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Monitoring and assessment of treated river, rain, gully pot and grey waters for irrigation of *Capsicum annuum*

Rawaa H. K. Al-Isawi • Suhad A. A. A. N. Almuktar • Miklas Scholz

R. H. K. Al-Isawi • S. A. A. A. N. Almuktar • M. Scholz (corresponding author)

Civil Engineering Research Group, School of Computing, Science and Engineering, The University of Salford, Newton Building, Salford M5 4WT, England, United Kingdom

e-mail: m.scholz@salford.ac.uk; tel.: 0044-161-2955921; fax: 0044-161-2955575

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Abstract This study examines the benefits and risks associated with various types of wastewater recycled for vegetable garden irrigation and propose the best water source in terms of its water quality impact on crop yields. The aim was to evaluate the usability of river, rain, gully pot, real grey and artificial grey waters to water crops. The objectives were to evaluate variables and boundary conditions influencing the growth of Chillies (De Cayenne; *Capsicum annuum* (Linnaeus) Longum Group 'De Cayenne') both in the laboratory and in the greenhouse. A few irrigated Chilli plants suffered from excess of some nutrients, which led to a relatively poor harvest. High levels of trace minerals and heavy metals were detected in river water, gully pot effluent and greywater. However, no significant differences in plant yields were observed, if compared with standards and other yields worldwide. The highest yields were associated with river water both in the laboratory and in the greenhouse. Plant productivity was unaffected by water quality due to the high manganese, potassium, cadmium and copper levels of the greywater. These results indicate the potential of river water and gully pot effluent as viable alternatives to potable water for irrigation in agriculture.

Keywords Agricultural water supply • Chilli, Environmental evaluation • Pollution control • Water reclamation • Wastewater management

Introduction

Background

Due to rapid urban population increases and climate change, wastewater discharge volumes will increase. Diffuse pollution linked to untreated wastewater or the lack of wastewater disposal facilities negatively impacts on receiving water bodies (Jang *et al*. 2013) and leads to public health challenges (Corcoran *et al*. 2010; Khurana & Pritpal 2012). The proper management of reusing wastewater in agriculture could reduce the overall toxicity to both soil and crops as well improve water resource shortages. Asfaw *et al*. (2012) assessed the capability of different vegetable crops to grow under different concentrations of pollutants in wastewater used for irrigation purposes. Findings showed considerable tolerance in growing of vegetable seeds under low concentration levels whereas higher effluent concentrations were linked to inhibitory effects.

Water recycling for crop irrigation

The use of river water for irrigation of plants in the agriculture sector is rather common; e.g., Silvi et al. (2007) and Jain & Chaurasia (1998) found that river water is suitable for the irrigation of crops. In comparison, poor quality water may negatively affect irrigated crops such as industrially polluted water streams (Banerjee & Gupta (2010) or pathogen-contaminated water sources (Cooper & Lipe 1992). Tsado *et al*. (2014) and Rahman *et al*. (2014) highlighted the importance of variables such as conductivity, total dissolve solids, the sodium adsorption ratio (SAR) and specific ion toxicities for assessing the quality of river water used for irrigation.

Rainwater collection particularly in semi-arid areas can make a significant contribution to the irrigation of crops. Radaideh *et al*. (2009) assessed the suitability of rainwater collected in the northern region of Jordan. Findings indicated great variations in water quality depending on the storage tanks used, catchment area characteristics and the availability of public sanitary systems.

Gully pots are a common feature of many sewerage drainage systems in urban areas. Their main function is to retain solids from road run-off. They are used to minimise the challenges linked with sediment in downstream drainage structures, pumps, wastewater treatment plants and receiving watercourses. Gully pot water is regularly taken out of gully pots together with sediment and urban rubbish for subsequent treatment (Scholz 2004).

Grey water comprises wastewater from bath tubs, showers, wash basins, laundry facilities and kitchen sinks (Palmquist & Hanaeus 2005). Detergents and soaps are the predominant components of grey water (Jefferson *et al*. 1999). Mohamed et al. (2013) assessed grey water reuse in garden irrigation. The soil analyses results showed that salinity and the organic content of the soil increased as a function of time, subsequently affecting the growth of plants. In comparison, Pinto *et al*. (2010) undertook a glasshouse experiment to assess the effect of grey water on the growth characteristics of silver beet plants compared to the control treatment of pure potable water. Results indicated that grey water irrigation had no negative effect on the plant dry biomass, number of leaves and water use.

