils: Soil analysis exhibited relatively high levels of heavy metals compared to the treated sewage water (Table 3) this might be due to accumulation of mineral elements in the soils since the plants can not absorb some of the elements due to the soil plant barrier, which includes elements that are insoluble in soil and do not accumulate in plants (Pb, Hg); elements that are absorbed into the root but are insoluble in the root or have limited translocation to shoot (Fe, Al and occasionally Hg and Pb) . Nevertheless, the levels were within the typical and allowable levels in soil as shown in Table 1. There were no significant differences observed with respect to soil concentration with months. Some variation in trace elements detected in soils as a result of fluctuations between dry and wet seasons. Comparatively high concentrations of trace elements were detected in the dry season than the wet season. Some fluctuations were observed in the soils, in which there was some significant difference between seasons in Mn, Zn, Cu and Cd for the Rye field and Cd for the lucerne field. Cadmium is a potentially toxic heavy metal with no known benefit to animals. Plants are the predominant sources of Cd in animal and human diets. The Mn and Cu increased while the concentration of Zn and Cd decreased. This was also the case with Cd in the Lucerne field. This might be attributed to leaching and uptake of the heavy metals by plants. There were no correlations between the soil heavy metal loadings and water heavy metal loadings (Table 5). However, the water loadings might have contributed significantly to the soil trace element concentrations because frequent application of contaminated water may result in trace element accumulation in the soil because unlike organic compounds, they are not bio-transformed and hence persist in the environment resulting in biomagnifications as observed by Siebe[25]. Berti and Jacobs[9] also reported Pb, Cd, Cu, and Zn to have a tendency of accumulating in the upper layers of the soil. Soil is the principal source of Cd accumulated by plants. The availability of Cd in soil is related to the soil characteristics that affect the availability of most trace metals.

Forage plants: There were no significant differences ($p<0.05$) in concentrations of most constituents determined for lucerne and ryegrass except for Fe, Pb and Cd. In this case Lucerne having the highest loadings of both minerals except for Fe, which was high in ryegrass. This indicated that lucerne has a relatively high capacity to accumulate the heavy metals. This might be attributed to the fact that the crop is a perennial crop hence high accumulation since the Lucerne pastures at the BCA farm was established since 2001. The findings are in line with the results of Hillel *et al.*[2] and Ibekwe *et al.*[26] in which they observed that Lucerne tend to greatly accumulate heavy metals above allowable standards if irrigation water is contaminated. The marginal significant difference in heavy metal concentrations implies that heavy metal accumulation does not vary with length of plant in the field, as lucerne is a perennial crop while rye is an annual. This might be the case because lucerne, which is a perennial crop, is mowed every two months persistently hence new shoots behave like annual plants (rye) in terms of heavy metal accumulation.

The forage tissue analysis revealed high loadings of heavy metal compared to the soil samples. The results further revealed some correlation in heavy metal concentration in forage with that in the soil. This implies that heavy metal loadings in the soil influenced the levels of mineral concentration in plants. This is possible because heavy metals have a tendency to accumulate in the upper layers of the soil, which increase their environmental availability for plant uptake. Berti and Jacobs[9] reported the same when studying the chemistry and phytotoxicity of soil trace elements from repeated sewage sludge application. In addition the soil pH was slightly acidic (between 6 and 7) which according to Brady and Weil[5] is desirable for most plants because this pH conditions allows micronutrient cation to be soluble enough to satisfy plant needs without becoming so soluble as to be toxic.

It is apparent that for optimum growth and performance, living organisms need to be provided with essential mineral elements in their rations. In this case the plants studied contained most of the trace elements required to fulfill essential functions of living organisms. D'ltril *et al.*[7] reported that living organisms require trace amounts of Cu, Fe, Mn and Zn to fulfill their essential functions. The concentrations of minerals detected in rye and lucerne are adequate to fulfill those essential needs. However, non-essential heavy metals of concern, Cd and Pb were also detected in the forages. These minerals have been identified as non-essential elements of concern in the food chains by Kennish[27]. Increased concentrations of these heavy metals in the food chain over a long period of time can provoke detectable damage to health (carcinogenic and mutagenic effects). The loadings of the minerals (Pb and Cd) in the forages were within the range classified as one, which will not eventually give rise to toxicosis in livestock (Table 1). The mineral contents of Pb and Cd are relatively low to have any significant effect on livestock at the moment. However, ingested Pb regardless of concentration is stored in the bones where they would ultimately accumulate to toxic levels.

The study revealed that Cd, Pb, Cu and Fe are currently low in the irrigation water, while Ni and Mn, concentration were too low to be detected. Similarly the heavy metal concentrations were relatively low in the soil and plants evaluated. Thus the heavy metal loadings were within the acceptable concentration. There was some marginal variation in the heavy metal concentration between the annual plant (ryegrass) and the perennial legume (lucerne) and some relatively high proportion of heavy metals were detected in lucerne than ryegrass. There was no correlation between heavy metal concentration in water and soil, in both fields. Therefore, there is no multi-co linearity effect. Heavy metal concentrations were relatively low in forages, thus, cannot pose any toxicosis in animals.

Recommendations: Continuous monitoring of the water, soil and plants for heavy metal accumulation is necessary because trace elements are not biotransformed and has a tendency to accumulate on the soil surface hence their availability for uptake by plants.

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