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Environmental and Health Considerations for Utilization of Treated Wastewater for Agricultural Irrigation

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Environmental and Health Considerations for Utilization of Treated Wastewater for Agricultural Irrigation

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Abstract

The use of treated urban wastewater for irrigation in modern agricultural is steadily increasing world-wide and due to shortages of fresh water is common today in many regions throughout the world. Utilization of this water source for irrigation in the production fields is an environmentally sustainable approach, which incorporates the advantage of minimizing the disposal to the environment. Furthermore, irrigation with treated wastewater incorporate benefits to agricultural by reducing demands for fertilizers inputs as a result of the higher concentrations of macronutrients in this water. At the same time, inhibiting effects on the irrigated crops may source from the higher concentrations of salts, bicarbonate, boron, heavy metals, and pH level present in the treated wastewater. The use of treated wastewater for agricultural irrigation may result in human exposure to pathogens, creating potential public health problems. Although the concentration of human pathogens decrease during the wastewater reclamation process, the secondary treated effluents most commonly used for irrigation today still contain bacterial human pathogens. National and global regulations were developed and are applied to facilitate optimal and safe production under irrigation with treated wastewater.

Keywords Bacterial human pathogens, heavy metals, Treated wastewater
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Introduction

Water is the most valuable and restrictive resource in arid and semi-arid regions throughout the world where local population growth increases the demand for food, including crops and plant products. Developed countries might be affected as well as water shortage could potentially affect related technologies, such as hydroelectric power in addition to general water supplies (Daigger, 2008). Contemporary research offers potential for reduced consumption of water through a range of conservation and treatment technologies including water desalinization, disinfection and decontamination. Therefore, maintained or increased productivity in water limited regions increasingly relies on the utilization of marginal water for irrigation. Due to their availability and relatively low cost, treated sewage effluents are becoming the main source of alternative marginal water for agricultural irrigation (Toze, 2006). Environmental protection considerations for minimizing discharge to the environment also encourage the use of wastewater for agricultural purposes. The use of wastewater for agricultural irrigation is, therefore, increasing steadily world-wide, and is practiced today in almost all arid regions of the world (Scott et al., 2004). Numerous countries have established water resource planning policies based on maximal re-use of urban wastewater.

Despite the economic and ecological advantages associated with the use of treated wastewater for irrigation, its use also carries risks to public health and the environment. Pathogenic microorganisms present in the treated wastewaters can pose a health risk to farmers, contaminate the irrigated crops and/or be carried along to the consumers. Irrigation with contaminated water may increase the risk of bacterial, parasitic and viral infections (Shuval et al., 1985, 1986, 1989; Fattal et al. 1986; Campbell et al. 2001; Doyle and Erickson 2008; Nygard et al. 2008). Additionally, these microorganisms may persist in the soil and be transported to surrounding areas together with the agricultural drainage (Bernstein et al., 2009). In addition to the heavier microbiological load, the treated effluents differ from the potable water also chemically and they may contain higher concentration of heavy metals (Feigin et al., 1991; Bernstein et al., 2006; Friedman et al., 2007; Ben-Hur, 2004) as well as anthropogenic chemicals (e.g., hormones, pharmaceuticals and pesticides) (Graber and Gerstl, 2011) than the potable water. These pollution elements can enter the biotic components of the ecosystem, accumulate also in the agricultural food produce and endanger growth and health of the human consumers (Akbar Jan et al., 2010). The sanitation quality and chemical quality of treated wastewater is therefore a key issue in their reuse for agricultural irrigation.

In addition to public health risks, treated effluents may also have detrimental effects on the irrigated crops (Feigin et al., 1991). In particular, the high salinity levels in the effluents can restrict plant growth (Bernstein, 2013), decrease biomass production (Neves-Piestun and Bernstein, 1995) and reduce yield quality (Friedman et al., 2007). Nevertheless, many successful agricultural production systems that utilize this water have been developed (Bernstein et al., 2006; Friedman et al., 2007; Feigin et al., 1991).

