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Use of Secondary Effluent in Food Production in Botswana

V.E. Emongor
Department of Crop Science and Production,
Botswana College of Agriculture, Private Bag, 0027, Gaborone, Botswana

Abstract: The use of secondary effluent for irrigated agriculture offers an opportunity to conserve limited water resources and increase food production in Botswana. Effluent irrigation is a means of ecological waste water management and it's a resource of economic development. The secondary effluent contains both macro-and micro-nutrients needed for crop growth and development. The secondary effluent contains phosphorus and nitrogen which are responsible for eutrophication of rivers and other water bodies where the effluent is discharged. The sludge that results from municipal waste water treatment processes contains organic matter and nutrients that, when properly treated, composted and applied to farmland, can improve the physical properties and agricultural productivity of soils and its agricultural use provides an alternative to disposal options, such as incineration, or landfilling. For the safety of food products and the sustainability of agricultural land, the use of waste water treatment technology that destroys all pathogens and toxic chemicals in raw municipal waste water and stringent waste water discharge requirements are important. The sewage sludge must be treated to levels that allow it to be reused. In order to minimize the potential health and environmental consequences in the use of secondary sewage effluent and sludge, the quality of the effluent for irrigation and treated composted sludge has to be monitored continuously to meet the specific set standards for the particular purpose. This study discusses the uses of secondary effluent, health-risks, reuse standards, irrigation suitability and management guidelines in the use of secondary effluent for irrigation.

Key words: Secondary effluent, crop production, health, environmental safety, management guidelines

INTRODUCTION

In many arid and semi-arid regions of the world (such as Botswana) water is a limiting factor, especially for agricultural and industrial development. Water resources planners are continually looking for additional sources of water to supplement the limited resources available to their region. In Botswana, the annual precipitation ranges between 200-650 mm. The evapotranspiration rate is 1800-2000 mm per year. While the mean annual underground water recharge is 3 mm per year. The country relies on a few perennial rivers and a few underground aquifers. Water resources are being exploited at increasing distances from centres of demand, at increasing cost. More than 60% of the food demand is satisfied by importation. In such situations, source substitution is the most suitable alternative to satisfy less restrictive uses, thus allowing high quality water to be used for domestic supply[1]. Low quality water such as waste water, secondary sewage effluent, drainage water and brackish water, should be considered as alternative sources of water for less restrictive uses such as irrigation, air-conditioning and cooling, industrial processing, toilet-flushing, vehicle washing and construction.

Irrigation with secondary effluent has been practiced for centuries throughout the world[2]. It provides farmers with a nutrient enriched water supply and society with a reliable and inexpensive system for waste water management and disposal[3,4]. It has been estimated that typical waste water effluent from domestic sources could supply all of the nitrogen and much of the phosphorus and potassium needed for agricultural crop production[5]. Irrigation with secondary effluent can increase the available water supply or release better quality supplies for alternative uses. Forage crops have been grown under sewage effluent irrigation because of their long growing season, high evapotranspiration demand and removal of large quantities of nutrients from the biosystem[6]. The other reason why forages were grown under sewage effluent is that forages are not consumed directly by humans, the transfer of human diseases is unlikely[7]. Pathogens in domestic waste waters are subjected to an adverse environmental condition once they are introduced into the soil[8]. They are not expected to survive for extended periods of time or to multiply. While the pathogenic organisms undergo the decaying process, the hygienic risk of waste water land application diminishes[8].

Many trace elements are micronutrients essential for the growth of animals and plants. Several trace elements have no well known physiological functions[8]. At high concentrations all trace metals, regardless of whether they are essential or non-essential, become toxic to animals and man. Unlike pathogens whose transmission relies entirely on direct contact, trace elements introduced into soil may be translocated into plant tissue through absorption from soil by plant roots. Through land application of waste water, the input of trace metals to soil is not likely to result in any immediate and acute toxicity. However, excessive accumulation of certain trace elements such as lead, cadmium, mercury, arsenic and selenium in plants, can expose consumers to potentially hazardous levels of trace metals. There is also a possibility of long-term build up of trace elements with long-term application of waste water into soils leading to phytotoxicity. However, with the recent advances in waste water treatment technology and stringent waste water discharge requirements, it is possible to produce effluent of high quality suitable for irrigation. The Gaborone activated sludge treatment plant so far produces secondary sewage effluent suitable for irrigation because it is low in heavy metals, faecal and total coliforms and meets the requirements for irrigation water quality[4].