Travis *et al*. (2010) undertook a controlled experiment to study the effect of using raw and treated artificial grey water for irrigation purposes. Findings indicated that raw artificial grey water considerably increased hydrophobicity in both the sand and loam soils, and subsequently affected plant growth. In comparison, treated artificial grey water was successfully used for irrigation without any negative impact on soil or plant developments.

Selection of Chillies

The authors concentrated on Chilli (De Cayenne; *Capsicum annuum* (Linnaeus) Longum Group 'De Cayenne') as an example vegetable. Chillies grow well in climates, which are moist and warm and where the soils are rich in nutrients. This fruiting vegetable is commonly grown as an annual in temperate climatic regions.

Nutrients and minerals

Heavy metals can be toxic to peppers, particularly if they are grown in acidic soil (FAO 2003). FAO (1994) classified treated wastewater for recycling. Acceptable ranges for ammonia-nitrogen, ortho-phosphate-phosphorous and potassium were from 0 to 5 mg/l, 0 to 2 mg/l, and 0 to 2 mg/l in that order. Pescod (1992) highlighted that there is no restriction for irrigation water, if nitrate-nitrogen concentrations are below 5.0 mg/l. There are slight to moderate restrictions between 5 and 30 mg/l, and severe restrictions for values above 30.0 mg/l.

Johnson & Decoteau (1996) recommended that Chillies should not be grown when nitrogen is higher than 280 kg/ha. Furthermore, Haifa Chemicals (2014) highlighted the following needs of pepper: nitrogen (390–920 kg/ha), phosphorus pentoxide (200–330 kg/ha), potassium oxide (640–1530 kg/ha), calcium oxide (100–210 kg/ha), magnesium oxide (60–150 kg/ha) and sulphur (40–50 kg/ha).

Rationale, aim and objectives

The benefits of recycling various types of wastewater for agricultural purposes are widely known. However, their appropriate management to maximize yield productivity and keep the environment safe remain thinly implemented. Furthermore, instead of using expensive drinking water in agriculture, various recycled water and wastewater streams might be suitable for the successful irrigation of Chillies. The presence of contaminants including nutrients in such waters might reduce the need for fertiliser application.

The overall aim of this study is to evaluate if Chillies can be grown with success on river, rain, gully pot and grey waters. The objectives are to assess (a) the impact of the environmental conditions such as humidity and temperature on growth in different environments, (b) the growth characteristics when using various waters, and (c) the economic return of various experimental set-ups both within the laboratory (benchmark) and a greenhouse.

Methodology

Water sources and planting locations

Five different water sources were collected and used as irrigation water both within laboratory and greenhouse settings. River water was collected freshly directly from the River Irwell (located east to the main campus of The University of Salford). Rain water was collected from the roof of a greenhouse via gutters discharging into a clean plastic tank. Gully pot water was randomly collected freshly from manholes located on The University of Salford campus. Gully pot waters were filtered using a sieve with a diameter of approximately 250 µm. Two grey water types were used for irrigation of the Chillies. Real grey water and artificial (synthetic) grey water. The real grey water was obtained freshly from the private property of the lead author (located in Withington, south-east of Salford) and used directly for irrigation purposes. In comparison, the artificial grey water was prepared according to the recipe by Nghiem *et al*. (2006) using the following compounds: humic acid (20 mg/l), cellulose (50 mg/l), kaolin (50 mg/l), calcium chloride (0.5 mM or 20 mg/l of calcium), sodium chloride (10 mM) and sodium bicarbonate (1mM at pH 8). All chemicals used for preparing the synthetic grey water were provided by Fisher Scientific UK Ltd, Loughborough, England, UK.

