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Application of domestic greywater for irrigating agricultural products: A brief study

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Abstract

The decline in annual rainfall, coupled with the growing demand for water in agricultural fields, triggered a new crisis in today's world. Thus, the focus is on finding solutions to new water resources. Taking a look at the normal daily life, most of the households' effluents can be ranked into a less-polluted category, called greywater. Excluding human dejects, greywater comprises the outflow from washing machines, dishwashers and bathtubs. It is considered an effluent with a more economic treatment, because it contains less microbial pollution. Hence, this work revises the effects of greywater irrigation on the quality of crops, and provides a comprehensive study of the effects of greywater on the quality of soil. Furthermore, a comprehensive discussion is carried out to evaluate the energy consumption of facilities for both greywater and wastewater treatment to provide water used in irrigation. It also addresses current methodologies for treating greywater and evaluates the effects of crops irrigation with treated and untreated greywater, indicating the type of treatment chosen depending on the type of crop to be irrigated.

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Keywords: Agricultural products; Greywater; Irrigation; Wastewater

1. Introduction

Nowadays, the water crisis is an upcoming phenomenon that threatens countries all over the world. Various parts of the world are suffering from a shortage of water resources. Regions such as the Middle East, Australia, and southwest of United States are possible regions confronting drought. A study of the daily life of a typical citizen, in urban areas of developed countries, shows that the water consumption can vary from 15–55 L up to 90–120 L

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per day per capita [1]. Providing such amounts of water from first-hand resources requires not only a great effort, but also a lot of energy [2].

There are alternatives that can be used instead. As an instance, treatment and reuse of wastewater in each household can be considered as a local solution to the emerging problems of water supply needed to irrigate crops. To be more precise, the discussed solution has already been used by farmers worldwide since it is estimated that 10% of the world's population consumes foods which are irrigated with wastewater [3]. However, there are significant concerns about the safety of reusing wastewater for irrigation, including the possibility of contamination of soil and plants and the impacts on human health. Studies have shown that the microbial population of untreated wastewater is very diverse. Diseases such as food-borne illness are thought to have direct connection with pathogens [4] presented in the irrigation water.

Greywater is defined as water collected from sewage discharge of cloth washers, bathtubs, showers and sinks, excluding wastewater from toilet [5]. Greywater recycling not only reduces water requirements of a building but can also significantly reduce the volume of effluents being sent to the sewer or septic system. Therefore, it is economic and vital, especially for residents of water-scarce regions [4].

The second section of this paper includes the details of three experiments utilizing domestic greywater with different treatments for irritating agricultural crops, while in Section 3, they are evaluated based on their outcomes. In the discussion section, the benefits of greywater treatment facilities are evaluated with respect to the energy sector. Finally, in the fourth section, the studied experiments are concluded, considering necessary requirements before irrigating crops with domestic greywater.

2. Irrigation of crops with greywater: experimental setup

To have a comprehensive study to know the influences of domestic greywater, three experiments were performed.

2.1. Crop irrigation with untreated greywater

In a study by Finley et al. [4], authors tried to carry out a research to know the effects of irrigating crops with both treated and untreated greywater collected from household, compared with tap water. The greywater was collected from two showers, one bathtub, and one washing machine. The house was inhabited by a family consisting of three adults and one small child, using biodegradable, phosphate free shampoos and detergents, while diapers were not washed in the machine that flows into the greywater system. To extend the study over the type of plant, they considered three plants to evaluate the direct contact of edible part with soil. The following plants and seeds were used in the experiment: baby finger carrots or *Daucus carota sativa*; grand rapid lettuce or *Lactuca sativa*; and gypsy red peppers or *Capsicum annuum*. The statistical design consisted of applying one of the three sources of water (3 choices), tap water, untreated greywater, or treated greywater, to triplicate pots (3 choices) of each plant type (3 choices), for a total of 27 experimental blocks.