In the next 20 years the demand for domestic water use may double due to increasing population in Botswana. Therefore, the need for controlled use of treated secondary sewage effluent for crop production will increase because of consumer health protection, scarcity of alternative water supplies, need to increase local food production and need to improve rural health standards. The objective of this study was to review the literature and other information sources to determine secondary effluent irrigation standards used in other parts of the world.

LITERATURE REVIEW

Health risks: There are many successful waste water use schemes throughout the world where nutrient recycling is a major benefit to the project[5,9]. However, the primary constraint to any use of waste water is public health. Domestic waste water contains pathogens that can cause disease spread when not managed and treated properly. The health risks from the use of waste water can include the spread of infectious diseases by bacteria (typhoid fever, dysentery, tetanus, cholera, salmonellosis, gastroenteritis, yersiniosis, leptospirosis and legionnaire's disease), virus infection (meningitis, hepatitis, respiratory diseases, eye infections, gastroenteritis, diarrhoea, vomiting and fever), worm infection (ascariasis, ancylostomiasis, necatoriasis, cutaneous larva migrams, stronglyoidiasis, trichuriasis, taeniasis, enterobiasis and hydatidosis), protozoa (ameabic dysentery, giardiasis, balantisiasis dysentery, cryptosporidiosis, diarrhoea and fever) and other diseases. Health guidelines for irrigation with treated waste water developed in California indicated that for agricultural reuse of effluent waters on food crops, waste water must be disinfected, oxidized, coagulated, clarified and filtered[10]. Total coliform count should not exceed a median value of 2.2/100 mL or a single sample value of 25/100 mL. Total coliforms must be monitored daily. Turbidity should not exceed 2 NTU (nephelometric turbidity units) and must be monitored continuously. Less restrictive guidelines were developed and adopted by most of the international agencies, indicate that the effluent water reuse was relatively safe to use if it contained less than 1 helminth egg per litre and less than 1000 faecal coliforms/100 mL[2].

Analyses of secondary effluent from Gaborone activated sludge treatment works for faecal and total coliforms ranged between 5-30 colonies per 100 mL[4], indicated that waste water to be safe for crop irrigation according to the existing health guidelines[2,10,11]. Field and laboratory studies indicated that faecal bacteria is susceptible to pressure and is killed by rapid pressure changes normally occurring during effluent pumping and spraying[6]. Those bacteria surviving the application are sensitive to ultra-violet rays from bright sunlight, high summer temperatures and to desiccation from windy hot weather. These conditions are prevalent in Botswana. Complete elimination of pathogenic bacteria can be achieved with 30 to 40 days retention time in maturation ponds, particularly a high temperature (> 25°C). In Botswana where summer temperatures are normally above 30°C, with a RH humidity of less than 30% and hot windy conditions, elimination of pathogenic bacteria in the maturation ponds can be achieved in less than 30 days.

Bacteria: The survival time of bacterias in surface soil and on plants is only of concern when decisions must be made on how long a period of time must be allowed after last application before permitting access to people or animals, or harvesting crops. The factors that affect bacterial survival in soil[12-16] are: 1) Moisture content. Moist soils and periods of high rainfall increase survival time of bacteria. This has been demonstrated for *Escherichia coli*, *Salmonela typhi* and *Mycobacterium avium*; 2) Moisture-holding capacity of the soil. Survival time is shorter in sandy soils than those with greater water-holding capacity; 3) Temperature. Survival time is longer at lower temperatures, e.g., in winter; 4) pH.