The greenhouse is located on the roof of a building belonging to The University of Salford, Greater Manchester, UK (Al-Isawi *et al*. 2014; Almuktar *et al*. 2015). Chillies were grown between 12 February and 24 December 2014. In the laboratory, 30 Chilli plants in total were grown for control purposes. In comparison, the other 30 plants of this experiment were moved to the greenhouse to be grown under more realistic but rather uncontrolled environmental conditions. Six replicates for each of the five water types tested were grown in both laboratory and greenhouse plant set-ups.

Water quality analysis

The water quality analysis was carried out according to APHA (2005) standards. The spectrophotometer entitled DR 2800 Hach Lange (Salford, England, UK) was utilised for the determination of the variables chemical oxygen demand (COD), ammonia-nitrogen, nitrate-nitrogen, ortho-phosphate-phosphorus and SS.

The five-day biochemical oxygen demand (BOD) was measured with the help of the OxiTop IS 12-6 system supplied by the Wissenschaftlich-TechnischeWerkstätten, Weilheim, Germany. Nitrification in the BOD bottles was suppressed by adding 0.05 ml of 5 g/l N-Allylthiourea (WTW chemical solution No. NTH600) solution per 50 ml of sample water.

A Turbicheck Turbidity Meter (Lovibond Water Testing, Tintometer Group, Amesbury, England, UK) was used to estimate the turbidity. The pH was determined with a sensION+Benchtop Multi-Parameter Meter provided by Hach Lange, Düsseldorf, Germany. A VARIO pH meter (Wissenschaftlich-TechnischeWerkstätten (WTW), Weilheim, Germany) was applied to measure the redox potential. The electrical conductivity was estimated with a Mettler-Toledo AG (Schwerzenbach, Switzerland) conductivity measurement device. The dissolved oxygen was determined with a Hach Lange HQ30d dissolved oxygen meter (Salford, England, UK).

All analyses of water samples for trace elements were performed using a Varian 720-ES Inductively Coupled Plasma – Optical Emission Spectrometer (ICP–OES) provided by Agilent Technologies UK Ltd, Wharfedale Road, Wokingham, Berkshire, UK. This equipment item was used to determine nutrient and trace element concentrations. Water samples of 50 ml were preserved in glassware bottles at 4°C (EPA 1994). The samples were then acidified, if appropriate, by adding 1 ml of 70% concentrated nitric acid to dissolve any suspended material in order to extract heavy metals and to reduce the pH to below 2, which was required for analysis. The samples were then filtered through a paper with a pore diameter of 0.45 µm before analyses by ICP–OES.

Environmental monitoring

Table 1 provides an overview of the boundary conditions in the laboratory and greenhouse. Considerable differences in temperature and relative humidity values were recorded in the two different places. The higher temperature records were observed in the laboratory compared to those in the greenhouse. In contrast, the relative humidity values recorded in the greenhouse were higher than those in the laboratory.

A LUX meter ATP-DT-1300, which is suitable for the range between 200 LUX and 50,000 LUX, was supplied by TIMSTAR (Road Three, Winsford Industrial Estate, Winsford, Cheshire, UK) to measure light. The humidity and temperature were determined by a Thermometer-Hygrometer-Station provided by wetterladen24.de (JM Handelspunkt, Geschwend, Germany).

Electric heaters (Rhino H029400 TQ3 2.8kW Thermo Quartz Infrared Heater 230V) provided by Express Tools Ltd. (Alton Road, Bournemouth, UK) were used to control the room temperature. Humidifiers (Challenge 3.0L Ultrasonic Humidifier; Argos, Avebury Boulevard, Central Milton Keynes, England, UK) controlled the humidity in the laboratory.

First planting

Chilli (De Cayenne) seeds were purchased from B&Q plc (Chandlers Ford, Hants SO53 3LE; www.diy.com) on 10 February 2014. The 144 seeds were sown into seed and cutting compost (verve; B&Q plc), and a 6-mm layer of compost was put on top of the seeds on 12 February 2014. The propagators used comprised 72 planting cells and each had a mean depth of 5 cm.

After germination on 10 March 2014, the plants were placed in a laboratory benefiting from OSRAMHQL (MBF-U) High Pressure Mercury Lamp (400 W; Base E40) grow lights purchased from OSRAM (North Industrial Road, Foshan, Guangdong, China) and placed into a H4000 Gear Unit provided by Philips (London Road, Croyden CR9 3QR). The temperature close to the plants was within the range from 15.3 to 29.5°C (average of 23.7°C). The light conditions in Salford were simulated (http://www.timeanddate.com).

