Turning (storm)water into food; the benefits and risks of vegetable raingardens

Evaluation des performances et des risques d'un jardin de pluie potager

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RÉSUMÉ

L’adoption des techniques pour le contrôle à la source des eaux pluviales, telles que les jardins de pluie, repose sur la perception des bénéfices par les particuliers. Un jardin potager recevant les eaux ruisselées combine les objectifs de la rétention du ruissellement urbain avec l’intérêt grandissant pour la production alimentaire en milieu urbain. Cette étude expérimentale a pour but d’évaluer les performances – en termes de récolte, de rétention du ruissellement et du risque de contamination – de deux configurations de jardins de pluie « potagers », et deux potagers classiques alimentés par le réseau d’eau potable ou par une citerne d’eau de pluie. Les analyses montrent que le jardin de pluie conçu pour maximiser la rétention et l’infiltration de l’eau de pluie a permis de réduire la fréquence de ruissellement de 90%, pour une production de légumes similaire. Le risque de contamination chimique ou microbienne d’un jardin potager alimenté en eau de pluie ne semble pas plus important que celui d’un jardin alimenté en eau potable, mais on note que ce risque dépendra du contexte local. Le concept d’un jardin de pluie potager semble ainsi prometteur, combinant la capacité à réduire les rejets urbains par temps de pluie, tout en promouvant la production alimentaire urbaine. Des études supplémentaires sont nécessaires pour établir la fiabilité d’un scenario où le jardin recevrait les eaux pluviales provenant de tout type de surfaces imperméables urbaines.

ABSTRACT

The adoption of stormwater source control techniques such as raingardens at the household scale depends on the perception of benefit to the householder. Vegetable raingardens integrate the ability to retain stormwater at the source, while supporting a growing interest in urban food production. We compared the performance of two designs of raingarden for vegetable growing with normal vegetable gardens fed either by potable water or rainwater collected in a tank. We evaluated their yield, stormwater retention and risk of contamination. The vegetable raingarden designed to promote stormwater retention and infiltration reduced the frequency of runoff by more than 90%, yet produced a vegetable yield comparable with traditional vegetable garden designs. The chemical and microbial contamination risk from raingardens irrigated with roof water is no higher than from a vegetable garden irrigated with potable water, but we note that results may be context-specific. The concept of a vegetable raingarden has promise for its ability to simultaneously reduce stormwater runoff and support urban food production; further studies are necessary to determine if it is suitable where the raingarden receives general stormwater runoff from urban impervious surfaces.

KEYWORDS

Pathogens, Raingarden, Risk assessment, Stormwater retention, Vegetables

1 INTRODUCTION

Bioretention systems are a widely used technology for retaining, treating and filtering urban stormwater runoff. They are an effective means to reduce concentrations and loads of pollutants (Davis et al., 2009; Hunt et al., 2006), attenuate quantities and rates of urban runoff (Davis, 2008; Hatt et al., 2009; Li et al., 2009), and potentially improve the amenity and aesthetics of urban landscapes. Numerous agencies around the world are attempting to engage the community in the implementation of bioretention systems, with the term “raingardens” being used to convey the potential benefit in the urban landscape, including at the lot scale. For example, Melbourne Water has the “10,000 Raingardens Programme” (http://raingardens.melbournewater.com.au/), while the Greater City of Lyon (Grand Lyon) has a similar push towards the use of raingardens (http://www.grandlyon.com/Gestion-des-eaux-pluviales.947.0.html). However, the rate of adoption by householders of such technologies depends substantially on their perceived benefit to the householder (Frey et al., 2008; Shaw et al., 2011; Thurston et al., 2008).

Recent interest in urban food production and food security (Bettencourt & West, 2010; Dixon et al., 2009) provides a new opportunity to combine food production with at-source stormwater management. The use of raingardens to grow vegetables could have great potential to both increase adoption of raingardens at the household scale and contribute to a sense of community self-sufficiency and wellbeing. A vegetable raingarden thus allows householders to decrease the environmental impact of their diet through a reduced dependence on the industrial food system, while reducing impacts of stormwater on receiving waters.

Urban stormwater is, however, typically polluted with a range of contaminants including sediments, elevated levels of nutrients, metals, pathogens and other toxicants, posing a potential risk to humans where it comes into contact with food.

Furthermore, water availability in a raingarden will be markedly different to conventional systems for cultivating vegetables. As such, the design of a raingarden will have to be modified to optimise the growing conditions for vegetables. For example, conventional raingardens generally receive their water at the surface. For growing vegetables, however, sub-irrigation (ie. watering from below) appears to be a more efficient irrigation method than surface irrigation. This has been demonstrated for tomato cultivation by Goodwin et al. (2003), Santamaria et al. (2003) and Incrocci et al. (2006). Through these modifications, and in growing less drought tolerant plants that are likely to need some supplementary irrigation, it is important that the ability of raingardens to attenuate quantities and rates of urban runoff is retained.