The first sample irrigated with the untreated greywater was obtained after a primary settling stage with a hydraulic retention time of around ±8 h, while the second sample was related to treated greywater that was obtained after coarse filtration and treatment by slow sand filtration with an HRT of 24 h. The third sample was irrigated with tap water, used as standard sample for comparisons. Plants were spread randomly and irrigated daily with 300 mL of either tap water or one of the two greywater samples at the same time, manually pouring on the surface of the soil. Plants were watered 6 days per week, first 5 days with samples, no watering on the sixth day, and briefly sprayed freshwater on the last day.

The duration of the experiment was reported to be around 8 weeks. Both treated and untreated greywater were obtained weekly from the containers and characterized for nutrients (N, P, and K), pH, heavy metals, and indicator organisms (fecal coliforms and fecal streptococci). Upon maturity, the edible portion of each plant type was harvested in three successive batches taken on separate days (for lettuce, carrots, and peppers, respectively 55, 65, 75 days). In the laboratory, 50 g samples of each crop were cut into small pieces using sterile scissors and immersed in sterilized solvent. The resulting elution was shaken and then tested for fecal coliforms and fecal streptococci according to the method outlined in Collins [6] for the microbial evaluation of fresh foods.

2.2. Crop irrigation with treated greywater

In situations where the quality of untreated greywater dissatisfies the requirements, or it contains compounds which may affect the crops, it is essential to improve the quality of greywater to be able to use it on irrigation. Al-Hamaiedeh and Bino [7] analyzed the effects of irrigating crops (both plants and soil) with treated greywater using a 4-barrel and confined trench (CT) units were used for greywater treatment. In the first barrel, the floating grease, oil and small solids were removed. The second and third barrels were filled with gravel filter media of 2–3 cm diameter, connected in order to pass the water through them in an upward fashion. The fourth barrel was fitted with a small electric pump and a float switch to pass the treated greywater to an irrigation system.

The study area was at Al-Amer villages in Karak in the middle part of Jordan. Dominated by the Mediterranean climate, the studied region is characterized by dry and hot summer seasons [7]. Raw greywater samples were taken from barrels that received water over 24 h while treated greywater samples were collected from barrels that received treated greywater. All the collected samples were subjected to multiple analyzes, including of pH, TSS, BOD, COD, total nitrogen (T-N), nitrate as well as cadmium Cd and Pb, by considering all the standards of analyzing wastewater [8]. Soil samples were collected from five designated home gardens irrigated with greywater for one to two years. Six soil samples were collected from each garden irrigated with greywater: three from the surface layer at depths of 0–30 cm and at depths of 30–60 cm. For analyzing the plant quality, composite samples of fresh olive leaves and fruits were collected from five gardens irrigated with greywater for two years. To provide reference samples, the same number of olive leaves and fruit samples were collected from the same gardens two years before the greywater irrigation experiment. Leaves and fruits were first washed with distilled water, dried at 50 °C until constant weight and then the samples were homogenized. Dissolving 0.2 g of each sample in 10 mL of solvent, they were covered with a watch glass, and the contents were boiled on a hot plate for approximately 30 min. The contents were then evaporated to near dryness and finally, measured to find out nitrogen, phosphorus, potassium, sodium, chloride, cadmium, and lead.

2.3. Passive irrigation with greywater

Fagan [9] studied the growth of tomato being irrigated with greywater effluent from a household in the village of Chirifoyilli, Ghana, to investigate the possibility of using greywater in rural areas for crop irrigation. Planting beds were assembled to simulate the greywater garden schemes from the Peace Corps project. Secondary effluent from a local wastewater treatment plant was used as a greywater substitute, while for comparison, two sources of freshwater were used: freshwater in high volume, and freshwater in low volume. The plants were planted with tomato cultivars with similar characteristics to those found in Ghana [9].

Batches, which contained 12 seeds were planted between July 14 and August 4, 2015. Healthier plants were transferred into 6-inch pots when they reached heights of 5–10 inches. Plants were measured at transplantation to beds and then, every 5 days. Finally, 63–72 days after they were moved to the beds, the plants were harvested for the analysis purposes. During their growth, the plants were irrigated with high volumes of the greywater substitute, high volumes of fresh water (FHV), or low volumes of fresh water (FLV).