Second and final planting

The second and final planting of the strongest 60 Chilli plants took place on 8 April 2014. The weakest 56 Chilli plants were not replanted. Thirty Chilli plants were kept permanently indoors. The remaining 30 plants were moved to the greenhouse. Chillies were planted individually into 10-litre plastic pots provided by scotplants (Hedgehogs Nursery, Crompton Road, Glenrothes, Scotland, UK). The Chillies were planted to a depth of 17.5 cm and covered by a further 2.5 cm of bark.

Results and discussion

Water quality analysis

Table 2 shows the inflow water quality. The COD can be used as an indication for organic pollutants that may induce lipid peroxidation and toxicity to plants. The COD values were the highest for real grey water (301.0 mg/l). In comparison, the lowest values were measured for river water (6.3 mg/l). Pots receiving rain and gully pot water had relatively similar COD concentrations (15.9 and 17.7 mg/l, respectively). Artificial grey water had lower COD values (87.5 mg/l) than real grey water (301.0 mg/l). The five-day BOD was elevated for gully pot water and real grey water (64.8 and 64.3 mg/l, respectively). In contrast, the lowest five-day BOD was recorded for river water (5.6 mg/l).

According to Ayers & Westcot (1994), crops are relatively unaffected until nitrogen in the irrigation water exceeds 30 mg/1. High ammonia-nitrogen concentrations that exceeded 5 mg/l (FAO 1994) were measured for both gully pot and river water (11.1 and 9.9 mg/l, respectively). Table 2 indicates that the nitrate-nitrogen concentrations for all types of irrigation water were below the maximum threshold of 30 mg/l (Pescod 1992). However, there are minor concerns for both river and gully pot water, because moderate restrictions exist for values between 5 and 30 mg/l. Nitrate is very soluble in water and can easily move through soil (Saba *et al*. 2006).

Phosphorus is essential and often limited in freshwater; it plays a significant role in many ecosystems due to its impact on eutrophication (Scholz 2010; Thomas 1973). Considering the threshold of 2 mg/l for ortho-phosphate-phosphorus (FAO 1994), the values for all types of irrigation water (with the exception of rain water (1.7 mg/l)) were linked with too elevated ortho-phosphate-phosphorus values.

The highest mean value for SS was recorded for real grey water (449.9 mg/l) followed by that for gully pot water (106.3 mg/l). In comparison, the lowest mean value was noted for river water (3.7 mg/l). Turbidity was high for real grey water (249.5 NTU). River water (2.9 NTU) had the lowest turbidity values. However, high values of SS and turbidity linked with grey water will lead to an increase of hydrophobicity in the soils, affecting the growth of plants (Travis *et al*. 2010).

The pH values for all types of irrigated water were within the acceptable range between 6.0 and 8.5 (Pescod 1992; Scholz 2010), which is unlikely to cause a nutritional imbalance. Conductivity is an important measure of salinity, which poses a hazard to crops and determines the suitability of irrigation water. Conductivity plays an important role in the suitability of water for irrigation. High levels of electrical conductivity in water create saline soil. According to Subba (2006), salts impact adversely on plant growth, soil structure and permeability, which indirectly affect plant development. The conductivity was high for artificial grey water (1447.5 μS/cm), which considerably increased the salinity of the irrigated soil and subsequently affecting plant growth negatively (Hamaiedeh & Bino 2010). However, the lowest value of conductivity was observed for rain water (74.6 μS/cm). If the experiment would have been continued over winter, it is likely that the conductivity of gully pot water would have been the highest due to salting of roads in the UK (Scholz 2004). However, the experiment was stopped before road salting was necessary.

Table 2 also indicates the findings of an overview of the ICP–OES analysis for irrigation water types. Based on the threshold of 2 mg/l for potassium (FAO, 2003), river water and gully water were linked to too high potassium concentrations (5.5 and 6.1 mg/l respectively). Regarding manganese, the recommended threshold is 0.2 mg/l (FAO 2003). Real grey water is high (0.26 mg/l) in manganese compared to other water types. However, manganese is an important trace element for plants. Nevertheless, too much manganese is often toxic. Manganese phytotoxicity causes a reduction of biomass and photosynthesis, and subsequent biochemical disorders (Millaleo *et al*. 2010).