In this project we investigated the performance of two sub-irrigated vegetable raingardens, which capture roofwater, in terms of hydrology, vegetable production (yield), and chemical and microbial contamination. One of the raingardens was lined and the other free-draining. In particular, in this study we aimed to determine whether:

1. Sub-irrigated raingardens can reduce the frequency, volume, flow rate and pollutant load of stormwater discharge to receiving waters.
2. Sub-irrigated raingardens produce vegetable yield that is similar to (or better than) that produced by traditional, surface-irrigated vegetable gardens.
3. The chemical and microbial contamination of vegetables irrigated with roofwater is greater than that experienced by vegetables irrigated with potable water.

2 METHODOLOGY

2.1 Experimental design

The study was conducted at the University of Melbourne’s Burnley campus. The site is surrounded by various land uses and activities that are typical of an urban setting (i.e. construction, train lines, large roads/freeways, etc.). Four 3.3m^2 raised garden beds were constructed, with three receiving roofwater from an adjacent building with a tile roof and lead flashing. All gardens contained the same three layers of filter and growing media, as shown in Figure 1; a bottom layer of gravel overlain by a layer of fine sand and a top layer of commercially-available vegetable garden “mix” (a blend of two soils and three manures). All gardens were fitted with Campbell CS616 moisture probes (3-10cm depth) and iButton temperature probes (5cm depth), which logged at 6- and 120-minute intervals, respectively.

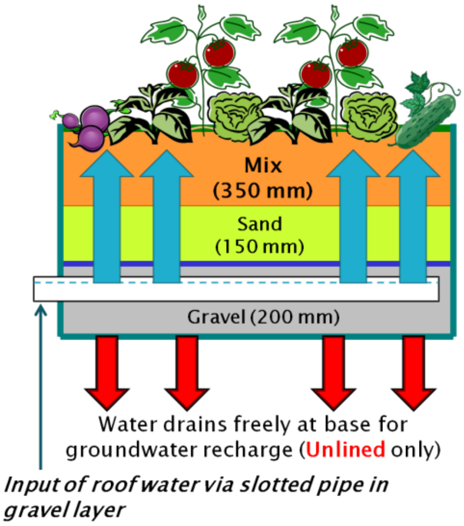

Figure 1: Cross section diagram of the raingarden design. Blue arrows represent the upwards movement of water through capillary rise, and red arrows represent infiltration into the underlying soil.

The four beds differed in their water source, method of irrigation and the presence of a lining material. The features of the four gardens are as follows:

1. **Potable conventional garden:** a free draining garden irrigated with potable water via microsprays. This garden was considered the control for the yield and contamination components of the project.
2. **Tank conventional garden:** a free draining garden irrigated with roofwater (stored in a rainwater tank) via microsprays. This garden was a second control for the yield component of the project.
3. **Unlined raingarden:** a free draining garden irrigated with roofwater (stored in a rainwater tank) via drip irrigation during dry weather. During wet weather, roofwater was delivered directly for subsurface irrigation via a slotted pipe, and subsequently moved upwards through the media via capillary action (Figure 1). An overflow pit regulated the water level in this bed to prevent waterlogging.
4. **Lined raingarden:** a garden lined with pond liner to inhibit water movement out of the bed. This garden was irrigated only via subsurface methods, in both wet and dry weather; i.e. it had no surface irrigation system. It was otherwise identical to the unlined raingarden.

During dry weather, all gardens were irrigated using a deficit irrigation strategy, which aimed to maximise water use efficiency rather than maximising yield. The soil moisture content was checked three times a week (Mon, Wed, Fri) and if the moisture content dropped below a minimum threshold (<10%), determined from the permanent wilting point, a garden would receive irrigation. For the potable, tank and unlined gardens the volume of water received was 138L for each irrigation session. The volume applied to the lined garden varied as only enough water to ‘fill’ the system (ie. to fill the gravel component at the base) was applied.

During wet weather, all roofwater generated from the 133m^2 roof was directed into a flow splitter box, which partitioned flow into three equal parts; directing it to the rainwater tank and the lined and unlined vegetable raingardens (Figure 2). Given that the two raingardens each received approximately one third of the total water from the roof, each raingarden was approximately 7.5% of the size of its catchment area (based on realistic sizing for a domestic vegetable garden).

