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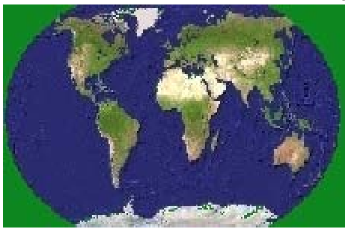

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Effect of powder and liquid laundry detergents on Swiss chard plants

Sachin Madhavrao Kanawade

Abstract
Reuse of grey water (non-toilet household wastewater) for irrigation is a potential means of recovering water and nutrients which would otherwise be lost through discharge. Irrigation of food crops can improve food security in poor communities. Laundry grey water represents a substantial proportion of overall household grey water. It holds potential benefits for irrigation use in that it contains some plant nutrients, but also has potential problems because it contains salts which can be harmful to plants and soil. In this study, Swiss chard plants were irrigated for 96 days with laundry grey water generated with either powder or liquid laundry detergent. A balanced nutrient solution and tap water were used as comparative treatments. Plants irrigated with nutrient solution performed markedly better than all other treatments. Laundry grey water generated with powder detergent produced similar plant growth and yield as tap water. However, high electrical conductivity, sodium concentration and sodium adsorption ratio in the grey water indicated that soil problems were likely in the longer term. Plants irrigated with laundry grey water generated with liquid detergent fared the worst. Grey water analysis suggested that this could be attributed either to high chemical oxygen demand, resulting from higher detergent concentration in the liquid detergent than in the powder detergent, or to boron which was present in only the liquid detergent. Comparison of accumulation of biomass by roots and leaves in all treatments other than the nutrient solution treatment was suggestive of nutrient deficiencies. The pH of all irrigated soils increased slightly over the experimental period, but did not differ significantly among treatments.

Keywords: Grey water, treatment, laundry water, soil, detergent

1. Introduction

It is estimated that by 2013 India will be facing severe constraints on fresh water supplies. Many developing countries are facing a similar dilemma. Innovative approaches are required to find alternate sources of water. Concepts such as ecological sanitation (EcoSan) have arisen to address this need. The underlying principle of EcoSan is that domestic waste should be seen as a potential resource for further use to recover water and plant nutrients which would otherwise be lost through discharge to the environment (1). Grey water is untreated household effluent from baths, showers, kitchen and hand wash basins, and laundry (*i.e.* all non-toilet uses). More than half of indoor household water use is normally used for these purposes and can potentially be intercepted by the householder for additional uses to relieve pressure on fresh water supplies. Uses to which grey water can be put include pour-flush toilets, irrigation of gardens, lawns, shrubs and trees, and dust control (2,3). In view of seasonal water restrictions in many part of the country, and perennial poverty in low-income communities, the use of grey water to supplement irrigation water is particularly attractive. This is already practiced on an informal basis in urban gardens in middle to upper income suburbs in times of drought, or in food gardens in lower income informal, peri-urban and rural areas.

Grey water irrigation holds the potential to contribute significantly to food security in poor communities by providing a source of both irrigation water and nutrients for crop plants. Where crops are produced in excess of household needs and can be sold or exchanged for other goods or services, it further holds the potential for informal employment. However, microbiological and chemical constituents of grey water pose hazards to human health and to the environment. These need to be characterised so that appropriate measures can be taken to control these. Mixed grey water streams in non-sewered areas in South Africa are often too polluted for further use except under controlled conditions (3). One form of control which is easily practiced at household level in all income strata is separation of grey water by source (*i.e.* bath, laundry, kitchen). In general, in sewered areas grey water represents about 68% of the total wastewater stream whereas in non-sewered areas the production of grey water could theoretically reach 100%. A survey studies of grey water generation in homes with piped water supply and waterborne sanitation in several countries has shown that the biggest contributor to grey water is bath grey water (Table 1). Bath grey water is also the least contaminated and hence the preferred source of grey water for further use. Laundry water constitutes the next largest contributor to grey water production **(Table 1)**, and also the next most suitable for further use in terms of quality (2). Thus further investigation of the suitability of laundry grey water for irrigation use is warranted. Microbiological contamination of laundry grey water originates predominantly from washing of faecally soiled items, such as nappies. Chemical contamination derives predominantly from detergent compounds and salts present in laundry detergents, which vary with the manufacturer and formulation.

Table 1: Mean daily water consumption and grey water production according to household use type for a typical household with piped water supply and waterborne sewerage (from 2).

Domestic water use	Mean percentage volume used and percentage range	Greywater production: mean daily per person volume produced (L)
Kitchen	9 (5-16)	17
Bathroom	26 (12-40)	85
Laundry	18 (4-22)	52
Toilet flushing	47 (41-65)	
Total of means	**100%**	**154**

The focus of this paper is the impact of the chemical composition and formulation of laundry detergent on the ability of laundry grey water to support growth of a common food crop, Swiss chard. The effects of two detergent formulations were compared: a powder detergent and a liquid
detergent. Powdered detergent contains more salts while liquid detergent contains more detergent.

