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Reuse of grey water for Agricultural irrigation

Sachin Madhavrao Kanawade

Abstract
Grey water from eight households was collected and delivered to the University to investigate its suitability for plant irrigation and growth. Semi-field growth trials were conducted at an experimental site situated on the University campus. Two trials were conducted (others are planned) and the soil was re cycled. In the first trial representative vegetables used were: aboveground crops (spinach, and green pepper) and below ground tubers (potatoes and madumbes). In the second trial, aboveground (spinach and green pepper) and belowground (beetroot and onions) were selected. In all, three experimental treatments were employed throughout: tap water, hydroponic nutrient solution and grey water. Results from the first trial, showed that nutrient irrigated vegetables gave a significantly greater increase in plant growth, compared with grey water, and tap water treatments. However, in the second trial irrigation with grey water yielded significantly greater yields and overall plant growth for peppers, spinach and onion than was achieved with the hydroponic nutrient solution. The reason for the improvement in soil fertility and yield is not immediately clear, nor is there yet evidence of potential deleterious effects of grey water on plant growth. Additional information may be forthcoming from the further three planting trials envisaged and allow, in particular, negative factors that may accompany repeated grey water reuse to be controlled or ameliorated through research and appropriate guidelines. It will further help improve overall water usage, and promote public acceptance of the concept.

Keywords: Grey water, reuse, irrigation, pollutants.

1. Introduction
In India, the disposal of household wastewater arising from activities such as bathing, washing clothes and washing dishes (greywater) is commonly disposed off to the ground in the vicinity of the dwelling which can lead to the pooling of wastewater. This in turn could lead to unpleasant odours, pollution of groundwater and surface runoff, soil erosion, health hazards and mosquito breeding. Grey water has been identified as a widespread problem in all categories of dense informal settlements in India, exacerbated by poor or absent solid waste management (1). However, grey water contains nutrients that are beneficial to the growth of most plants, but could be harmful if it entered waterways (2). Therefore one way to improve food security, and contribute to environmental improvement in poor communities served with dry sanitation, is to re-use grey water for irrigation of food crops in a small-scale urban agriculture.

Although grey water may contain grease, food particles, hair and other impurities, it does not normally contain human waste unless laundry tubs or basins are used to rinse soiled clothing or baby's nappies/diapers (3; 4; 5). Grey water use in urban agriculture is potentially beneficial for a number of reasons, including: (a) Reducing the demand for potable water use for irrigation; (b) Environmental degradation, eutrophication and health hazards through pooling of wastewater can be resolved; (c) Potentially wasted nutrients can be reclaimed; (d) It contributes to poverty alleviation and food security; (e) could encourages people to use environmentally, friendly chemicals in their households. Thus although grey water reuse poses public health and environmental concerns, with adequate guidelines and education, issues around water saving, food shortage and malnutrition could be resolved.

Health hazards associated with grey water may arise from three sources: (a) Contamination by pathogenic micro-organisms, including bacteria, protozoa, viruses and parasites, in concentrations high enough to present a health risks; (b) Chemical pollution by dissolved salts such as sodium, nitrogen, phosphates and chloride, boron or by organics such as oils, fats, milk, soap, detergents and xenobiotic compounds which may either be biodegradable or promote, or restrict plant growth; (c) Physical pollution by particles of dirt, food, lint may degrade soil structure, clog groundwater flow paths or cause non-wetting characteristics in soils (6). However, risk to consumers can be greatly reduced by crop restriction, modifying irrigation techniques and human exposure.

In 2003-2004, trials were conducted, one rural and one informal peri-urban community. Householders were provided with water-collecting containers, seeds and implements, and received training. All participants were satisfied with the crop quantity and quality achieved. However, before the use of grey water for urban agriculture can be widely promoted by the municipal authority, the effect on plant growth, sustainability of grey water irrigation (in terms of medium-to-long-term effects on soil quality), community acceptance of the practice, and associated health risks both during irrigation, and as a result of crop consumption, need to be investigated. This paper presents preliminary results of the first and second semi-field trial conducted to determine the effect of grey water on plant growth and yield, and also compare plant growth patterns in different seasons.