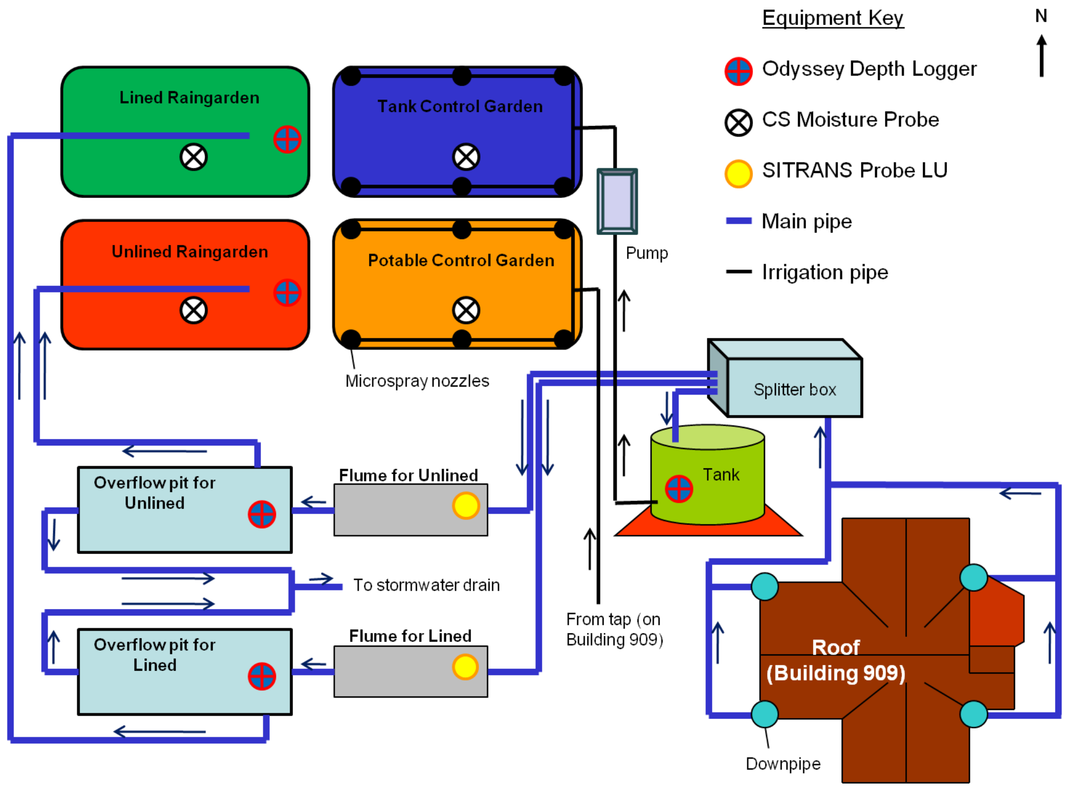

Figure 1: Schematic diagram of the plumbing and monitoring system. For clarity, the drip irrigation in the unlined raingarden is not shown. Arrows indicate the direction of water flow through the system.

Vegetable species were chosen to represent commonly planted vegetable types, including root, leaf, leguminous and fruiting vegetables. There were two growing seasons (Spring-Summer and Autumn-Winter) in the 12 month study and both cool and warm season crops were planted (Table 1).

Table 1: The full list of plants used in the first two growing seasons.

Type	Species	Common name	Variety	Season
Root & bulb	*Beta vulgaris*	Beetroot	Crimson Globe	Spring-Summer
	Raphanus sativus	Radish	Scarlet Globe	Autumn-Winter
	Allium cepa	Onion	Brown	Autumn-Winter
	Allium porrum	Leek	None specified	Autumn-Winter
Leafy	*Lactuca sativa*	Lettuce	Cos	Both
	Spinacia oleracea	Spinach	Viking	Autumn-Winter
Brassica	*Brassica oleracea*	Broccoli	Magic Dwarf	Autumn-Winter
Fruit	*Solanum lycopersicum*	Tomato	Mama's Delight	Spring-Summer
	Solanum lycopersicum	Cherry tomato	Sweet Bite	Spring-Summer
	Cucumis sativus	Cucumber	Lebanese	Spring-Summer
Legume	*Vicia faba*	Broad beans	Early Long Pod	Autumn-Winter
Herb	*Ocimum basilicum*	Basil	Sweet Basil	Spring-Summer
	Petroselinum hortense	Parsley	Afro	Both

2.2 Monitoring

Water quantity. We measured inflows to the two vegetable raingardens with flumes (each with a SITRANS Probe LU), upstream of the overflow pit for each garden (Figure 2). Outflow from the overflow pit (which occurred when the water level in the raingarden reached the top of the gravel layer, ie. 200 mm from the base) to the stormwater system was measured by means of a v-notch weir and an Odyssey capacitance depth logger. There was also a depth logger, housed in a PVC pipe, in each of the two raingardens themselves, to measure the saturated water level within the system. All of this apparatus logged data continuously (at intervals of 1 minute) for 12 months.