2. Methodology

Experimental Design

Swiss chard and green pepper seedlings (moderately salt tolerant) obtained from a nursery were planted in 20 L planting bags. The bottom of each bag was layered with coarse gravel to facilitate drainage, and the bags filled with Berea red soil (a sand-derived highly leached red soil common in the Durban area) sourced from the Unilever head-office grounds. A 500 mL plastic bottle with six holes in the base at the bottom was buried to approximately twothirds of its length beside each seedling **(Figure 1).** This served as a form of sub-surface irrigation and ensured that the irrigation treatments were delivered directly to the root zone of each plant. All seedlings were irrigated with tap water for two weeks after transplantation. Thereafter, plants were randomised and received 500 mL of one of the following irrigation treatments: a hydroponics solution providing a balanced source of plant nutrients (referred to as nutrient solution hereafter), tap water, grey water generated using a powder laundry (grey water G1), or grey water using a liquid laundry detergent (grey water G2). Each plant received only one treatment for the duration of the
growth cycle. Plants were harvested when the first treatment reached maturity. In the case of Swiss chard, this was a period of 96 days (14 weeks) starting in July 2009. Results for Swiss chard only are presented here since green peppers were ready for harvesting too late for inclusion. Results are for one growth cycle only, although a total of three cycles is planned for each crop.

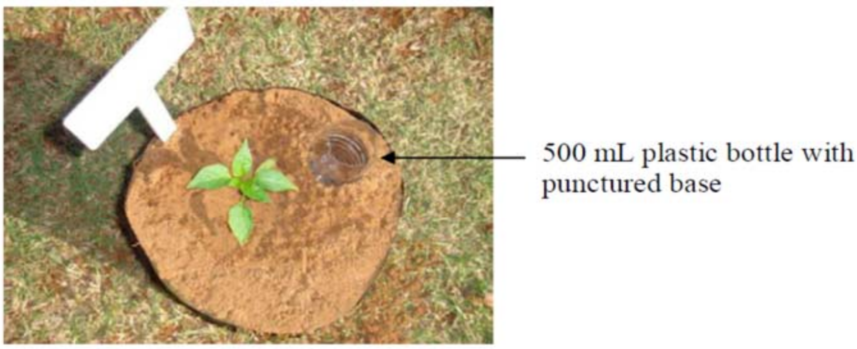

Figure 1: Green pepper seedling planted in Berea red soil, showing top of a 500 mL plastic bottle buried alongside through which sub-surface irrigation was provided.

Grey water Generation
Grey water was produced on-site every second day, using a top loader (twin tub) washing machine with the powder detergent to simulate hand washing conditions and a front loader washing machine with the liquid detergent to simulate machine washing. Technical observation data collected by external research houses for Unilever were used to identify the 16 most common types of stains in India **(Table 2).** Standard samples of these stain types, spotted onto white cotton squares, were used to generate a uniform dirt load per wash. The remainder of each laundry load comprised ballast (standard white cotton pillow cases). Standardized conditions were used for washing **(Tables 3 and 4).** Grey water was collected into separate 200 L ground tanks. Nutrient solution was made upeach day according to manufacturer's directions (Chemicult®). Tap water was drawn directly from a garden tap supplied with municipal water supply. Samples of each irrigation treatment were collected periodically and sent to the laboratories for analysis. Water samples were tested for chemical oxygen demand (COD), pH, electrical conductivity (EC), nitrate-nitrogen, ammonianitrogen, total nitrogen, phosphorus, potassium, sulphur, aluminium, boron, calcium, magnesium and sodium.

Table 2: Stain types used in each laundry load during the generation of laundry greywater.

Stain type
Black tea
Black coffee
Red wine
Berocca vitamin drink
Cooking oil
Curry
Black polish
Grease
Red soil
Rust
Chocolate
Grass
Tomato sauce
Jam
White tea
White coffee

Plant growth and yield measurement
Plant height was recorded daily for each plant and aggregated on a weekly basis. Following harvesting, fresh weights and dry weights of the above-ground and below-ground portions of each plant were recorded. Dry weights were determined by weighing the fresh plant material on a mass balance, drying the fresh plant material in an oven at 80°C for 72 h, and then reweighing.

Soil analysis
Soil pH, moisture and temperature were measured daily with appropriate soil pH, moisture and temperature probes, of which only pH data are presented here. Soil sampled from a representative number of plant bags at the beginning and end of the growth cycle was sent to Soil Laboratory for fertility assessment and sodium analysis. These results were not available at the time of writing.

Statistical analysis
Statistical comparisons among all treatments for above and below ground dry plant biomass and
proportion contributions thereof to overall dry plant biomass were conducted using use of one-way analysis . The beginning and end harvest cycle soil pH values were statistically compared using the parametric paired sample *t*-test. Assumptions of all tests were tested and statistically verified. Where data failed to satisfy these assumptions, logarithmic transformations of these data were performed. In those instances where this and other data transformation functions did not achieve resolution of assumption violations, the associated non-parametric analyses were instead used.