Regulations for Usage of Treated wastewater in Aagricultural systems

With the increasing demand for reclaimed water usage in agriculture in developing as well as developed countries, guidelines have been established for its use in agriculture by both the Environmental Protection Agency (EPA, 2004) and the World Health Organization (WHO, 19889; Blumenthal et al., 2000). Numerous countries throughout the world have developed recommendations and regulations for sanitation quality and chemical quality of effluents to be used in the agricultural setups for irrigation of food crops. These regulations are aimed at protecting the population from exposure to pathogens and chemical contaminants (Bernstein et al., 2011). For example, the World Health Organization (WHO) guidelines recommend that, to be used unrestrictedly for irrigation of all crops, water must have no more than 1000 fecal coliforms (FCs) per 100 mL. These guidelines put a special emphasis on the removal of helminth eggs (to a concentration of no more than one egg per liter) during effluent treatment (WHO, 1989). The U.S. Environmental Protection Agency (US EPA) guidelines require that there be no detectable FCs per 100 mL (EPA, 2004). California's wastewater reclamation standard is 2.2 coliforms/ 100 mL, and the Israeli regulations for "unrestricted irrigation" with effluents in agriculture is ≤10 FCs / 100 mL (IMH, Israel Ministry of Health, 2001).

Additionally, in order to protect public health and the environment, various approaches were developed for the sanitation of the effluents prior to their use in agricultural irrigation. The major factor affecting the selection of regulatory strategy in a given situation is usually economics. While most developed countries have adopted conservative, low-risk standards based on a high technology/high cost approach, a number of developing countries have developed a low technology/ low cost approach based on the WHO recommendations (US EPA, 2004). The realization that health protection can be gained not only by exercising strict water quality restrictions, but also by employing other practices able to create additional barriers against crop exposure to the pathogens, is gaining acceptance (Fine et al., 2006). An example of such an approach is the standards issued by the Israeli Ministry of Health (Israel Ministry of Health, 2001; Shelef and Halperin, 2002). These standards set a low coliform limit of less than 10 *E. coli* / 100 mL for reclaimed water that can be used for irrigation of vegetables which will be eaten raw, in the absence of any additional barriers. At the same time, additional barriers, either physical ones such as buffer zones between the wastewater and the above-ground part of the plants and inedible peels or shells, or others, such as high heat treatment of the produce prior to eating, are required if water of a lower quality is to be utilized for irrigation. The development of the physical barrier concept stems from the conventional notion that potential health risks to consumers from the consumption of agricultural produce irrigated with contaminated water arise primarily from the direct contamination of plants by human pathogens via the plant's above-ground organs, and not by internalization via the root system. However, recent studies suggest that human pathogens can also associate with the underground parts of the plants, penetrate internal plant tissues via the root as well as translocate and survive in edible, aerial plant tissues (For example: Bernstein et al., 2007a,c). The practical implications of these new findings for food safety needs to be assessed, but no doubt depend on the ability of the pathogenic microorganisms to penetrate the roots, translocate to the edible parts of the crop, and survive and multiply in water, soil, and the marketable crop yield in the field, and post-harvest.

A typical scheme of wastewater treatment process includes a Primary treatment, i.e., a physical process of pre-treatment and sedimentation. It involves a partial removal of suspended solids and organic matter from the wastewater by means of physical operations such as screening and sedimentation. A Secondary treatment includes a biological step followed by sedimentation. In the secondary treatment processes, micro-organisms, particularly bacteria, convert the colloidal and dissolved carbonaceous organic matter into various gases and cell tissue thereby reducing BOD and COD. In some cases a Tertiary step is also applied and includes processes aimed at removal of specific contaminates such as nitrogen, phosphorus, heavy metals, biodegradable organics, bacteria and viruses. In addition to biological nutrient removal processes, other processes such as chemical coagulation, flocculation and sedimentation, followed by filtration and activated carbon, or ion exchange and reverse osmosis for specific ion removal or for dissolved solids reduction are sometimes used (Lakshmana Prabu et al., 2011)

The quality of reclaimed wastewater depends on the degree of treatment. Generally, tertiary treated water that has undergone a disinfection stage is considered to be safe for irrigation of all crops, including vegetables that are consumed raw. Primary and secondary treated waters are of variable microbial quality and may be adequate for restricted irrigation of specific crops that are not consumed raw.