Vegetable yield. Edible parts of plants were harvested as regularly as necessary; this was generally weekly or fortnightly for the fruiting and leguminous vegetables (fruits and pods were harvested when size thresholds were reached), but less frequently for the others. The root vegetables were harvested at the end of the growing season. The yield measurements comprised fresh and dry weights and, where applicable, the number of fruits or pods harvested. For each vegetable species these data were pooled for each garden, rather than treating individual plants within gardens as replicates. In comparing yield from the four vegetable gardens, the traditional vegetable garden watered with potable water was considered to be the control.

Contamination. Both the soil in the gardens and the roofwater were tested for a subset of chemical and microbial contaminants considered of concern from a human health perspective. In addition, vegetable samples were tested for metals, *E. coli* and *Pseudomonas aeruginosa* at each harvest. Vegetable samples were not tested for *Campylobacter spp.,* nor organic micropollutants, as they were not detected in the soil or water samples. Details on the sampling and analytical methods used are provided in Table 2.

Table 2. Sampling and analysis methods for microbial and chemical contaminants for roofwater, potable water, soil and vegetables. R = roofwater and P = potable water; the *n* value for each sample type is shown brackets.

Sample matrix	**Contaminant**	**Sampling method**	**Analysis method**
Soil	Metals	One composite sample for each garden consisting of five soil cores sampling the top 15cm. Sampled with a sterilised stainless steel soil corer.	ICP-MS[2]
	E. coli		Colilert® MPN method (IDEXX, Westbrook, Maine)[3]
	Pseudomonas aeruginosa		AS 5013.21-2004 with modifications[4]
	Campylobacter sp.		Presence/absence tested with AS/NZS 4276.19:2001 with modifications[5]
	Organic micropollutants[1]	One composite sample of three soil cores taken from each garden. Sampled as above.	GC-MS[6]
Roof and potable water	Metals	One composite sample of roofwater consisting of roofwater from the irrigation outlets of the tank, unlined and lined gardens. Sampling outlet sterilised and allowed to run for 30 to 60 seconds prior to sampling. Potable water sampled from potable garden irrigation outlets using same sampling method as roofwater.	ICP-MS[2]
	E. coli		Colilert® MPN method (IDEXX, Westbrook, Maine)
	Pseudomonas aeruginosa		AS 5013.21-2004
	Campylobacter sp.		Presence/absence tested with AS/NZS 4276.19:2001 with modifications[7]
	Organic micropollutants[1]		GC-MS[6]
Vegetables	Metals	One composite sample of the edible components of a crop taken from multiple plants of the same species within the same garden. Samples taken using gloves sterilised at the start and between samples.	ICP-MS[2]
	E. coli		AS 5013.21-2004
	Pseudomonas aeruginosa		

[1] Phenols, polyaromatic hydrocarbons, total petroleum hydrocarbons, pesticides and herbicides. [2] ICP-MS: Inductively Coupled Plasma Mass Spectrometry [3] MPN: most probably number. One gram of soil was diluted into 100mL of sterile de-ionised water. [4] One gram of soil was diluted in 100mL of sterile de-ionised water. [5] One gram of soil sample was aseptically transferred into each tube of enrichment broth. [6] GC-MS: Gas Chromatography Mass Spectrometry [7] 250mL of roofwater was water filtered for each tube of enrichment broth and a total of 1L of roofwater that was tested.

3 RESULTS

3.1 Hydrology

The water level in the lined raingarden was consistently much higher than the water level in the unlined, unsurprising given the loss of water through exfiltration in the unlined system, in comparison to the evapotranspiration-only losses in the lined system. Despite this, there was little difference in soil moisture between the two raingardens until the final weeks of the study period. Indeed, there was also little difference in soil moisture between the raingardens and the two conventional vegetable gardens. Under the deficit irrigation regime, all four gardens required frequent irrigation (i.e. back-up irrigation in the case of the raingardens) during the summer months, particularly January to March 2012. However, neither of the raingardens required any back-up irrigation during the Autumn-Winter growing season, while the conventional vegetable gardens required irrigation towards the end of the season. Over these winter months, an ever-increasing disparity occurred between the two raingardens, whereby soil moisture became notably higher in the lined raingarden than in the unlined.

