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Vegetable raingardens can produce food and reduce stormwater runoff

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ABSTRACT

Raingardens are garden beds designed to capture and filter urban stormwater runoff using a permeable soil substrate and plants tolerant of both drought and inundation. The construction of raingardens is actively promoted in many cities, primarily to protect local waterways from the negative impacts of stormwater such as channel erosion and degradation of water quality. To increase the adoption of raingardens by householders, it might be possible to expand raingarden functionality to simultaneously serve as "vegetable raingardens". Vegetable raingardens would be beneficial in the context of urban agriculture, as they could overcome both space and water scarcity constraints on home vegetable gardening. However, the potential to grow vegetables in raingardens has not been explored and vegetables are significantly different to conventional, hardy raingarden plants. In an 18-month field trial, we assessed vegetable production in purpose-built raingardens. Stormwater was collected from an adjacent rooftop and was applied to the vegetable raingardens through sub-irrigation. One of the vegetable raingardens was lined underneath and the other was unlined, allowing infiltration of excess water to underlying soils. Sub-irrigation was used to limit plant stress and ensure food safety by reducing vegetable contact with potential contaminants present in stormwater. Control gardens were treated with stormwater delivered through overhead spray irrigation, or with potable water delivered by overhead sprays to also examine differences in water source on yield. A range of vegetables were planted including beetroot, onion, spinach, tomato and broad bean. The vegetable raingardens that were tested produced yields generally similar to the control gardens, which represented traditional watering methods for vegetable gardens. The infiltration-type raingarden, sized 7.5% of its catchment area, reduced both the volume and frequency of runoff by >90%. Results indicate that it is possible to both produce adequate yield in raingardens and maintain the function of raingardens in reducing urban runoff, in terms of discharge to waterways.

1. Introduction

In cities, stormwater runs off impervious surfaces at unnaturally high rates and poses a significant threat to the health of urban waterways, with impacts such as channel erosion and degradation of water quality (Paul and Meyer, 2001). In these urban landscapes, Water Sensitive Urban Design (WSUD) and similar concepts such as Low Impact Development (Fletcher et al., 2014) are a way of reducing the quantity of stormwater runoff by increasing infiltration and evapotranspiration (Denman et al., 2006; Lloyd et al., 2002), bringing the flow of runoff in urban landscapes closer to pre-developed, natural levels (Bratieres et al., 2008; Williams and Wise, 2006). These WSUD technologies include raingardens, which are a type of biofiltration or bioretention system (Davis et al., 2009). Raingardens are garden beds that are engineered, using specified permeable substrates (commonly loamy sands) and hardy plants tolerant of both drought and inundation, to retain and treat stormwater that runs off impermeable surfaces such as roads and roofs. The construction of raingardens is being actively promoted in many cities to improve waterway health. For example, in Melbourne, Australia, a programme to install 10,000 raingardens ran from 2008 to 2013. That programme, operated by Melbourne Water, specifically targeted adoption by private householders, highlighting the aesthetic and landscape amenity benefits of such systems. The programme exceeded its 10,000 target, and was effective at raising awareness of stormwater issues (Melbourne Water, 2014). It was adapted from a similar programme in Kansas City (Sustainable Cities Institute, 2013). In Australian and North American cities, particularly those with dry summer climates, there is potential to further increase

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uptake of raingardens among householders by expanding the functionality of these systems. In particular, raingardens have the potential to be used as vegetable gardens, or *vegetable raingardens*.

Using vegetable raingardens as an extension of traditional home vegetable gardening would help to overcome the common negative perception that raingardens offer no tangible benefit to people (Brown et al., 2014). Vegetable raingardens could have the particular benefit of overcoming constraints on vegetable gardening related to water scarcity. Water scarcity is an intermittent problem in many Australian cities, and countless other cities throughout the world, caused by below-average runoff into water catchments (Barker-Reid et al., 2010; Edwards, 2011). A common response has been to implement water restrictions, which require households to avoid or ration some uses of potable water, particularly in relation to gardening (DEPI, 2014). Such restrictions were in place in Melbourne for over ten years, between 2001 and 2012 (Edwards, 2011). Water restrictions are also an important contemporary issue in the USA, particularly in California, Colorado and Texas. A vegetable raingarden would capture stormwater (particularly from roofs) and use it to irrigate vegetables. This is consistent with the increasingly common practice of using stormwater and greywater in home gardening, which is not subject to water restrictions (Barker-Reid et al., 2010; Hatt et al., 2007; Misra et al., 2010).