Table 3: Wash conditions used for greywater generation in front loader washing machines.

Variable	Wash conditions
Load size	3 kg
Dosage	100 mL liquid detergent
Wash temperature	Ambient
Wash cycle	Quick 30 (30 min; economy cycle)
Rinse cycle	1 cycle

Table 4: Wash conditions used for greywater generation in twin tub washing machines.

Variable	Wash conditions
Wash water volume	25 L
Load size	2.4 kg
Dosage	125 g powder detergent
Wash temperature	Ambient
Wash cycle	15 minute soak, 15 minute wash
Rinse cycle	1 rinse cycle of approximately 6 min in 25 L water

3. Results

Chemical analysis of water from the four irrigation treatments showed that nutrient solution contained all nutrients at extremely high concentration (Table 5), considerably higher than required to support plant growth, suggesting that the concentration of hydroponics mixture should be decreased in subsequent growth cycles. The high concentration of nutrient ions resulted in a high conductivity. Tap water had neutral pH and low to undetectable levels of all variables. Grey waters G1 (from powder detergent) and G2 (from liquid detergent) both had high COD, that of grey water G2 being three times that of grey water G1 **(Table 5).** Grey water G1 had higher pH, electrical conductivity (EC), phosphorus, sulphur, sodium and sodium adsorption ratio (SAR) than grey water G2. The SAR of grey water G1 was more than three times higher than that of grey water G2 and 14 times higher than that of the nutrient solution. Measurement of growth of Swiss chard plants irrigated with the four irrigation treatments showed that plant growth for all treatments followed a logarithmic growth trend **(Figure 2).** However, Swiss chard plants irrigated with nutrient solution grew considerably more rapidly than all other treatments and attained mean final harvest heights of between 10 cm and 20 cm higher than all other treatments. Growth rates of the remaining treatments were only marginally different on a weekly mean basis. Growth trends among these treatments were similar throughout, as were the final mean plant heights. The growth trends shown in Figure 2 are illustrated by the appearance of representative plants from each treatment at the time of harvest **(Figure 3).**

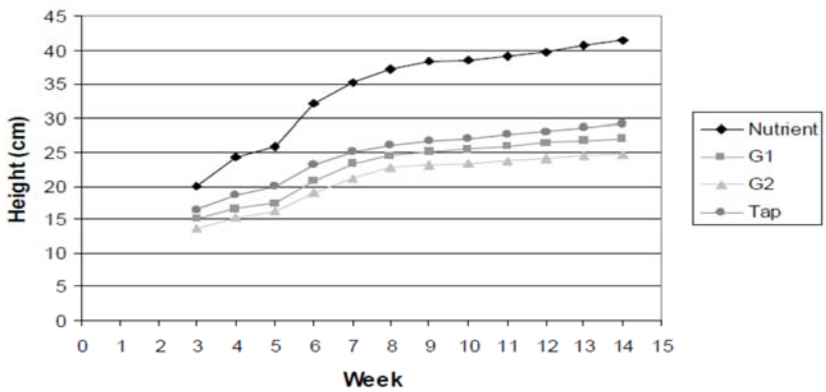

Figure 2: Mean weekly growth of Swiss chard plants, measured as plant height, for four irrigation treatments over 14 weeks (96 days) of irrigation (n = 9 replicates per treatment). Nutrient = irrigation with plant nutrient solution; G1 = irrigation with greywater generated using powder laundry detergent; G2 = irrigation with greywater generated using liquid laundry detergent; Tap = irrigation with tap water

Table 5: Analysis of the chemical composition of water for four irrigation treatments: balanced nutrient solution, tap water, greywater generated with powder detergent (G1), greywater generated with liquid detergent (G2).

Variable	**Nutrient solution**	**Tap water**	**G1**	**G2**
Chemical oxygen demand (mg/L)	40	< 1	402	1235
pH	5.0	7.5	9.2	7.2
Electrical conductivity (mS/m)	2507	12	121	28
Nitrate-nitrogen (mg/L)	7.5	< 1	< 1	< 1
Ammonia-nitrogen (mg/L)	400	< 1	< 1	< 1
Total nitrogen (mg/L)	1300	2.0	1.0	5.0
Phosphorus (mg/L)	1207	< 1	69	2.4
Potassium (mg/L)	6290	< 1	2.4	3.6
Sulphur (mg/L)	1995	5.2	101	< 1
Aluminium (mg/L)	< 1	< 1	2.3	< 1
Boron (mg/L)	9.0	< 1	< 1	3.6
Calcium (mg/L)	832	6.6	13	6.1
Magnesium (mg/L)	1064	3.7	5.4	3.2
Sodium (mg/L)	220	7.2	306	56
Sodium adsorption ratio (SAR[1])	5.1	2.2	71.3	18.4

[1] **SAR = $[Na^+]/([Ca^{2+}] + [Mg^{2+}])^{½}$** **[1]**
where $[Na^+]$, $[Ca^{2+}]$, and $[Mg^{2+}]$ are the concentrations of sodium, calcium, and magnesium (mmol/L) (4).