Trace elements and heavy metals in treated wastewater

Wastewater and sewage effluents may contain high concentrations of heavy metals depending upon the water sources and the treatment applied. Heavy metals such as Zn, Cd, Pb, Fe, Mn and Mo from wastewater and sewage effluents may be toxic to plants at high concentrations, and their accumulation in edible parts of crops may impose a health risk to consumers (Yadav et al., 2002). Under long-term wastewater applications, heavy metals and trace elements can accumulate in the soil to levels toxic to plant growth (Chang et al., 1992). Soils may absorb and retain heavy elements from irrigated wastewater. However, due to continuous loading of pollutants and irrigation-induced changes in pH, the capacity of soils to retain the heavy metals may change resulting in their release to the soil solution and thereby increased availability for plant uptake (Mapanda et al., 2005). Numerous studies revealed increase in concentrations of trace and heavy elements in soil and plants irrigated with secondary treated wastewater. Nevertheless, under conditions where the contaminates levels in the treated effluents are within the limits set for irrigation of crops, concentrations in the crops are found to be below the permissible limits regulated for health standards. Thereby, consumption of plants irrigated with this secondary treated wastewater is considered to be safe. However, secondary treated wastewater irrigation along with proper monitoring and continuous assessments are required in order to prevent long term risks to humans and environment (Ali and Shakrani, 2012). The main souse of heavy metals in the wastewater is industrial sewage. Thereby, numerous countries has adopted regulation for pre-treatment of the industrial wastewater, for specific removal of trace elements and heavy meals contaminates, prior to their introduction to the wastewater treatment facilities of urban water.

Presence of Human Pathogenens in treated wastewater

It has been estimated that at least one-tenth of the world's population consumes foods produced by irrigation with wastewater (Smit and Nasr, 1992). In 2000, Homsi (2000) estimated that about 10% of all wastewater in developing countries is treated, while WHO/UNICEF (2000) estimated that the median percentage of wastewater effectively treated is 35% in Asia, 14% in Latin America and the Caribbean, 90% in North America and 66% in Europe. These percentages have increased since, and in Israel for example, about 90% of the wastewater are treated. Raw municipal sewage in developing countries can harbor high loads of human pathogens (Kirby et al., 2003; Steele and Odumeru, 2004). Variable numbers of pathogens were estimated by others, as follows (per liter): $5x10^3$ enteroviruses, $7x10^3$ Salmonella spp., $7x10^3$, Shigella spp., 10^3 V. cholerae, $4.5x10^3$ E. histolytica and $6x10^2$ A. lumbricoides (Feachem et al., 1983). These numbers emphasize the risk of environmental contamination when raw wastewater is directly applied to crops.

Although bacterial pathogens have adapted for survival in the nutrient-rich environment of their animal and human hosts, studies have suggested that they may persist in other environments, including water, for long periods of time. The ability of a microbial pathogen to survive in water is an important determinant in the risk of human infection. The viabilities of most microbial pathogens decrease over time, however their capacity to survive in water greatly varies. The longer a pathogen can survive in the environment, the more likely it is to contaminate water and crops. The capabilities of individual pathogens to persist in water and wastewater have been studied by many researchers (reviewed by Steele and Odumeru, 2004).

A variety of human pathogens were identified in sewage water (Armon et al., 2002). Raw municipal wastewaters intended for agricultural irrigation should be treated to a quality suitable for the prevention of threats to the grower, consumer, and damage to the environment. Although the high numbers of human pathogens present in non-treated sewage decrease successively at each step of the wastewater reclamation process (Van der Steen et al., 2000), the secondary treated effluents which are the effluents most commonly used for irrigation still contain fecal coliforms that may pose a threat to public health (Maynard et al., 1999; Armon et al., 2002; Kirby et al., 2003; Bernstein et al., 2006, 2008; Sacks and Bernstein, 2011). There is a risk of direct contamination of crops by human pathogens present in the treated effluents used for irrigation, as well as indirect contamination of crops through contaminated soil at the agricultural site.