2. Materials and Methods

Experimental design

Grey water from eight households in this community was collected by Municipality, and delivered for use in semi-field trials. Cato Crest was selected for grey water collection on the basis of convenience of access. The selection of households was conducted in a preliminary study and was based on the number of people per household, ages, gender and washing applications (bath, hand basin, laundry and dish washing). Interviews and questionnaires were used to measure the grey water-producing activities. The total numbers of residents were 53, comprising 37 adults (18-100 year olds), 12 children (2-18 yr) and 4 infants (0-2yr). These households were supplied with 20 litre plastic buckets for grey water collection, which was collected by Municipality, weekly from Monday to Friday. Grey water from various households was pooled into a single 200-litre container prior to use for irrigation, and there was no pre-treatment before use.

Semi-field growth trials were conducted at an experimental site. Representative vegetable used for the first trial included, aboveground (spinach, green pepper) and belowground (potatoes, madumbes) crops after consultation with eThekwini Municipality. For the second trial, aboveground (spinach, green pepper) and belowground (beetroot, onions). These were grown in 20 L heavy polyethylene plastic bags at the site. The soil from the first trial was re-used and will be used for all five-crop cycles. Due to health risks implicit in the use of greywater, water was delivered directly to the root zone of each plant by a low-technology form of drip irrigation, a 500 ml plastic bottle, which had been punctured at the base and buried to half its length beside each plant.

Three experimental treatments were employed. Tap water containing no nutrients, served as a negative control, water amended with a commercially available plant nutrient medium served as a positive control, and grey water served as experimental treatment. Plants were watered daily with 500ml of the respective treatments, with the exception of the positive control. In accordance with usage instructions, the nutrient medium was applied once weekly and tap water was used on the remaining days for the positive control plants. A total of 25 plants of each crop type were used for each treatment. Of the 25 plants of the same type, 10 were sampled for microbiological analysis at the end of the crop cycle. To date, three cycles has been completed.

Grey water characterization

Prior to irrigation with grey water, fresh grey water samples were sent to EWS laboratories for physico-chemical and microbiological analysis. Physico-chemical analysis included; alkalinity, conductivity, pH, free ammonia, BOD, COD, cadmium, calcium, chloride, chrome, copper, lead, magnesium, nickel, nitrate+ nitrite, ortho-phosphate selenium, sulphate, total Kjeldahl nitrogen, total phosphate and zinc. Microbiological analysis included total coliforms, *E. coli,* coliphages and *Ascaris spp.*

Plant growth monitoring

Plant growth was measured weekly in both trials. Growth parameters included stem height, number of leaves, number of fruits, fresh weights and dry weight. Harvested crops were assessed for fresh and dry weights. Although other results were obtained in this report, only stem height and yield will be compared.

Soil analysis

Soil from all three treatments were analysed for physico-chemical parameters and nutrient content prior to any irrigation with grey water, nutrient solution and tap water. The physico-chemical analysis included electrical conductivity, sodium absorption ratio (SAR), total nitrogen, total phosphate, boron and pH. Nutrient content included total Kjeldahl nitrogen, total phosphate, potassium, manganese, calcium, zinc, manganese, cobalt, chloride and alluminium. The soils will be analysed again for following 2006 autumn crop cycle to determine the effects of grey water irrigation.