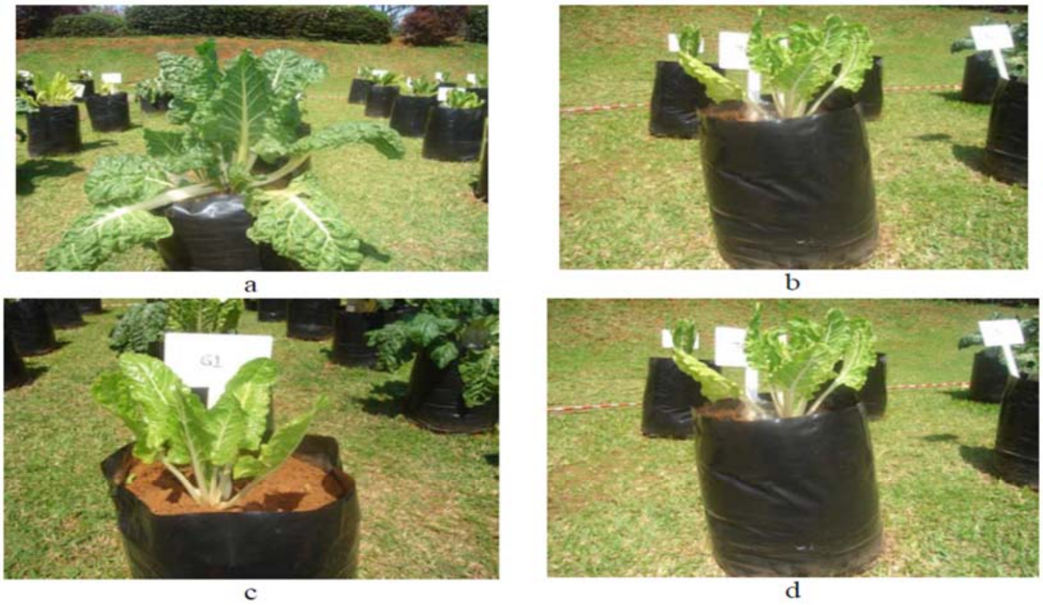

Figure 3: Swiss chard plants at harvest, following 96 days irrigation with (a) plant nutrient solution, (b) tap water, (c) greywater generated with powder laundry detergent (G1), and (c) greywater generated with liquid laundry detergent (G2).

After harvesting of the above-ground parts of the Swiss chard plants, roots were carefully loosened from the soil and excavated as intact as possible. Root morphology varied among treatments. Roots from plants irrigated with nutrient solution had a dense network of fine roots **(Figure 4a).** By contrast, roots of plants irrigated with the other three treatments had fewer and coarser roots. These roots also had areas of thickening resembling nodules, which were absent from roots of plants irrigated with nutrient solution **(Figure 4b-d).** Irrigation with nutrient solution yielded significantly higher dry biomas values than any of the other irrigation treatments, both of leaves (Figure 5) and of roots **(Figure 6).** There were no significant differences ($p < 0.05$) in dry biomass of leaves or roots between plants irrigated with tap water and those irrigated with grey water G1 (from powder detergent). Grey water G2 (from liquid detergent) yielded significantly lower ($p < 0.05$) dry biomass yield of leaves and roots than all other treatments. When allocation of biomass to leaves and roots was compared among the four irrigation treatments, the nutrient solution treatment showed a statistically significantly higher proportion ($p < 0.05$) of total dry-weight biomass allocated to leaves compared to all other treatments **(Figure 7).** By contrast, the proportions of total dry-weight biomass allocated to roots were significantly higher ($p < 0.05$) for the grey water and tap water treatments when compared with the nutrient solution treatment.

Figure 4: Roots of Swiss chard plants at harvest, following 96 days irrigation with (a) plant nutrient solution, (b) tap water, (c) greywater generated with powder laundry detergent (G1), and (d) greywater generated with liquid laundry detergent (G2).