With the significant loss of water through exfiltration, outflow (to the stormwater system) from the unlined raingarden occurred for only 6% of rainfall events. This difference was particularly pronounced during the Autumn-Winter growing season (Figure 3). In contrast, in most months, the number of days of outflow from the lined raingarden equalled or exceeded the number of days of inflow (Figure 3), demonstrating the consequence of storage and detention. Generally, the unlined raingarden was also much more effective than the lined for reducing runoff quantities, as well as for reducing peak flow rates.

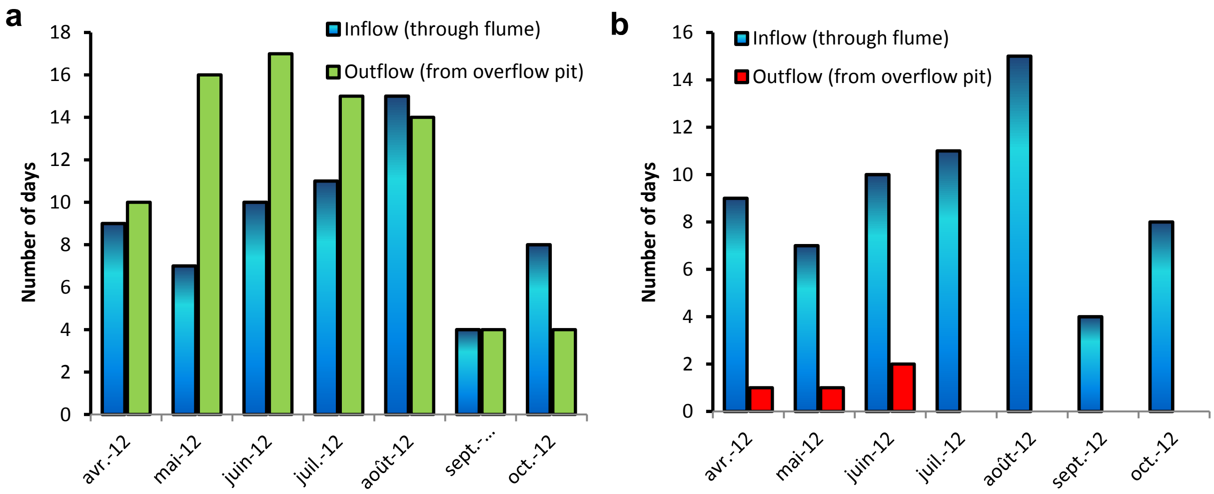

Figure 3: Number of days per month when some flow (> 1 L m^{-1}) was recorded in the flume in comparison to the number of days when some outflow (to the stormwater system) occurred from the overflow pit of a) the lined raingarden; and b) the unlined raingarden.

3.2 Yield

There was considerable variation between vegetable species, but yield was generally higher in the two conventional vegetable gardens than in the two raingardens (Table 3). In the Spring-Summer growing season, the only species with greater yield in the two raingardens was beetroot. The lined raingarden also produced slightly greater yield for parsley. In the Autumn-Winter growing season, the yields of spinach, leek and onion were lowest in the lined raingarden, while the yield from the unlined raingarden was generally comparable to the conventional vegetable gardens. Therefore, it seems that the relatively high soil moisture in the lined raingarden came too late in the Autumn-Winter growing season to affect yield. However, the yield of broad beans was highest in the Lined raingarden and the potable garden, and lowest in the tank garden.

Table 3: Yield (by fresh weight) of the Tank control garden and the Unlined and Lined raingardens as a percentage of the yield of the Potable control garden.

Plant type	**Plant name**	**Tank control**	**Unlined raingarden**	**Lined raingarden**
Leaf	Lettuce	115.01	79.30	82.92
	Spinach	136.70	124.70	15.19
Fruit	Cherry tomato	91.57	61.34	60.54
	Tomato	119.26	48.02	23.67
	Cucumber	149.83	115.25	25.98
Root and bulb	Beetroot*	106.19	189.43	190.61
	Onion	204.28	71.10	24.96
	Leek	104.35	97.07	50.45
Legume	Broad bean	55.64	78.82	104.52
Herbs	Basil	183.85	77.96	93.05
	Parsley	112.00	97.64	112.42

*For beetroot, the total weight (as used for the other plants) was unsuitable for analysis because of pest damage. Instead, the mean weight of the edible root (undamaged) has been used in this table.

3.3 Chemical contamination

There were minor differences in the average metal concentrations between the potable water and roofwater samples, with the roofwater containing marginally greater concentrations for most metals (Figure 4). However, copper concentrations in the potable water were considerably greater than the roofwater. In six out of ten sampling events, the roofwater met the Australian Drinking Water Guidelines (NHRMC & NRMMC, 2011) for metals. For the remaining four sampling events, the lead concentrations were only marginally greater than the guideline specifications, represented by the solid line in Figure 4.