Tomatoes were grown in three different variable groups, chosen to determine whether the effect on the plant growth was caused by a higher volume of water alone or by the combination of high volume and added nutrients. The plants were measured both throughout the growth process, and after harvesting to determine the effect of these variables on the growth rate. Table 1 shows the parametric measurement of greywater from the experiment.

In this work, in order to use wastewater similar to the Fagan [9] greywater applied in the field, this experiment used a secondary effluent, after filtering through a settling tank where most solids were removed and after biological treatment, but prior to chemical disinfection.

At the time of harvest, each plant was measured for height, and leaves were counted a final time. The plant was carefully removed from the soil, keeping the root structure intact. The root mass was measured for length. Each plant was then cut by its soil line, and the root and the top shoot were weighed separately. Putting both root and shoot in an oven at 38 °C for 12 h, they were dried and then weighed.

3. Irrigation of crops with greywater: experimental analysis

In this section, the results of the evaluation are described as follows.

Table 1. Measurement of greywater metric from Fagan experiment [9].

Parameter	Unit	Ghana Bath-area wastewater
Nitrate	mg/L	13.73
Phosphate	mg/L	10.63
Potassium	mg/L	64
Fecal coliform	cfu/100	28×10^4
BOD	mg/L	14
pH	–	7.95
TDS	mg/L	774.9
Dissolved oxygen	mg/L	14.5
COD	mg/L	1915
Total coliform	cfu/100	482×10^4
E. coli	cfu/100	11×10^4

3.1. Crop irrigation with untreated greywater: Evaluation

Surprisingly, the untreated and treated greywater samples were not significantly different for all measured parameters, indicating that the treatment was not effective to improve the quality of greywater. In terms of crop dried weight per experimental block, there is no significant difference between the irrigation with greywater and with regular tap water. Authors justified the results by the low nutrient content of the greywater, and low heavy metals. All plants grew well and produced healthy fruits, with only one lettuce control block suffering from pest-related weakness.

Fecal coliforms were detected in small numbers of lettuce leaves and carrot surfaces, but not on the surface of peppers. The high variation of bacterial results in this study echoes previous researches, where other greywater flows [10], sludge applications [11], and full wastewater [12] were not found to increase crop contamination when contact was avoided. This is significant because it opens the door for the exploration of alternative requirements for non-potable sources of irrigation water. While there is no conventional standard for Enterococci levels on foods, the real danger of their presence is unclear. Fecal streptococci naturally occur in some foods, most notably meats and cheeses, and their relationship to other pathogenic organisms in that setting is unclear [13].

Data for the probability of infection and likeliness of illness per incidence of infection are based on Hurst et al. [14], who provides overall values for enteric pathogenic bacteria. It is assumed that the risk analysis is performed in the situation where the vegetable crops are consumed at an estimated rate of one 40 g serving/day (approximately one pepper, three carrots, or six lettuce leaves), every other day, over a 3-month harvest period.

3.2. Crop irrigation with treated greywater: Evaluation

The average BOD, COD and TSS concentrations for the effluent at As-Samra Waste Stabilization Ponds are 709 mg/L, 1868 mg/L and 559 mg/L, respectively [15]. COD values were reported to vary for raw greywater between sites from 92 to 2263 mg/L, with similar variations arising at an individual site, due to changes in the quantity and type of detergent products employed.

Soil properties, mainly salinity, SAR, and organic content, are important for plant health and growth. The average SAR value of treated greywater in this study was 3.62 lower than the values suggested in Al-Hamaiedeh and Bino [7]. Therefore, authors concluded that the proposed method provided a suitable framework for irrigation with treated greywater, as well as the average salinity value of treated greywater. Besides, studies indicated a gradual increase of salinity and SAR as long-term effects of greywater reuse on soil properties during the period extending from 2006 to 2007. No evidence of chemical impact on leaves and fruits of olive and crops, due to irrigation with greywater, was reported. This makes the reuse of treated greywater for olive trees irrigation a high potential solution for the study area. Considering heavy metals such as cadmium and lead, measurements showed almost no increase in the uptake by plants, since their concentration was low in treated greywater and soil. However, long term use of reclaimed water can lead to salt and metal accumulation in the soil and subsequent uptake by the plants [7]. The chemical properties of vegetable crops irrigated with greywater, did not differ from the properties of the same crops irrigated with fresh water.