Survival times are shorter in acidic soils (pH 3-5) than in neutral or alkaline soils. Soil pH is thought to have its effect through control of the availability of nutrients or inhibitory agents. The high level of fungi in acid soils may play a role; 5) Sunlight. Survival time is shorter at the surface, probably due to desiccation and high temperatures, as well as ultraviolet radiation; 6) Organic matter: Organic matter increases survival time, in part due to its moisture-holding capacity. Regrowth of some bacteria such as salmonella, may occur in the presence of sufficient organic matter. In highly organic soils anaerobic conditions may increase the survival of *Escherichia coli*[17]; 7) Soil microorganisms. The competition, antagonism and predation encountered with the endemic soil microorganisms decreases survival time. Protozoa are thought to be important predators of coliform bacteria[17]. Enteric bacteria applied to sterilized soil survive longer than those applied to unsterilized soil.

The survival of bacteria on plants, particularly crops, is of important because some vegetables and fruits may be eaten raw by animals or humans, may contaminate hands of workers touching them, or may contaminate equipment contacting them. Such ingestion or contact would probably not result in an infective dose of a bacterial pathogen, but if contaminated crops are brought into the kitchen in an processed state they could result in the regrowth of pathogenic bacteria such as salmonella, in a food material affording suitable moisture, nutrients and temperature[18].

Pathogens do not penetrate into vegetables or fruits unless their skin is broken[14,18-21]. The same factors affecting the survival of bacteria in soil, affect bacterial survival on plants, especially sunlight and desiccation.

Viruses: Viral survival is longer than bacterial survival in water and is greatly increased at lower temperatures. In the 20-30°C range, 2 months, whereas at 10°C, nine months[14]. The factors that affect viruses survival in the soil are solar radiation, moisture, temperature, pH and adsorption to the soil particles. The soil microorganisms have less effect on virus degradation. Adsorption to inorganic surface is believed to prolong the survival of viruses. Adsorption results in physical disruption of viruses[22]. Desiccation and high temperatures decrease the survival time of viruses[19].

The absorption of enteric viruses by plants is a theoretical possibility. It has been reported that enterovirus can be absorbed by tomato plant roots grown in hydroponic culture under some conditions and in some cases to be translocated to the aerial parts[23]. The rapid adsorption of viruses by soil particles under natural conditions make them unavailable for plant absorption, thereby indicating that plants or plant fruits would be unlikely reservoirs or carriers of viral pathogens. The surfaces of vegetables are impenetrable for enteroviruses[24].

On the leaf surface of crops virus survival is expected to be shorter than soil because of the exposure to deleterious environmental effects, especially sunlight, high temperature, drying and washing off by rainfall[13,14]. In Mexico, where secondary effluent was applied by ridge-and-furrow irrigation for 33 years, no enteroviruses were found on or in the leaf and grain portions of maize[25]. Viruses do not regrow on foods or other environmental media, as bacteria sometimes do[14,16,19]. Therefore, the risk of infection is completely dependent upon being exposed to an infective dose in the material applied.

Protozoa: Waste water stabilization ponds accomplishes much better removal of protozoan cysts. In India, it is reported 100% reduction of protozoan cysts from the effluent can be accomplished by a series of 3 maturation ponds, with a 7-day retention time[26]. It is also reported in Texas(USA), 100% reduction of giardia cysts by a storage lagoon[27]. Entamoeba cysts have been reported to survive for several months in water at 0°C, 3 days at 30°C, 30 min at 45°C and 5 min at 50°C[28]. Giardia cysts can survive up to 77 days in water at 8°C, 5 to 24 days at 21°C and 4 days or less at 37°C[29]. Under Botswana conditions, where the summer day and night temperatures ranges between 30-40°C will undergo complete inactivation in 7 days. Protozoa cysts are poor survivors in any environment[14,30].