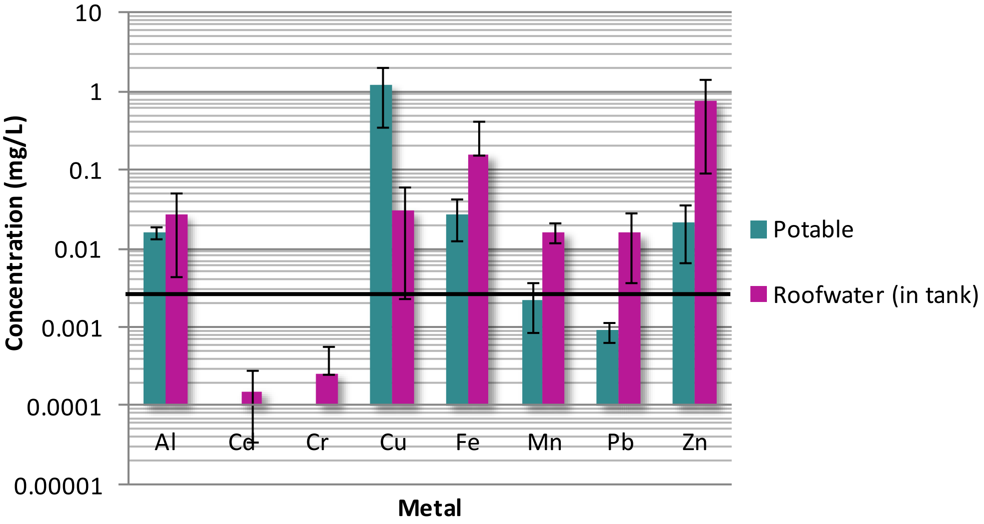

Figure 4. Average metal concentrations for potable water and roofwater samples from January to October, 2012. The black line indicates the guideline value for lead in the AWDG (2011); concentrations of cadmium and chromium were below detection limits for potable water (<0.00002 and <0.00005 mg/L, respectively).

Metal concentrations in the soil showed considerable spatio-temporal variation. By July 2012, iron, aluminium, chromium and zinc concentrations had increased by 200 – 400% compared to the baseline concentrations in all four gardens. By October 2012, however, the concentrations of these metals had declined to the original baseline concentrations. It is likely that this variation is a combination of atmospheric pollution influenced by local conditions (such as the presence of an adjacent train depot) and the changing levels of plant uptake of metals from the soil during different developmental stages. Copper, lead and manganese have remained at relatively stable concentrations for all treatments except the potable control, with variations limited to within ± 30% of their initial concentration. Copper concentrations in the potable control garden have almost tripled since the beginning of the experiment due to the high concentrations of copper in the potable irrigation water (see Figure 4). Nonetheless, soil metal concentrations for all treatments have consistently been well below the National Environmental Protection Measure (NEPM, 1999) Health Investigation Levels (HILs) and interim Ecological Investigation Levels (EILs) for urban areas.

Considerable variation between the garden types and between plant species was also observed in the crop metal concentrations. This includes a clear difference in concentrations between fruiting (e.g. tomato, Figure 5a) and herbaceous (e.g. parsley, Figure 5b) species, with concentrations in the latter an order of magnitude higher. Furthermore, samples consisting of edible leafy biomass (e.g. lettuce, parsley, leek) had consistently higher concentrations compared with root (e.g. radish), fruiting (e.g. tomato) or bulb samples (e.g. onion). This is consistent with previous reports of an increased uptake of metals from leafy and fast-growing crops (Abdu et. al., 2011; Luo et. al., 2011) and may also be partly explained by inputs from atmospheric deposition. Aluminium, iron and zinc were present in the highest concentrations for all crops. Chromium was only detected in the broccoli (leaf samples only), onion, lettuce, radish, broad beans and leek samples. Cadmium and lead were always below the detection limit of 0.1mg/kg, and therefore none of the samples tested exceeded the Food Standards Australia New Zealand (2011) limit for cadmium and lead concentrations.