3. Results and Discussion

Greywater characterisation

Results of physico-chemical and microbiological characterisation of the raw grey water for both trials, as received at the experimental site, are shown in Table 1. Typically, chemical characteristics (ammonia, COD, orthophosphate, total nitrogen and total phosphorus) were greater than literature values by a factor of 2 to 10 (7; 8). This is consistent with the respective origins of the grey water. The cited studies were all conducted in Europe, with households receiving unlimited water supply. In contrast, households contributing grey water in this study were from a low-income peri-urban community, restricted to 200 litres/day free basic water supplies, and might be expected to yield higher levels of compounds. Nonetheless, when the ratios of nutrients were compared to published values for grey water, based on European conditions, there was no difference for those elements for which information was available. (9) Report a ratio of 2:1:2:3 for N: P: K: S in grey water, comparing this with a corresponding ratio of 4-10:1:1-8:0.3-1 for crop uptake of these elements. The ratio of N: P: S in this study was 2:1:3. (9) Comment that the excess of sulphur added via grey water may result in acidification of the soil. Also of concern are the high concentration of chloride and the high conductivity of the grey water, which may lead to salinisation of the soil (Table 1). High carbonate or alkali content as in the second trial is sometimes as a result of laundry grey water, which has a significant effect on pH of water and subsequently on the soil pH. When soil pH exceeds 8-8.5, some micronutrients deficiencies occur (10). These are potential problems, which will require monitoring in subsequent growth cycles. Conductivity, pH, ammonia, calcium, chloride, chrome, magnesium, ortho-phosphate, sulphate, total Kjeldahl nitrogen and total phosphate fractions increased to a certain extent when compared with grey water from the previous trial. These components are problematic if discharged to soils; therefore a strict monitoring of soil will be required.

Table 1: Characteristics of greywater from two trials, Nov-Feb and April-July respectively.

	Ranges from the 1st trial	Ranges from the 2nd trial	Units
Alkalinity	300-334	300-334	mg/l
Ammonia (free)	20	157	mg/l
BOD	280-310	300-320	mg/l
Cadmium	<0.05	<0.05	mg/l
Calcium	<5.0	7.5	mg/l
Chloride	210	220	mg/l
Chrome	0.11	0.14	mg/l
COD	1135	1140	mg/l
Conductivity	144-148	267	mSiemens/m
Copper	0.1	0.1	mg/l
Lead	0.2	<0.05	mg/l
Magnesium	5.6	7.1	mg/l
Nickel	<0.1	<0.10	mg/l
Nitrate + Nitrite	<0.1-1.2	<0.10	mg N/l
Ortho phosphate	11	40	mg P/l
pH	5.8-6.3	8.1	
Selenium	<0.05	<0.05	mg/l
Sulphate	113	137	mg/l
Total Kjeldahl Nitrogen	24-30	206	mg N/l
Total phosphate	13	69	mg/l
Zinc	0.22	0.20	mg/l
Total coliforms	$4x10^5$	$4.2x10^9$	cfu/100ml
E. coli	$4x10^5$	$4.2x10^9$	cfu/100ml
Coliphage	Not detected	Not detected	pfu
Ascaris spp	Not detected	Not detected	ova

Originally microbiological quality of the grey water used in the first trial of this study was in the same range as reported in the studies cited above but there was an increase in the bacterial counts in the second trial. An in increase in the bacterial count from the second trial may be due to many factors such, seasonal change, increased total phosphate and increased total Kjeldahl nitrogen. According to (11), proposing a modification of the 1989 WHO Guidelines for the Safe Use of Wastewater in Agriculture, this quality would be considered suitable only for restricted use, specifically localised irrigation of cereal crops, fodder crops, pasture and trees by trickle, drip or bubbler irrigation. This corresponds to the type of use, but not to the crops, for which grey water irrigation was piloted in communities by eThekwini Municipality and for which it was tested in the present study. Minimum treatment by primary sedimentation was also prescribed (11), but this is not likely to be implementable in the local context.

Growth measurement

Figure 1 and 2 shows the plant growth as indicated by stem height for the first and second trials for grey water treatment, the positive control (nutrient solution) and the negative control (tap water). The results indicated that, in the first trial there was a consistent increase in plant height when crops were irrigated with nutrient solution and with grey water, as compared with tap water. Although growth with grey water-irrigated crops was less than with nutrient solution irrigated crops, it was still significantly greater than with tap water irrigated crops. Plants irrigated with tap water did not increase significantly in height throughout the crop cycle, whereas height increased steadily over time with both nutrient solution and grey water irrigation. The limited growth in tap water irrigated vegetables is due to the fact that Berea red sand used is a nutrient poor clay soil, which supports plant growth to a limited extent. In the case of potato growth it was seen that, plant growth increased over the entire crop cycle with nutrient solution, whereas the stems dried out in the final two weeks with grey water irrigation (Fig. 1C). In general, nutrient irrigated vegetables showed a significant increase in plant growth, compared with grey water and tap water over the first trial.