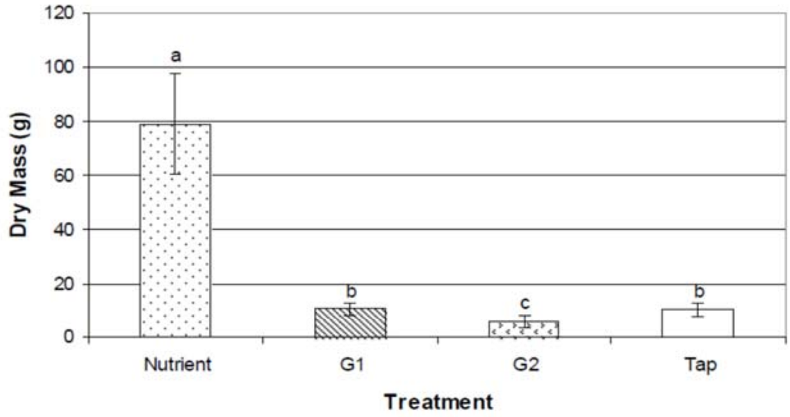

Figure 5: Mean dry mass of leaves of Swiss chard plants from four irrigation treatments after 96 days irrigation. Nutrient = irrigation with plant nutrient solution; G1 = irrigation with greywater generated using powder laundry detergent; G2 = irrigation with greywater generated using liquid laundry detergent; Tap = irrigation with tap water
Vertical bars represent standard deviations. Letters represent mean separation by Scheffe's multiple range test ($P < 0.05$; $n = 9$ per treatment).

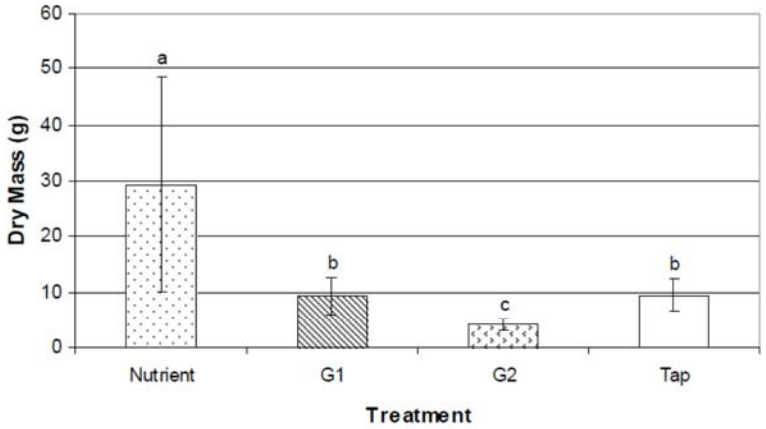

Figure 6: Mean dry mass of roots of Swiss chard plants from four irrigation treatments after 96 days irrigation. Nutrient = irrigation with plant nutrient solution; G1 = irrigation with greywater generated using powder laundry detergent; G2 = irrigation with greywater generated using liquid laundry detergent; Tap = irrigation with tap water
Vertical bars represent standard deviations. Letters represent mean separation by Scheffe's multiple range test ($P < 0.05$; $n = 9$ per treatment.

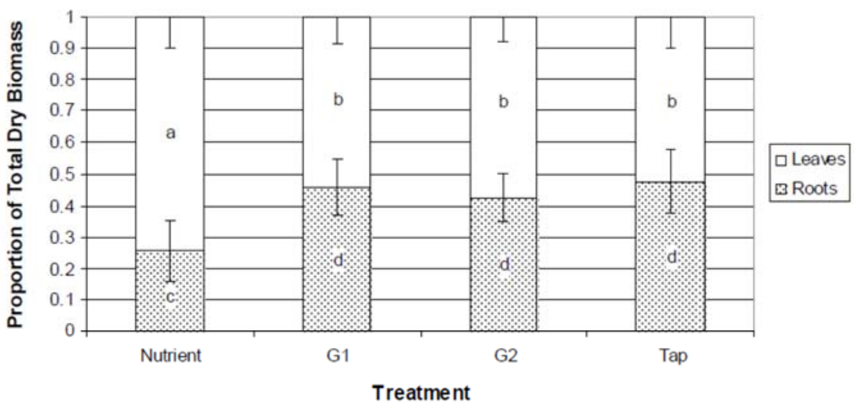

Figure 7: Partitioning of biomass to leaves and roots after irrigation for 96 days with four irrigation treatments. Nutrient = irrigation with plant nutrient solution; G1 = irrigation with greywater generated using powder laundry detergent; G2 = irrigation with greywater generated using liquid laundry detergent; Tap = irrigation with tap water
Vertical bars represent positive and negative standard deviations (roots) and negative standard deviations only (leaves). Letters represent mean separation by Scheffe's multiple range test ($P < 0.05$; $n = 9$ replicates per treatment).

The pH of soil in planting bags was monitored throughout the 96 days (14 weeks) of irrigation. In all four irrigation treatments, mean soil pH, aggregated on a weekly basis, was found to increase significantly ($p < 0.05$) over this period when initial and final pH values were compared **(Figure 8).** However, the final pH was in the neutral range.