Exploratory research has indicated that another WSUD technology, green roofs, can be successfully used for vegetable production without negative impacts on stormwater retention or runoff water quality (Whittinghill et al., 2013, 2014). Nonetheless, the feasibility of a vegetable raingarden has not yet been evaluated. A fundamental issue is that vegetables are significantly different to the plants that are conventionally used in a raingarden, which tend to be perennial, native species selected for their ability to survive the extreme wetting-drying regime in a raingarden, and for their capacity to remove pollutants from runoff (Read et al., 2008). In comparison, vegetables are generally much more sensitive to drought and over-watering, both of which can lead to poor growth and yield, and ultimately plant death in severe conditions (Bahadur et al., 2011; Vartapetian and Jackson, 1997). Vegetables also need relatively high levels of nutrients to ensure desired yields (Nonnecke, 1989), which may be in conflict with objectives of reducing concentrations and loads of pollutants in stormwater runoff.

Fluctuation in water availability is a critical issue in sustaining productive yields in a vegetable raingarden, particularly in the summer months when water might be limited. Therefore, it is necessary to optimize the design of a raingarden to reduce potential water limitations. In particular, it might be preferable to invert a vegetable raingarden so that it is irrigated from below, as a sub-irrigated or "wicking" type of garden bed, instead of from the top like conventional raingardens. Sub-irrigation has been found to offer higher water use efficiency than spray and drip irrigation in tomatoes (Ahmed et al., 2000; Goodwin et al., 2003; Incrocci et al., 2006; Santamaria et al., 2003). A key advantage of a sub-irrigated raingarden would be reduced evapotranspiration rates and therefore reduced plant stress, minimizing the need for supplemental irrigation. Ideally, a vegetable raingarden would require no supplemental irrigation, as is typically the case for conventional raingardens, to reduce demand for potable water and maximize storage capacity for stormwater runoff. Sub-irrigation might also be beneficial for food safety, as pollutants could be filtered out of the runoff water as it moves upwards through the raingarden before coming into contact with plants (Tom et al., 2013).

However, modifying or managing a raingarden for vegetable production may reduce its ability to capture stormwater runoff. For optimal capture, a raingarden should only be wet during and immediately after rainfall, so that the soil pore spaces are largely empty within 72–96 h (Davis et al., 2009; Melbourne Water, 2010), allowing the next rainfall event to be captured. Pore spaces will rarely be empty if the raingarden is kept constantly moist through regular irrigation, or through using a sub-irrigated design or waterproof lining. For example, it has been reported that sub-irrigation leads to more runoff from green roofs than overhead irrigation (Rowe et al., 2014). It is also well established that lined raingardens have relatively poor hydrologic performance (Li et al., 2009), although lined raingardens also have important benefits; they can be built close to buildings because the lining prevents water damage to foundations, and they can be used in situations where hazardous runoff is anticipated (Davis, 2008; Davis et al., 2009).

To address these knowledge gaps and inform raingarden design for implementation as a WSUD technology, we built two sub-irrigated vegetable raingardens and two surface-irrigated vegetable gardens (as controls), and assessed their performance over an 18-month period to account for seasonal variation. The following research questions were evaluated:

1. Can a sub-irrigated "vegetable raingarden" produce vegetable yield comparable to a surface-irrigated (control) vegetable garden?
2. Does this raingarden require irrigation to supplement rainfall, to maintain adequate soil moisture (under Melbourne conditions)?
3. Can the runoff management function of a raingarden be retained, if it is used and modified for vegetable production?
4. In relation to the preceding three questions, how does performance vary between a raingarden that is lined and an unlined raingarden in which runoff water is allowed to infiltrate into the underlying soil?

2. Methods

Two purpose-built, 3.3 m^2 raised garden beds (pre-fabricated, corrugated steel beds sourced from Birdies Garden Supplies), with dimensions of 2.2 m (length) × 1.5 m (width) x 0.8 m (height), were installed and plumbed as *vegetable raingardens* at the University of Melbourne's Burnley campus in Melbourne, Australia (37°49′44.22″ S, 145°1′13.40″ E). Both received roof water from an adjacent building with a tile roof of area 133 m^2 (Fig. 1). One of the raingardens was lined with a PVC liner to prevent water from draining into the underlying soil. This raingarden is referred to as

Fig. 1. Field trial raingardens; the Lined in the foreground and the Unlined to the right of the photo, with the two control gardens and the tile roof in the background. Each of the four gardens was constructed using a pre-fabricated modular raised garden bed made of corrugated steel. The four gardens were arranged in a non-random quadrant formation.