However, irrigation with grey water in the second trial yielded significantly greater stem heights for green peppers, spinach, and onions whereas tap water irrigated vegetables showed poor growth. Increased plant growth noted in crops irrigated with grey water in this study, is in accordance with those obtained by (12) and (13) who observed that crops irrigated with treated effluent, which had raised inorganic nutrients, produced higher growth and yields than similar crops irrigated with ground water. Plants irrigated with tap water did not increase significantly in height throughout the crop cycle, whereas height increased steadily over time in both grey water and nutrient solution irrigated crops. It is tempting to speculate that either plant growth on the balanced hydroponics solution was less than grey water irrigated plants because of enhanced soil microbial activity in the latter, or potential inhibition by excess micronutrients in the former. Thus, overall grey water irrigated vegetables showed the greatest plant heights throughout the entire crop cycle.

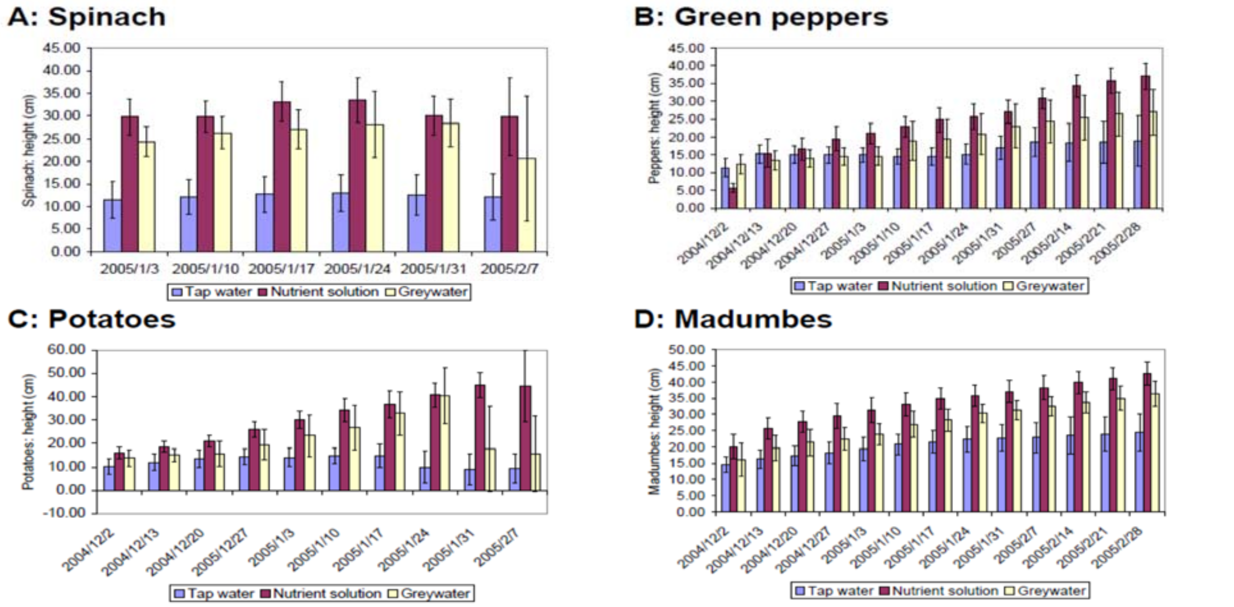

Figure 1: Stem height of spinach (A), green peppers (B), potatoes (C) and madumbes (D), monitored throughout one crop cycle. Figures show means and standard deviations for 25 plants.

Spinach (A): Crops irrigated with nutrient solution and with greywater were consistently significantly taller than crops irrigated with tap water. Crops irrigated with nutrient solution and grey water were similar in height after 24/1/2005. Peppers (B): Crops irrigated with nutrient solution and greywater were generally significantly taller than crops irrigated with tap water. Potatoes (C): Crops irrigated with nutrient solution were significantly taller than the rest throughout. Crops irrigated with greywater were taller than cops irrigated with tap water except on 20/12/2003, 31/1/2005 and 7/2/2005. Madumbes (D): Crops irrigated with nutrient solution were significantly taller than crops irrigated with greywater, which in turn were significantly taller than crops irrigated with tap water. All comparisons by 1-way ANOVA, p≤0.05.