3.3. Passive irrigation with greywater: Evaluation

The experiment revealed that plants irrigated with greywater have grown faster, while plants that received high volumes of freshwater grow less than the others. The full-grown plants irrigated with high volumes of greywater grew slightly faster than plants irrigated with high volumes of freshwater. The full-grown plants final heights for both greywater irrigated plants and freshwater high-volume irrigated plants were significantly greater ($p < 0.05$) than the ones of freshwater irrigated plants. However, the greywater irrigated plant heights were not significantly different from the heights of the freshwater high-volume irrigated plants. The root measurements for the seedlings show that the greywater irrigated plants had, on average, a slightly longer root than the other plants, but distinctly outpaced the other plants in root mass. As the greywater encouraged these young plants to establish a stronger root system early in development, they will most likely be healthier through maturation. Fig. 1 depicts the plant sample irrigated with different water sources.

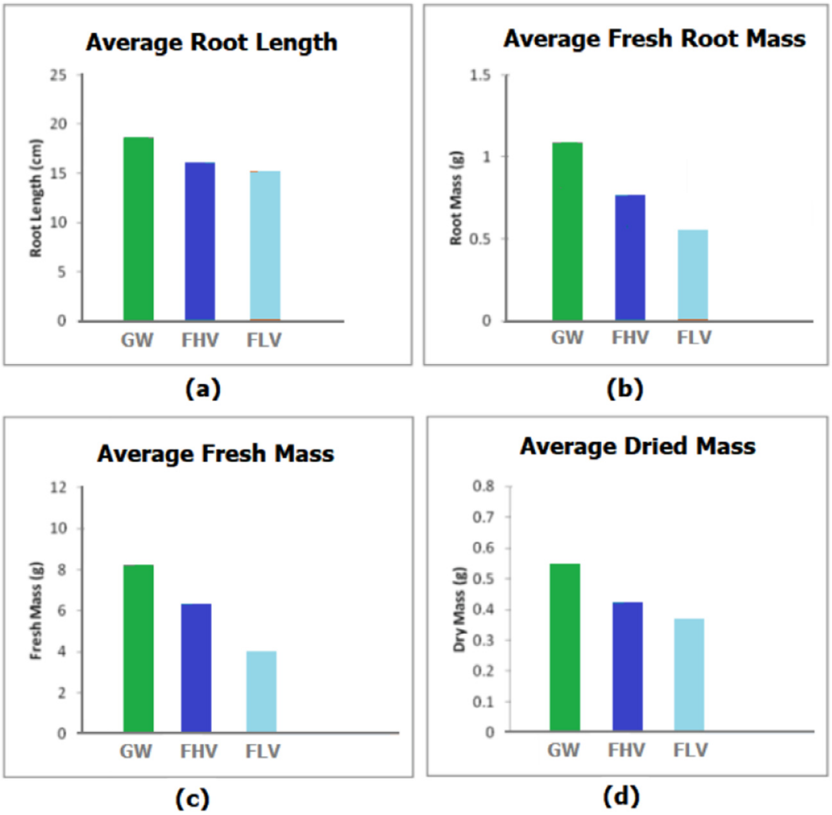

Fig. 1. Comparison of plants irrigated with greywater (GW), high volume of freshwater (FHV) and low volume of freshwater (LFV): (a) Average final root length of seedlings; (b) Average final fresh root mass of seedlings; (c) Average final fresh mass of seedlings; (d) Average final dry mass of seedlings.
Source: adapted from Fagan [9].

Fagan [9] stated the possibility of risk, when watering in large volumes, that a plant will not establish a strong root system. However, the mature plants under high volume irrigation were able to grow similar root masses when compared to plants under low volume irrigation.

The same author identifies another risk of greywater irrigation that is high amounts of nutrients can damage young plants. Overall, the results of this study, though limited in scope, indicate that simple greywater irrigation systems, like those established during the project in Chirifoyilli, in Ghana, as well as those already in place in other villages, serve as a valuable source of nutrients and water, and will likely not harm plants.