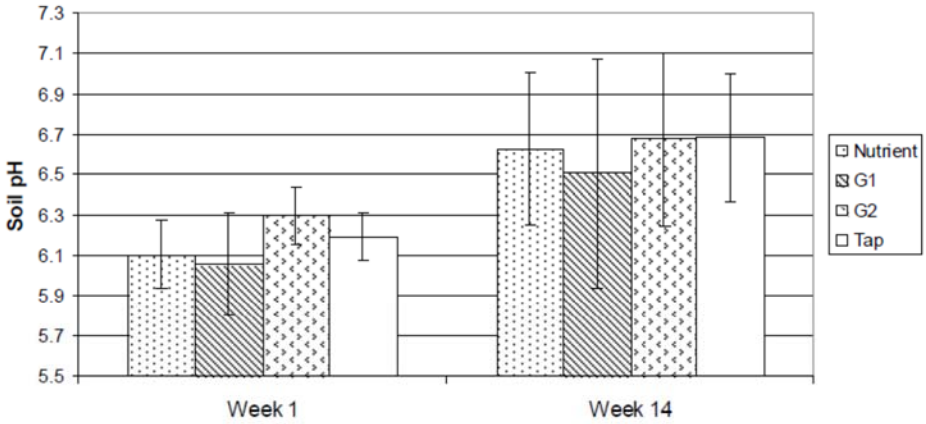

Figure 8: Mean pH of soil after irrigation for 96 days (14 weeks) with four irrigation treatments. Soil pH was measured daily and aggregated by week. Nutrient = irrigation with plant nutrient solution; G1 = irrigation with greywater generated using powder laundry detergent; G2 = irrigation with greywater generated using liquid laundry detergent; Tap = irrigation with tap water
Vertical bars represent standard deviations (*n* = 9 replicates per treatment).

4. Discussion

Grey water quality

PH

The optimal pH range for irrigation water is 6.5 to 8.4, to avoid negative impacts for both soil and plants (4). The pH of grey water that originates from laundry is generally in the range 9.3 to 10, while other sources of grey water have lower pH values, ranging from 5.0 to 8.7 (5). High pH values in laundry grey water are the result of high concentrations of powdered detergents, soaps and softeners (6). This was borne out in a limited survey of grey water by source **(Table 6)** and in the present study by laundry grey water generated with powder detergent (G1) **(Table 5).** However, grey water generated with liquid detergent had a pH close to neutral. All irrigation treatments, including nutrient solution and tap water, increased the average pH of the soil in this study from an initial value of 6.1 to 6.3 to a final value of around 6.6 (Figure 8), probably because the initial pH was slightly acidic relative to all treatments. Despite the higher pH of grey water G1 relative to other treatments, 96 days irrigation did not raise soil pH above that of other irrigation treatments. However, change in soil pH is a long-term phenomenon so it may require more than one growth cycle for the more alkaline grey water to have an impact.

Chemical oxygen demand

Chemical oxygen demand is used to measure organic pollution in water in terms of the amount of oxygen required to oxidise all oxidisable compounds in water. Concentrations of COD in laundry grey water are derived from household chemicals such as dishwashing and laundry detergents, food waste from the kitchen sinks, and body dirt in the bathtub and laundry (7). In this study, COD of grey water generated with powder detergent **(Table 5)** was consistent with that of laundry detergent in an earlier survey **(Table 6).** The COD of laundry grey water generated with liquid detergent was much higher, at the upper end of ranges reported for mixed grey water **(Table 7).** Unless laundry is very heavily soiled, laundry detergent is the largest contributor to COD of laundry grey water. Thus the higher COD of grey water generated with liquid detergent may be expected to relate to the detergent formulation of that product.

Electrical conductivity, sodium and sodium adsorption ratio

Electrical conductivity measures the concentration of dissolved salts, both positively and negatively charged ions. Sodium, calcium, magnesium, chloride and sulphate ions are the main contributing ions to salts in grey water. The most common sources of salts in grey water are sodium-based soaps, nitrates, and phosphates found in detergents and powdered soaps (8). The EC of irrigation water in general, and here specifically in laundry grey water, indicates the potential impact on soil salinity (4). There are a number of negative effects of salts in grey water on soils. These include tendency to raise soil alkalinity and salinity, swelling and dispersion of clay particles, reduction in the ability of soil to absorb and retain water, increased soil osmotic potential and hence decrease in plant water uptake, and reduced availability of vital mineral nutrients needed for plant growth (4,9).

The EC of grey water from powder detergent (G1) was markedly higher than that of grey water from liquid detergent (G2) (Table 5), being similar to that of other laundry grey water surveyed (Table 6) and in ranges reported in studies of mixed grey water (Table 7). The higher EC of grey water G1 relative to grey water G2 is consistent with the higher salt content of powder laundry detergent relative to liquid detergent. Sulphur, presumably mostly in the form of sulphates, was highest in grey water generated from powder detergent (G1) (Table 5). This most likely originates from sulphate salts, such as sodium sulphates, present in powder detergent. Sulphate is non-toxic so it is unlikely to have an effect on plant growth and yield, or on soil. High sulphate concentrations in irrigation water can lower soil pH, which may counteract the alkalinisation of soil by the high pH of grey water G1 in the longer term.