SAR is seen as a measure of the tendency of water to be responsible for the replacement of calcium (Ca) and magnesium (Mg) ions attached to the soil minerals with sodium (Na) ions. This indicator is used to estimate the sodium hazard of irrigation water and higher SAR values will potentially cause damage to the soil structure. The results of the analysed water samples show that all types of irrigation water have low SAR values (0.2-3.5), which present no irrigation problem as the standard range is between 0 and 15, and will be highly suitable for irrigation of edible crops (Tsado et al. 2014; FAO 2013).

Cadmium values (Table 2) considerably exceeded the threshold of 0.01 mg/l for both gully and artificial irrigation water types (FAO 2003). This heavy metal is toxic to most organisms. Some crops take up cadmium from soil or contaminated irrigation water, and it may enrich it in their corresponding roots and shoots. Cadmium-induced effects include oxidative stress, geno-toxicity as well as inhibition of the photosynthetic process and root metabolism (Andresen & Küpper 2013).

Table 2 indicates that artificial grey water is linked to a high copper concentration of 0.27 mg/l. This value is above the threshold of 0.2 mg/l set by FAO (2013). According to Panou-Filotheou *et al* (2001), the impact of copper toxicity on plants may result in significant structural alterations, which result in reduced metabolic activity and subsequently negatively affect plant growth.

No significant effect of metals in terms of plant growth, density of plants and the growth of chilli fruits was noted for the first eight months of the experiment. Dalahmeh *et al*. (2012) suggested that soil and bark adsorb metals and other pollutants associated with wastewater to reduce pollutants to below their corresponding guideline values. It follows that the top soil layer and the bark (on top of the soil to reduce evaporation) used in the current experiment may be responsible for some of the reduction in pollutants.

Furthermore, SAR values for all water sources were within the standard range between 0 milliequivalent per litre (me/l) and 15 me/l (FAO, 1994). Therefore, concerns of soil salination were minimal.

Irrigation volume and growth comparisons

The results of the total water volumes associated with each chilli plant indicate that there is no obvious difference in the water consumption rates between both the laboratory and greenhouse locations (range between 23.54-28.62 l). However, with respect to river water, the laboratory set required considerably more water (28.62 l) compared to the greenhouse set (26.34 l). This can be explained by the relatively higher yield associated with river water compared to the other water types. Moreover, the relative difference in yield between river water tested in the laboratory and all other experimental set-ups both in the laboratory and in the greenhouse was also very high.

Figure 1 summarises bud, flower and fruit developments for Chillies, which did reasonably well in both the laboratory and greenhouse environments. However, the total number of buds, flowers and fruits produced by plants in the greenhouse were considerably higher than those generated by plants in the laboratory, possibly due to lower temperature and higher relative humidity. Low humidity impacted negatively on Chilli plants during the flowering and fruiting stage. A relative humidity between 60 and 90% has low impact on plants. Values below 60% in arid climates may cause water stress when plants are young and have small leaves.

For both sets of plants, most flowers successfully reached the fruiting stage (Figure 1(b)). Regarding the laboratory set, the highest number of fruits was linked to plants irrigated by river water followed by those irrigated by gully pot water. In contrast, the low fruit numbers correlated well with plants irrigated with real grey water. However, plants irrigated by rain water and artificial grey water produced similar numbers of fruits. In the first stages of crop growing, the rate growth of Chillies for all types of water showed no significant difference (P>0.05) between all pots. This suggests that small amounts of pollutants would not affect the growth of plants.

In the third period, these plants exhibited less fruit numbers than those for plants irrigated with rain water and grey waters (P<0.05). For rain water, this suggests that the plants feed on nutrients that originate from the compost, as there is a lack of nutrients in the rain water. However, with time the nutrient depletion in soil leads to a reduction of the yield of plants. For grey waters, it is suggested that high COD values for real grey water lead to accumulation of chemical compounds in the soil media, which are toxic to the growth of plants with time. Moreover, high conductivity values for artificial grey water with time results in the blocking of porous media, reducing the infiltration of water and solubility of nutrients, which are necessary to plants. This will subsequently impact negatively on the growth of plants.