It has been well established that irrigation with contaminated water may increase the risk of bacterial, parasitic and viral infections (Shuval et al. 1985, 1986, 1989; Fattal et al. 1986; Campbell et al. 2001; Doyle and Erickson 2008; Nygard et al. 2008). Fresh produce has been implicated as a major vehicle for food borne pathogenic outbreaks (Doyle and Erickson, 2008; Warriner and Namvar, 2010). Therefore, the potential transmission of infectious diseases by pathogenic agents is the most common concern associated with the agricultural use of treated wastewaters (Shuval et al., 1986).

The quality of the reclaimed wastewater depends on the level of the treatment. Tertiary-treated water, after a disinfection stage, is generally considered to be safe for irrigation of all crops, including vegetables that are consumed raw. Primary- and secondary-treated wastewater may have variable microbial quality and may be suitable for restricted irrigation of specific crops that are not consumed raw. Therefore, a major role of wastewater treatment is the removal or inactivation of pathogens to safe levels. The risk of disease transmission from pathogenic microorganisms present in irrigation water is influenced by the level of contamination, the persistence of the pathogens in water, in the soil on the crop, and the route of exposure (reviewed by Steele and Odumeru, 2004).

Presence of organic micro contaminants in treated wastewater

Among the potential risks associated with effluent irrigation is the presence of anthropogenic chemicals in the effluents (e.g., hormones, pharmaceuticals and pesticides), enhanced transport of these chemicals out of the root zone due to their interaction with effluent-borne dissolved organic matter, and the possible uptake of these anthropogenic chemicals by plants and crops (Graber and Gerstl, 2011).

Organic contaminates were usually reported to be present in effluents only at low, sub-mg/L levels. For example, nonionic surfactants (between 1–30 μg/L), antioxidants, caffeine, fecal steroids, and cholesterol have been identified in treated effluents (Brown et al., 1999), as well as pharmaceuticals, fire retardants, plasticizers, industrial solvents, disinfectants, polycylic aromatic hydrocarbons, and high-use domestic pesticides (Daughton and Ternes, 1999). Estrogens concentrations were reported from a few ng/L up to several tens of ng/L (Falconer et al., 2006).

The various organic compounds vary considerably in their persistence throughout the effluent treatment process. Conventional wastewater treatment plants have been observed to be unable to totally remove 'Pharmaceuticals and personal care products', PPCPs (Joss et al., 2006). In a recent study, Miege et al. (2009) evaluated the available data from 117 scientific publication involving removal of PPCPs, from sewage treatment plants. Using their database, which compiled 6641 data covering 184 PPCPs, they identified the most persistent PPCPs in the dissolved phase and were able to compute reliable removal rates for about 50 compounds. They reported that triclosan, norfloxacin, 17 β-estradiol, and estriol are highly removed contaminants, whereas atenolol, carbamazepine, metoprolol, trimetoprim, mefenamic acid, and clofibric acid have low removal efficiency. They suggested that the variability they observed for individual compounds could be attributed mainly to the variation in treatment procedures between sewage treatment facilities. Hijosa-Valsero et al. (2010) assessed the ability to remove PPCPs of three different full-scale hybrid pond-constructed wetlands and a. The hybrid systems were no less efficient in PPCP removal as the conventional wastewater treatment plant, removal efficiencies mainly exceeding 70%.

Potential effects of the organic substances present in the treated effluents used for irrigation on environmental safety are dependent on their potential effects and fate in the environment. Potential health risk to consumers depends also on the ability of plants to take up the organic contaminates and, their accumulation in the edible parts of the plant. Al Nasir and Batarseh, (2008) found that different plant species display different uptake and translocation behavior for the various contaminants, and that roots were contaminated more than above ground parts of the plant. Khan et al., 2008 reported that in pot grown lettuce, polycyclic aromatic hydrocarbons accumulated almost exclusively in the roots and were not translocated into the lettuce leaves. The available results demonstrates very low uptake of PPCPs into the plant, and breakdown of most compounds throughout the wastewater treatment process.

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