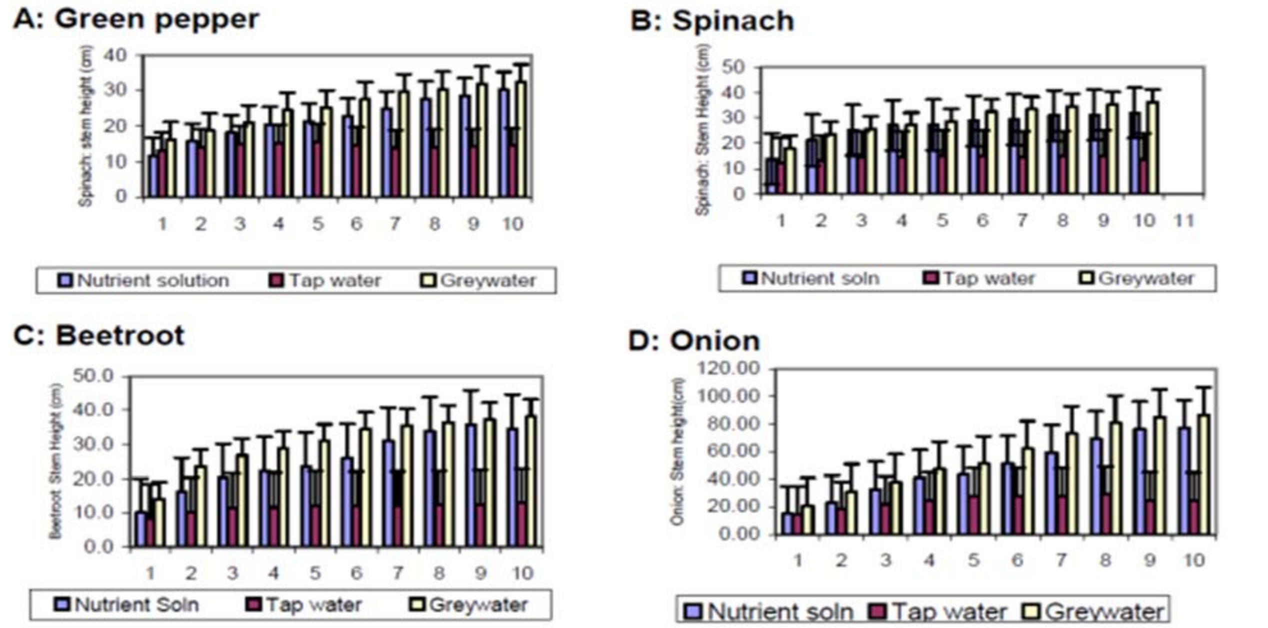

Figure 2: Stem height of green pepper (A), spinach (B), beetroot (C) and onion (D), monitored throughout the second trial crop cycle. Figures show means for 15 plants.

Green pepper (A): Crops irrigated with grey water and with nutrient solution were consistently taller than crops irrigated with tap water. Crops irrigated with grey water were taller than any other crop in other treatments. Spinach (B): Crops irrigated with greywater and nutrient solution were generally significantly taller than crops irrigated with tap water. Beetroot (C): Crops irrigated with grey water were significantly taller than the rest throughout. Crops irrigated with nutrient solution were taller than cops irrigated with tap water. Onion (D): Crops irrigated with grey water were significantly taller than crops irrigated with nutrient solution, which in turn were significantly taller than crops irrigated with tap water. All comparisons by 1-way ANOVA, p≤0.05.