4. Discussion on greywater irrigation energy footprint

Amongst the investigations pointing to the application of greywater for irrigation purposes, there are studies targeting the financial benefits of the proposed irrigation alternative. Such financial benefits are considered either in generating energy directly from greywater infrastructures or consuming less energy (compared to wastewater treatment) to prepare appropriate water resource for irrigation.

Focusing on energy production, Sajithkumar and Ramasamy [16] proposed an effective technique, not only to treat greywater, but also to generate electricity via double-chambered microbial fuel cells (MFCs). Considering anaerobic technologies as their comparison baseline, Ghangrekar and Shinde [17] pointed out the main drawbacks of anaerobic reactors, including the process instability and microbial flush-out. However, they proposed to use MFCs in which electricity can be generated via degradation of organic contents by microorganisms. Note that they fed their treatment system with domestic greywater, stating that the output effluent is suitable enough for irrigation purposes. Evaluation of their experimental results showed a maximum open circuit voltage of 0.64 ± 0.04 V and 114 ± 1.41 mA of current in the research period using a small lab-scale facility [16].

Highlighting the energy consumption, Melo-Batista in Melo-Batista [18] showed that by adopting a correct irrigation source an increase in water efficiency is reached in agriculture, as well as savings of approximately 65 M€/year in Portugal. Being treated in central wastewater treatment plants, wastewater is generally reused for irrigating not only crops, but also gardens and golf courses. Briefly, municipal wastewater is treated to meet primary, secondary and sometimes tertiary degrees of treatment, followed by disinfection. Primary treatment is relatively standard among different wastewater treatment plants and includes waste collection, filtration, screening, chemical treatment, grit removal and sedimentation. Matos et al. [19] reported that in a wastewater treatment plant, the energy consumption of the primary treatment varies between 0.01 and 0.37 kWh/m^3. For the secondary treatment, considering the use of membrane bioreactors, energy consumption varies between 0.10 to 0.82 kWh/m^3, while for an advanced tertiary treatment energy consumption range between 0.23 and 10.55 kWh/m^3. While the water used for irrigation purposes does not necessarily needs to follow the regulations required for drinking purposes, less treatment stages can be applied, resulting in lower energy consumption. Therefore, the authors proposed an alternative for decreasing energy consumption by replacing wastewater treatment plants with in-situ greywater treatment facilities for treating water required for irrigation purposes. To prove the concept of saving energy via the proposed solution, the same authors compared the energy consumption of two treatment facilities: a wastewater centralized reuse system (WWCRS) and a greywater decentralized reuse system (GWDRS), concluding that GWDRS consumed between 11.8 and 37.5% of the energy required in WWCRS.

5. Conclusion

The objective of the current study was to review the effects of greywater irrigation on the quality of crops, as well as soil properties. Considering the fertility of soil and the studied researches, it can be concluded that fertilizer should be applied to crop fields to supply the nutrients which are not present in greywater, to enable optimal growth of plants. The reviewed studies have shown that greywater has been analyzed to be used for many irrigation purposes. Comparing with tap water, the nutrients and minerals (including both macro and micro) have been proved to affect the plants. Besides, not only the type of irrigating water, but also the irrigation method can influence not only the content, but also the risk factor of edible parts. Concerning yield, results showed that the response of leafy, root or bulbous vegetable crops remains unclear. Therefore, the effect of greywater on leafy or root crops is unclear. In the case of aesthetic evaluation of crop appearance, the studies reported negative impacts of greywater irrigation on some crops. Spinach, carrots and lettuce were negatively affected due to greywater irrigation, but cabbages, onions and beetroot presented only minimal effects. Different studies revealed that irrigation water quality can be manipulated to obtain the desired crop quality. In terms of energy consumption, there have been studies which investigate either the production of energy using greywater facilities or evaluating consumed energy required to provide water complying with irrigation norms. In either study, greywater showed promising potentials in both generating energy, or consuming less energy compared to wastewater treatment plants. Regarding the concerns about the health risk of consumers because of irrigation of crops with greywater, special attention should be considered. Briefly, it can be concluded that the application of greywater for irrigating crop products can increase yield and nutrients of the crops in case the type of plant and the irrigation water is well-studied.

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