Sodium is of particular concern for irrigation use of grey water use because it affects the cation exchange capacity of soil. The presence of sodium sulphate, sodium carbonate, sodium tripolyphosphates sodium citrate, sodium silicate, sodium perborate and sodium hypochlorite salts, particularly from laundry detergents, increases the concentration of sodium in grey water and hence of sodium in grey water-irrigated soils (6,8). Sodium can have an impact on plant growth and crop quality directly via sodium toxicity. The adverse effect of sodium on soil is measured in terms of the sodium adsorption ratio (SAR, Equation 1). This is defined as the potential of a given irrigation water to induce sodic conditions in the irrigation soil, where sodicity is the percentage of the soil cation exchange capacity that is occupied by sodium. The value of SAR is primarily its usefulness for predicting reduction in soil permeability. Permeability is reduced through reduction in either infiltration or hydraulic conductivity (and sometimes both), making it difficult for water to penetrate the soil. Another possible impairment in soil physical quality is deterioration in the upper layer, termed hard-setting. This makes soil difficult to cultivate, and causes poor tilth (*i.e.* soil is slippery when wet or hard when dry). Soil structure also becomes more dense, with a tendency for soils to compact (4,8). The SAR levels in grey water are typically within the range 2 to10 depending on the source of grey water (8).

In this study, the lower salt content of the liquid detergent yielded grey water (G2) with markedly lower EC, sodium concentration and SAR than that from powder detergent (grey water G1) (Table 5). The high sodium content of grey water G1 was similar to sodium concentration previously found in laundry grey water (Table 6) and towards the upper end of the sodium ranges reported in mixed grey water (Table 7), supporting arguments that detergents are a major contributor of sodium in grey water. Although sodium toxicity and soil effects did not appear to affect plant growth and yield of plants irrigated with grey water G1 relative to irrigation with tap water over one growth cycle (Figures 3, 6 and 7), the high SAR of this grey water indicates that soil deterioration is almost certain to occur in the longer term. The SAR of grey water G2 suggests that this is more likely to be tolerated by plants and soil, especially if soil is amended with gypsum periodically (4). Although sodium concentration in nutrient solution was also high, this was offset by correspondingly high concentrations of calcium and magnesium, resulting in a SAR which is well tolerated by plants and soil.

Nutrients

Literature reports elevated nitrogen and phosphate concentrations in grey water **(Table 7).** These are thought to originate primarily from washing and cleaning detergents. High concentrations of
phosphorus between, 6 and 23 mg/L, can be found where phosphorus detergents are used, while concentrations of 4 to 14 mg/L are found where non-phosphorus detergents are used (8). In the present study (Table 5), and in a previous survey of laundry grey water (Table 6), the concentrations of various forms of nitrogen were low and similar to concentrations in tap water. Thus minimal benefit of nitrogen as a plant nutrient is likely to derive from irrigation with laundry grey water generated using either powder or liquid formulations. This indicates that laundry detergent is not a major contributor to nitrogen in mixed grey water, where much higher concentrations can be found (Table 7). Phosphorus concentrations in grey water generated from powder detergent (G1) were found here to be elevated relative to tap water while those in grey water generated from liquid detergent (G2) were low (Table 5). The phosphorus concentration in grey water G1 was similar to that previously reported for laundry grey water (Table 6) and within ranges reported for mixed grey water (Table 7). Theoretically, this phosphorus could contribute to plant nutrients. However, phosphorus in irrigation water is generally tightly bound by soil and therefore unavailable to plants. If grey water with elevated phosphorus levels were applied repeatedly to the same soil, the soil could become saturated with phosphorus over time, where after it would become available for plant uptake. Thus a nutrient effect from phosphorus in grey water would be expected to become evident only in the longer term. This is borne out by results presented here – growth and yield of Swiss chard plants irrigated with grey water G1 (which had the higher phosphorus concentration of the two laundry grey waters tested) were not noticeably different from those of plants irrigated with tap water (Figures 2, 5 and 6).

Table 6: Greywater quality, analysed by source for middle income households.

	Greywater source		
	Kitchen	Bath	Laundry
Total phosphorus (mg/L)	8.8	0.54	91.06
Nitrate+Nitrite (mg/L)	0.14	0.17	0.21
Potassium (mg/L)		3.56	10.33
Chemical oxygen demand (mg/L)	2056	900	393
Sodium (mg/L)		41.3	229.4
Electrical conductivity(mS/m)	59.1	31.2	207.2
Boron (mg/L)	0.096	0.12	0.51
Chloride (mg/L)	78	47	61
pH	6.68	7.05	8.05
Sulphate (mg/L)	41.23	10.06	541.61
Calcium (mg/L)	15.68	11.25	16.6
Magnesium (mg/L)	9.02	4.08	8.48
Zinc (mg/L)	0.003	0.005	0.07
Ammonia-free (mg/L)	4.69	0.59	3.08
Alkalinity (mg/L)	115	90.8	480