Protozoa cysts are highly sensitive to drying. The survival times for *Entamoeba histolytica* is 18 to 24 h in dry soil and 42 to 72 h in moist soil[21]. It was further reported that the survival times for *Entamoeba histolytica* as 8-10 days in damp loam and sandy soils at 28 to 34°C[31]. On average protozoa survival time in waste water is less than 15 days[14].

Protozoan cysts deposited on plant surfaces die off rapidly because of their sensitivity to drying and desiccation. Contaminated tomatoes and lettuce were reported to be free from viable entamoeba cysts within 3 days and the survival time was unaffected by the presence of organic matter in the form of faecal suspensions[32]. The authors concluded that crops grown in the field and are consumed raw but subjected to contamination with cysts of *Entamoeba histolytica* are safe after one week in the temperate zone and two weeks in the wetter tropical regions[32]. Therefore, if recommendations based on bacteria are used for harvesting human food crops, it is extremely unlikely that any public health risk will ensue.

Helminths: Helminth eggs are denser than water therefore ordinary sedimentation or conventional primary treatment is a fairly efficient method of removal. One to 2 h of sedimentation detention time was reported to be efficient to remove most helminth eggs[33]. It has been shown experimentally that 98% of *Taenia saginata* eggs can be removed by 2 h sedimentation in the laboratory, but lower removals under field conditions[34]. Waste water stabilization ponds accomplish excellent degrees of helminth egg removal[14,20]. Complete removal of helminth eggs occurs in well designed multicelled stabilization ponds with an overall retention time of more than 20 days[20,27]. However, the sludge or pond sediment resulting from these processes will have high densities of viable helminth eggs and requires proper treatment before utilization.

Helminth eggs and larvae, in contrast to protozoan cysts, live for long periods of time when applied to the land because soil is the transmission medium for which they have evolved. While protozoa have evolved toward water transmission. Under favourable conditions of moisture, temperature and sunlight, *Ascaris lumbricoides* (roundworm), *Trichuris trichuira* (whip worm), *Toxocara canis* (dog roundworm), *Toxocara cati* (cat roundworm), *Taenia saginata* (tapeworm) and *Ancylostoma duodenale* (hookworm) eggs and larvae remain viable and infective for several years[14,35,36]. Hookworm, tapeworm and roundworm eggs can survive up to 20 weeks, 2 years and 10 years, respectively[14,20,36].

Desiccation and exposure to sunlight rapidly kills helminth eggs deposited on plant surfaces. Roundworm eggs sprayed on tomatoes and lettuce lived the longest and were completely degenerated after 27 to 35 days[37]. Due to the growth of crops and presence of people at irrigation sites and the longevity of helminth eggs, it is advisable to select a pre-application treatment method such as stabilization ponds, which will completely remove helminth eggs from secondary effluent at these land treatment sites.

Whether a person becomes infected from waste water pathogens depends on excreted load, latency, persistence, multiplication, infective dose, host response and non-human hosts[14,16,36]. A theoretical epidemiological model based on the above factors has been developed[36]. The model looked at their relationship to the probability that one of the four enteric pathogen groups described earlier would cause infections in humans through waste water irrigation. The factors necessary to cause a high probability of infection are long persistence in the environment, low minimal infective dose, short or no human immunity, minimal concurrent transmission through other routes such as food, water and poor personal or domestic hygiene and long latent period and/or soil development stage required[36]. The Shuval model showed that helminth diseases, if they are endemic, are very effectively transmitted by irrigation with raw waste water. While, the enteric virus diseases could be the least effectively transmitted by irrigation with raw waste water. The bacterial and protozoan diseases ranked between these two extremes. Based on the Shuval model pathogens have been ranked in the following descending order of risk: high (helminthes), lower (bacterial and protozoan infections) and least (viral infections). This ranking was consistent with the theoretical considerations of other scientists[14]. There is an evidence of disease transmission in association with the use of raw or partially treated waste water[16]. The evidence strongly pointed to the helminthes as the number one problem, particularly in developing countries[16].