In comparison, for the green house plants, the highest number of fruits was associated with plants irrigated by gully pot water followed by those irrigated by river water (Figures 1(c) and 1(d)). Low fruit numbers were linked to plants irrigated by artificial grey water. The fruits from rain and real grey water were relatively similar in terms of numbers.

Cost-benefit discussion

Seventy Chilli seeds were purchased from B&Q plc for 148 pence. One seed of Chilli costs therefore 2.11 pence. A single mature Chilli fruit costs in England about 16 pence each or 1040 pence per kilogram of Chillies.

The harvest classification scheme (Almuktar *et al*. 2015) shown in Table 3 was used in this study to estimate the economic value of the harvest. Regarding Chilli plants grown in the laboratory, the highest number of fruits categorised as Class A were harvested from Chillies irrigated with river water, which was also linked to the highest fruit numbers categorised as Class E. For gully pot water, the highest fruit numbers were categorised as Class C.

Regarding Chilli plants grown in the green house, river water and gully pot water were associated with the highest number of fruits categorised as Class A. Concerning rain water, most fruits belonged to Class B. For all types of water, the lowest fruit numbers were categorised as Classes D and E.

Figure 2 indicates the economic value of the harvest for Chilli plants. For both laboratory and greenhouse, the highest mean price of harvested fruits was associated with plants watered with river water followed by those irrigated with gully pot water. This confirms the suitability of river water for crop irrigation as discussed by Jain & Chaurasia (1998). The lowest mean price of harvested fruits in the laboratory experiment was associated with plants watered by rain water. While the lowest economic return in the green house experiment was noted for plants irrigated with artificial grey water. Overall yields of Chilies irrigated by grey water were low, indicating potential problems with salinity as discussed by Hamaiedeh & Bino (2010).

A comparison of the irrigation water qualities was undertaken (Table 4). Findings indicate that conductivity and SAR of river water was suitable for irrigation. Rain water was too low in nitrogen and phosphorus for proper Chilli growth (Radaideh et al. 2009). Gully pot water and real grey water show high variations in their water quality parameter values. Grey water sources (real and artificial) had good water quality. However, the reduction in the corresponding yield of Chillies could be attributed to high COD concentrations in real grey water and elevated conductivity values in the artificial grey water.

Conclusions and recommendations

The findings indicate that Chillies can be grown successfully applying river, rain, gully pot and grey waters for irrigation in both laboratory and greenhouse settings, despite of high heavy metal concentrations in some irrigation waters. However, results show that the marketable yield of plants grown in the greenhouse was considerably higher than that in the laboratory, possibly due to the adverse environmental boundary conditions such as a relatively low humidity in the laboratory. The greatest marketable yields in both the laboratory and the greenhouse were achieved when urban river water (followed by gully pot water) was used. The productivity of Chillies was independent of the water consumption. In general, the first eight months of the experiment showed the best growth of fruits for all plants. After that, the growth of fruits for plants receiving rain water and artificial grey water decreased gradually, possibly because of a lack of nutrients in these two types of water.

Further research to optimise nutrient and trace mineral provision using precision agriculture, which is, however, too inexpensive for most developing countries, is recommended. Further studies on using pre-treated grey water and gully pot water could also be useful to improve the quality of waters for irrigation purposes. Finally, the role of top soil and bark in reducing pollutants could also be assessed. Long-term monitoring programs will be required to evaluate the impact of accumulation of pollutants in soil as well as the ability of contaminants to reach groundwater.

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Fig. 1 Mean and standard deviation of buds, flowers and fruits for Chilli plants after the second replanting stage: (a) buds; (b) flowers; (c) total fruits and (c) harvested fruits

Fig. 2 Economic return for laboratory and greenhouse harvests of Chilli fruits in comparison to varied sources of irrigation water (RV, river water; RA, rain water; GP, gully pot water; RG, real grey water; and AG, artificial grey water). Values shown per plant represent pence (Sterling)