Boron

Boron is a naturally-occurring element found in soils, but it may also be present in detergents and laundry products containing ingredients such as sodium perborate and borax. In soil solution, boron occurs as undissociated boric acid except in highly alkaline soils (pH > 8.5) where it is in the form boric acid. It adsorbs to soil by both physical and chemical processes (4,9). Although irrigation with grey water containing boron may help remedy soil deficiencies of this essential nutrient, excess boron is very toxic toxic to plants. Boron tolerance varies from plant species; therefore careful selection of plants should be made for grey water irrigation implementations (4,6). Although Unilever no longer uses ingredients containing boron in its laundry detergent formulations, boron was unexpectedly elevated in grey water generated from powder detergent (G2,) to levels which could have an adverse effect on sensitive plants (4). The source of this boron is under investigation. Although levels of boron in grey water G2 were lower than in nutrient solution, the extremely high nitrogen levels in nutrient solution probably offset any adverse effect of boron in that treatment.

Table 7: Comparison of greywater quality results from a number of studies of greywater quality (from 3).

Variable	Review of international studies	Various unsewered areas, South Africa	Cato Manor, Durban, South Africa	Moshoeshoe Ecovillage, Kimberley, South Africa	Kwamathukuza, Newcastle South Africa
pH	5.0-8.7	3.3-10.9	5.8-6.3	6.1-7.0	-
Electrical conductivity (mS/m)	32-2000	28-1763	144-148	83-132	-
Phosphate-phosphorus (mg/L)	0.6-68	0.7-769	11	14.8-56.2	0.3-18.9
Chemical oxygen demand (mg/L)	13-549	32-11451	1135	530-3520	999-1625
Suspended solids (mg/L)	6.4-330	-	-	69.0-1420	265.2-1261
Oil and grease (mg/L)	3.1-12	8-4650	-	-	-
Total Kjeldahl nitrogen (mg/L)	2.1-31.5	0.6-488.0	24-30	-	-
Ammonia nitrogen (mg/L)	0.03-25.4	0.2-44.7	20	-	-
Sodium (mg/L)	29-230	96-1700	-	-	-

Plant growth

All measures of Swiss chard growth (plant height, dry weight of leaves, dry weight of roots –Figures 2, 5 and 6) are consistent with the very elevated concentrations of plant nutrients in the nutrient solution. Irrigation with grey water G1 yielded comparable growth and yield to irrigation with tap water, showing that in the short term at least, laundry grey water from powder detergent did not adversely affect plant growth relative to tap water. The long term picture is likely to be different because of the high EC, SAR and sodium concentrations in grey water G1, indicating that sodium toxicity, soil salinisation and soil sodicity may present problems. Growth of Swiss chard plants irrigated with grey water G2 were lower than of plants irrigated with tap water, indicating that constituents of grey water generated with the liquid laundry detergent were detrimental to plants. The two most likely candidates for this are elevated COD and boron levels in G2 grey water.

The nodule-like thickenings on roots of all treatments except the nutrient solution treatment (Figure 4) may represent a response to environmental stress, possible low nutrient nitrogen levels. This is consistent with the low nitrogen concentrations measured in all irrigation treatments other than nutrient solution. The higher allocation of biomass to roots in these treatments **(Figure 7)** is also suggestive of nutrient deficiency – a larger percentage of biomass was invested in maximizing extraction of nutrients from soil than in plants irrigated with nutrient solution.

5. Conclusions

Reuse of grey water (non-toilet household wastewater) for irrigation is a potential means of recovering water and nutrients which would otherwise be lost through discharge. Irrigation of food crops can improve food security in poor communities. Laundry grey water represents a substantial proportion of overall household grey water. It holds potential benefits for irrigation use in that it contains some plant nutrients, but also has potential problems because it contains salts which can be harmful to plants and soil. In this study, Swiss chard plants were irrigated for 96 days with laundry grey water generated with either powder or liquid laundry detergent. A balanced nutrient solution and tap water were used as comparative treatments. Plants irrigated with nutrient solution performed markedly better than all other treatments. Laundry grey water generated with powder detergent produced similar plant growth and yield as tap water. However, high electrical conductivity, sodium concentration and sodium adsorption ratio in the grey water indicated that soil problems were likely in the longer term. Plants irrigated with laundry grey water generated with liquid detergent fared the worst. Grey water analysis suggested that this could be attributed either to high chemical oxygen demand, resulting from higher detergent concentration in the liquid detergent than in the powder detergent, or to boron which was present in only the liquid detergent. Comparison of accumulation of biomass by roots and leaves in all treatments other than the nutrient solution treatment was suggestive of nutrient deficiencies. The pH of all irrigated soils increased slightly over the experimental period, but did not differ significantly among treatments.

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7. References

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