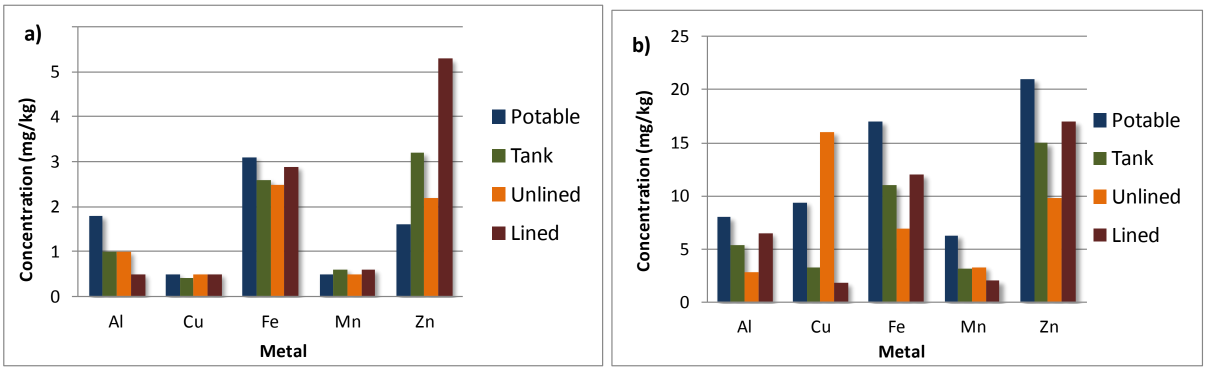

Figure 5. The metal concentrations in (a) tomato and (b) parsley from each raingarden. Notes: cadmium, chromium and lead concentrations for all samples were below the detection limit (<0.1mg/kg).

3.4 Microbial contamination

Campylobacter sp. and *Pseudomonas aeruginosa* were not detected in the roofwater and neither *Pseudomonas aeruginosa* nor *E. coli* were detected in the potable water. *E. coli* concentrations in the roofwater varied considerably over time and were influenced by the length of the antecedent dry period. Figure 6 demonstrates that with an increased antecedent dry period, fewer cells survive in the rainwater tank. This also indicates that the roof is a source of *E. coli* during wet weather.

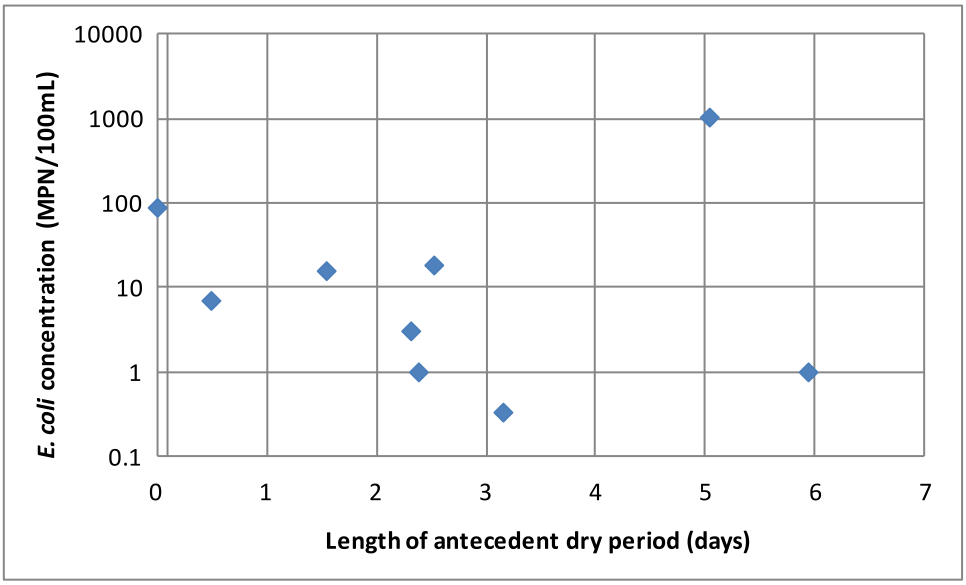

Figure 6. The relationship between *E. coli* concentrations in roofwater (tank) and the length of the antecedent dry period prior to the sampling event.

Neither *Campylobacter sp.* nor *Pseudomonas aeruginosa* were detected in the soil, whilst *E. coli* concentrations in the soil have decreased rapidly over time in all four gardens, from 200000 to 300000 MPN/per gram of dry soil (August 2011) to only 1-3 MPN/per gram (April, 2012). This reduction in *E. coli* cells may be attributed to predation by other soil organisms, competition with other soil bacteria, desiccation due to the drying of soil and cell death from direct ultra-violet exposure. To date, *Pseudmonas aeriginosa* has not been detected in any of the vegetable samples, while *E. coli* has been detected in very low concentrations in the radish from all four gardens. This presence is likely due to direct contact between the edible roots and the soil.