Total yield

Figures 3 and 4 show the yield for the first and second trials measured by total fresh weight (g) as yields per treatment. The first trial (Fig 3), indicated that yield was significantly higher in nutrient solution treatments for all plants than either grey water or tap water. There was no significant difference in yield between nutrient solution and grey water-irrigated spinach plants. Green pepper yield measured by fresh weight was greater with grey water irrigation than with tap water, but not significantly so. This contrasts with yield assessment on the basis on number of fruits, for which production with grey water was significantly greater than with tap water (5:3). Grey water did not increase the yield of potatoes (in fact, total yield was lower than with tap water). For madumbes, the yield of grey water-irrigated plants was significantly greater than tap water-irrigated plants, but also significantly lower than plants irrigated with nutrient solution. Crops such potatoes and madumbes have high requirements for both potassium and nitrogen, especially during early growth and tuber formation, which makes these results puzzling. Soil pH maybe excluded as a factor since it was in the range 5.8-6.3, which is optimal for potatoes.

Yields measured in the second trial by total fresh weight, per treatment, are shown in Figure 4. Yield was significantly higher with grey water-irrigated green peppers than nutrient irrigated ones. Tap water irrigated green peppers had the lowest yield compared to other treatments. Nutrient irrigated spinach produced a significantly greater yield than grey water irrigated spinach, while tap water irrigated spinach gave an almost negligible yield (5g). Beetroot and onion plants irrigated with grey water produced significantly greater yields when compared to nutrient solution irrigated and tap water irrigated underground plants In general; all crops irrigated with tap water produced poor yields. Except for spinach, all crop irrigated with grey water produced the greatest yield. The maximum yield increase was achieved in grey water-irrigated crops in the second trial in contrast to the first trial. It is necessary to highlight that grey water could increase fertility of the soils, *per se.* For instance, (14) observed that rice crops gave higher yields when irrigated with raw or partially diluted sewage effluent compared to unamended ground water. Initially rice grew better if a fertilizer was used concurrently with sewage effluent, but the requirement for additional fertilizer decreased over time due to the improved fertility of the soil. It points to grey water as a potential source for food production in poor peri-urban communities with minimal resources. Microbial results to date indicate that health-associated risks are small if the irrigation regime involves belowground watering, as in the study. Furthermore reusing grey water reduces the use of potable water. Possible negative impacts include cumulative buildup of heavy metals, salinization, and impacts on soil structure. These negatives factors can all be controlled through research and development of proper guidelines. Research and development of guidelines will improve and increase the use of grey water for irrigation purposes as well as public acceptance

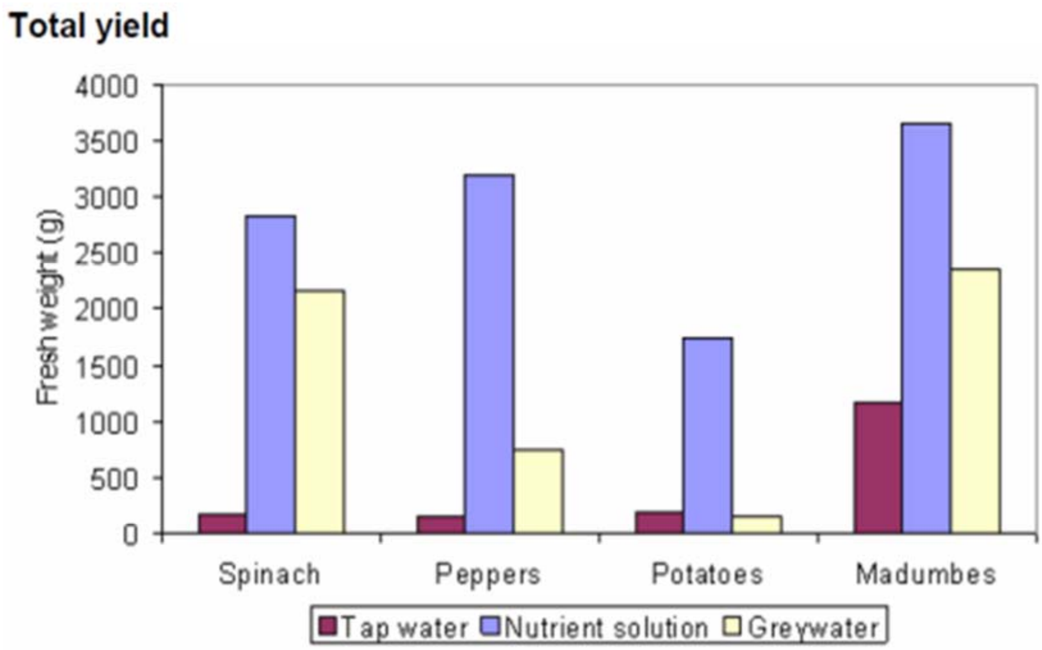

Figure 3. Total yield for spinach, green peppers, potatoes and madumbes for one crop cycle. This figure shows a total yield measured in fresh weight for all plants