From the above discussion, waste water contains pathogens and these pathogens do pose a health risk. Therefore, there is a need of developing a regulatory programme for health protection. These regulatory programmes should be centred on lowering the risk from water or restricting irrigation use. Lowering the health risk from water involves waste water treatment or treatment for disinfection. Agricultural restrictions can lower the potential health risk by restricting the use of waste water and crops to be grown.

Reuse standards: Effluent reuse standards varies worldwide. In Mexico and many South American countries untreated waste water is used for irrigation of agricultural crops[38]. The South American countries attempt to control the health risk associated with waste water irrigation by controlling the crops grown. Mexico does not allow waste water to be used to irrigate lettuce, cabbage, beets, coriander, radishes, carrots, spinach and parsley. Acceptable crops include maize, alfalfa (Lucerne), cereals, beans, chili and green tomatoes. Israel has very stringent water reuse requirements[39]. Effluent water requires a high level of treatment (large soil-aquifer recharge systems with dewatering) before the water can be reused for irrigation of vegetables to be consumed raw[40,41]. Caution is urged in using groundwater recharge systems since the long term impact of pollution is unknown[42,43]. In Japan, most of the reclaimed waste water is used for non-potable dual systems such as toilet flushing, washing and cleansing and landscape irrigation[44]. In Saudi Arabia, the reclaimed water through a two-stage trickling filter with aerated lagoons for final polishing, is used for agricultural irrigation, fire fighting, process waters for crude oil desalting and cooling towers and boiler feed-water[40]. In South Africa, secondary sewage water is used for irrigation, power plant cooling and industrial processes. Reclamation of waste water for human use occurs in Windhoek, Namibia[40]. In the United States of America, secondary sewage effluent is used for irrigating public landscapes (parks, highway medians, lawns), air conditioning and cooling, industrial processing, toilet flushing, vehicle washing, construction, grow hay, alfalfa, corn and small grains for cattle feed[40].

Irrigation suitability: The guidelines for acceptable salinity, sodicity and minor elements in secondary effluent irrigation water follows those of normal irrigation water[45]. These guidelines take into account leaching fractions and sodium and salt tolerances of crops[46-48], boron toxicity[49], trace elements[50] and low EC-high SAR permeable hazards[51-53]. The Gaborone secondary sewage effluent can be classified as class 2 water based on the above irrigation water quality guidelines[4, 45], which is suitable for irrigation. The water is low in total dissolved solids (<360 mg L^{-1}), electrical conductivity (0.51 dS m^{-1}), sodium adsorption ratio (1.51-2.26) and trace elements[4].

Management guidelines: The Botswana government developed a strategy for waste management in 1998[54]. However, the government of Botswana has yet to develop guidelines for land application of treated secondary sewage effluent and sludge. Specific regulations and guidelines that govern waste water reuse in agriculture need to be developed. The Ministry of Agriculture and Health should set health standards for water utilization for irrigation. An integrated planning approach is necessary in the use of secondary effluent for irrigation in agriculture as a management alternative in water stressed environment such as Botswana. The technological, economical and health aspect as well as legal framework have to be considered. Therefore the use of secondary effluent is an interdisciplinary challenge for the present and future.

CONCLUSIONS AND RECOMMENDATIONS

Botswana being a semi-arid to arid country, with recurrent and endemic droughts can utilize the secondary sewage effluent to meet some of its demands for water. The secondary effluent can be used for irrigation of agricultural crops to increase food production, irrigating public landscapes (parks, highway medians, lawns, soccer fields, golf courses, etc), air conditioning and cooling, industrial processing, toilet flushing, vehicle washing, construction, hay growing, lucerne, maize, sorghum and small grains for cattle feed. With proper waste water treatment technology, Botswana is able to turn this country into productive agricultural lands. If Israel has managed to turn the deserts into productive agricultural lands, with right government policy towards irrigation and water harvesting technologies, the Botswana government can turn this country to a net exporter of food, create employment and improve the living standards of the rural population.

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