4 DISCUSSION

A sub-irrigated vegetable raingarden can retain the role of conventional raingardens in regulating quantities and rates of urban runoff, provided that the raingarden is not lined. Consistent with the view that the use of an impermeable liner in biofiltration systems should be avoided unless necessary for the protection of surrounding infrastructure (Davis, 2008; Li, et al., 2009), to promote infiltration and restoration of baseflows, overflow (through the controlled overflow pit) from the lined raingarden was frequent and, therefore, the lined system performed relatively poorly in reducing the frequency, magnitude and total volume of stormwater discharge. Furthermore, the use of a liner to create a submerged saturated did not provide any benefits in terms of vegetable yield, with benefits in terms of maintaining soil moisture only becoming apparent later in the experiment, but not translating to productivity. The trade off between stormwater retention performance and vegetable yield will of course vary by site, with systems located on soils with very high permeability or in very warm, dry climates potentially experiencing frequent drying and thus reduced yield.

The chemical and microbial contamination of the soil and crop samples directly resulting from roofwater irrigation was minimal and dwarfed by inputs from the potable water and from atmospheric deposition or the natural soil properties. However, it is important to note that this is a relatively ‘new’ roofwater collection and storage system, and an ageing system may behave differently. Specifically, the accumulation of sediment over time at the bottom of a rainwater tank has been identified as one of the major sources of ongoing contamination for stored roofwater (Maygar et. al., 2008; Huston et. al., 2009). Interestingly, the potable control was the only treatment that demonstrated a manifestation of chemical contamination (ie. copper) from the potable irrigation water. The high spatio-temporal variability inherent in soil and crop metal concentrations may be indicative of the sensitivity to wet and dry atmospheric deposition of metals. The leafy and herbaceous crops experience the greatest level of metal contamination which may be attributed to their higher transpiration rates that promote greater root uptake of metals compared with root and fruiting crops (Abdu et. al., 2011; Luo et. al., 2011). These crops also have edible components with a large surface area which increases their exposure to physical contamination via atmospheric deposition (Luo et. al., 2011).

In terms of microbial contamination, despite the influx of *E. coli* cells during a rainfall event, the abiotic and biotic conditions in the soil were not conducive to the long-term survival and regrowth of *E. coli* within the soil. Furthermore, we have found that by using a manure compost soil (commonly used for vegetable gardens) that initially contained a high number of faecal bacteria, it is unlikely that crop contamination with these bacteria is a result of irrigation with roofwater. In this instance, root crops have a higher exposure to microbial contamination due to direct contact with the soil compared with other crop types.

This study represents an initial pilot investigation of the suitability of raingardens for vegetable production. Further work is needed to co-optimise the performance to (i) maximise stormwater retention, (ii) minimise contamination risk, while (ii) maximising the vegetable yield. Our initial observations suggest that the capillary rise from the submerged gravel zone was not as effective as it could have been, most likely because a capillary break formed in the gravel layer when the water level fell below that of the overlying sand layer. Specific modifications could be implemented to improve this performance, such as cylinders of fabric extending from the gravel layer into the upper (sand and soil) layers. In a subsequent stage, we will test whether vegetables grown with much more highly polluted stormwater (representative of that coming from an area of industrial land use. This step is important to determine if vegetable raingardens could be more broadly applied as part of stormwater management and urban food production strategies (for example, to serve community gardens).

5 CONCLUSION

The performance of vegetable raingardens (irrigated with roofwater) was evaluated using a field trial, with the stormwater retention, vegetable yield and contamination risk for two vegetable raingardens (one lined, one unlined) compared to that of normal potable water and tank water-fed raingardens. The unlined raingarden reduced the frequency of stormwater runoff by over 90%. Overall, the vegetable raingardens did not produce greater vegetable yields than standard designs, but did require less potable water. The roofwater inputs did not result in metal contamination of the soils, water or plants, with sources from atmospheric deposition and, in the case of copper, the potable water, being important. Uptake of metals was shown to occur most readily in rapid growing, leafy vegetables. The roofwater did contain *E. coli*, but not *Campylobacter sp.* or *Pseudomonas aeruginosa*, *E. coli* concentrations were reduced over time within the soil. To date, *P. aeruginosa* has not been detected in any of the vegetable samples, while E. coli has been detected in very low concentrations in the radish from all four gardens. This presence is likely due to direct contact between the edible roots and the soil. Overall, the results suggest that the chemical and microbial contamination risk from raingardens irrigated with roof water is no higher than from a vegetable garden irrigated with potable water, but we note that results may be context-specific. The concept of a vegetable raingarden has promise for its ability to simultaneously reduce stormwater runoff and support urban food production; further studies will determine if it is suitable where the water source is general stormwater runoff.

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