Statistical comparison of yield per plant showed that spinach yields were significantly greater for nutrient solution and greywater treatments, when compared to tap water; pepper and potato yields were significantly enhanced relative to tap water and nutrient solution but not by greywater; madumbe yield with greywater treatment was significantly greater than with tap water, and significantly greater with nutrient solution treatment than with greywater treatment. When yield of pepper fruits was compared by treatment, greywater treatment yielded significantly more fruits (total) than tap water, and nutrient solution treatment yielded significantly more fruits (total) than greywater. All comparisons by 1-way ANOVA, $p \leq 0.05$

Total yield

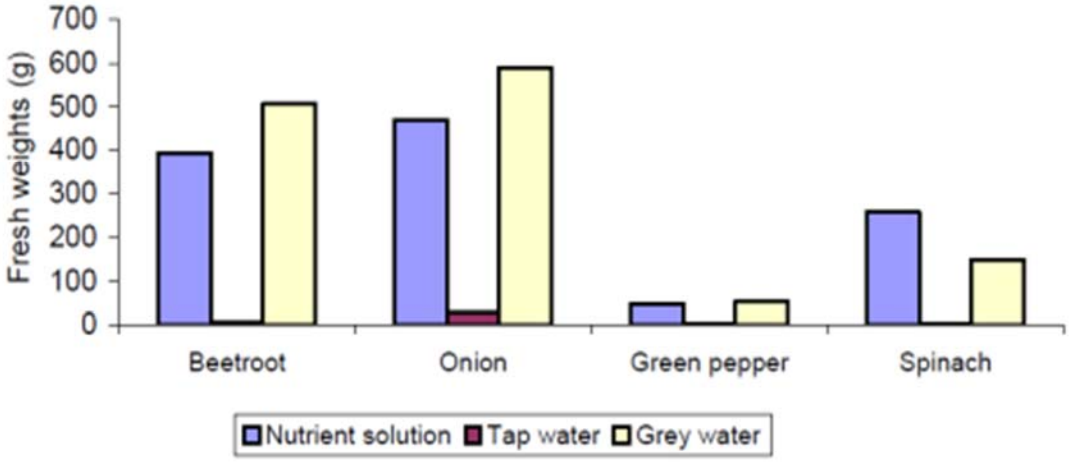

Figure 4: Total yield over time for beetroot, onion, green pepper and spinach. This figure shows a total yield measured in fresh weight for all plants.

Statistical comparison of yield per plant showed that beetroot and onion yields were significantly greater for greywater treatment followed by nutrient solution, tap water had the minimal beetroot yield. Green pepper yield was slightly higher with crops irrigated with grey water when compared to nutrient irrigated green pepper. Spinach yield was greater with nutrient irrigated followed by grey water irrigated, tap water had the lowest yield. In general, grey water treatment produced the greatest yield followed by nutrient solution.

4. Conclusions

Results from the first trial, showed that nutrient irrigated vegetables gave a significantly greater increase in plant growth, compared with grey water, and tap water treatments. However, in the second trial irrigation with grey water yielded significantly greater yields and overall plant growth for peppers, spinach and onion than was achieved with the hydroponic nutrient solution. The reason for the improvement in soil fertility and yield is not immediately clear, nor is there yet evidence of potential deleterious effects of grey water on plant growth. Additional information may be forthcoming from the further three planting trials envisaged and allow, in particular, negative factors that may accompany repeated grey water reuse to be controlled or ameliorated through research and appropriate guidelines. It will further help improve overall water usage, and promote public acceptance of the concept.

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