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Can raingardens produce food and retain stormwater? Effects of substrates and stormwater application method on plant water use, stormwater retention and yield

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ABSTRACT

Raingardens capture and filter urban stormwater using sandy soils and drought-tolerant plants. An emerging question is whether raingardens can also be used as vegetable gardens, potentially increasing their popularity and implementation. A successful vegetable raingarden will need to both retain stormwater and produce vegetables, despite potential water deficits between rainfall events. To determine whether raingardens can provide this dual functionality, we undertook a greenhouse pot experiment using two different substrates (loamy sand raingarden substrate and potting mix typical of containerised vegetable growing) and two methods of stormwater application ('sub-surface' and 'surface' watering) with the water quantity at each application determined by average Melbourne summer rainfall. Overall, potting mix produced bigger plants (biomass and leaf area) and greater yield than did the loamy sand. Yield effects were variable: tomato yield was unaffected by treatment, bean yield was greatest in potting mix, beetroot yield was greatest with sub-surface watering and parsley yield was greatest with surface watering. Bigger plants also had greater transpiration, which meant that stormwater retention was greatest for parsley and tomato plants growing in potting mix with surface watering. Although, a raingarden with potting mix and surface application of stormwater was optimal for producing food and retaining stormwater under our rainfall regime, potting mix could be problematic due to higher nutrient leaching and breakdown over time. Therefore, we recommend using a mix of loamy sand and potting mix. However, the choice of substrate and watering treatment require trade-offs between yield, stormwater retention and potential implications for water quality and long-term stability of hydraulic properties.

1. Introduction

In cities, stormwater runs off impervious surfaces at artificially high rates, threatening the health of local waterways through channel erosion, loss of habitat and pollution (Walsh et al., 2005). Approaches to urban stormwater management include raingardens (also termed biofiltration or bioretention systems) which protect waterways by retaining, treating and using stormwater at its source (Lloyd et al., 2002), restoring flow regimes closer to pre-urbanised levels (Bratieres et al., 2008). Raingardens are engineered garden beds with sandy soils and hardy perennial plants which capture and treat stormwater that runs off roofs and impermeable surfaces such as roads (Davis et al., 2009). As up to 50% of runoff from urban surfaces comes from private properties (Brown et al., 2014), where space for on-site stormwater management is limited, there is a need to ensure that raingardens maximize benefits to both humans and waterways (Burns et al., 2014; Jennings et al., 2012). While many homeowners are aware of the environmental benefits of raingardens, there are negative perceptions associated with 'loss of garden space' and 'lack of tangible benefit to the household' (Brown et al., 2014).

Expanding the functionality of raingardens to include vegetable production might increase their popularity, leading to wider implementation. Green roofs have been shown to produce vegetables without affecting their ability to retain stormwater runoff (Whittinghill et al., 2014) and raingardens may have similar potential. Using stormwater also increases overall security of water supply during drought, when restrictions on the uses of potable water may be imposed. Such restrictions were in place in Melbourne, Australia for ten years between 2002 and 2012, and included a ban on all outside watering, significantly constraining urban food production (Edwards 2011). Raingardens which utilize

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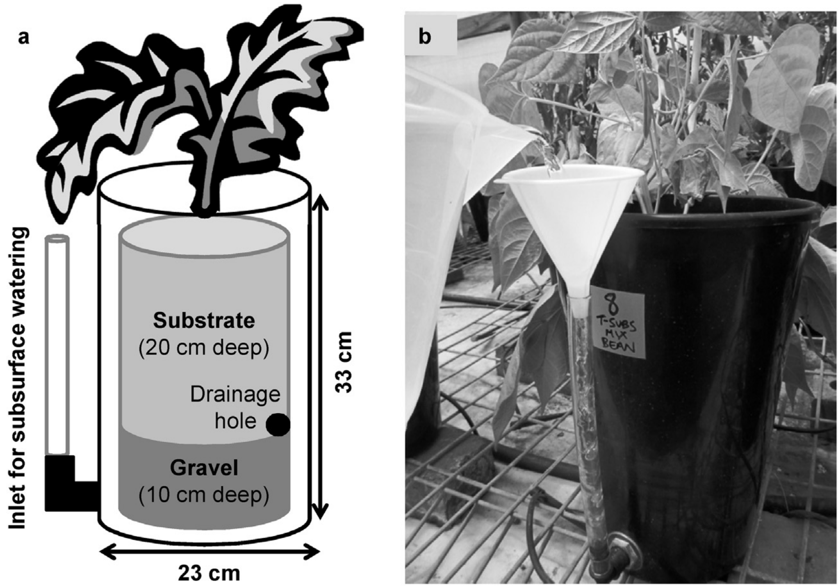

Fig. 1. a) Design of the sub-surface watered pots, and b) A sub-surface pot being watered. The surface watered pots were identical to the sub-subsurface watered pots, other than the presence of the inlet for sub-surface watering which filled the reservoir.

stormwater for food production may therefore be a win-win technology, protecting waterways from stormwater, while enabling food production that would otherwise be constrained. Vegetables produced without additional potable water irrigation could also provide a tangible return on money and time invested in constructing a raingarden.

However, vegetables differ greatly from the plant species conventionally used in raingardens (e.g. *Carex* spp.), which tend to be perennials selected for their capacity to remove pollutants, maintain infiltration through their root systems and survive large fluctuations in water availability (et al.,periods of drought between rainfall events, exacerbated by the typically free-draining substrate used in raingardens (Bratieres et al., 2010; Davis et al., 2009). To adapt raingardens for vegetable production, as *vegetable raingardens*, there are two major knowledge gaps and design issues that need to be resolved, particularly 1) the choice of substrate and 2) the method for delivering stormwater (harvested roof water).

Typically, loamy sand with low organic content (<5%) is used in raingardens, primarily to improve the quality of urban runoff (Bratieres et al., 2008; FAWB 2009). Raingarden substrates need to be low in organic matter to reduce phosphate leaching into receiving waters (Bratieres et al., 2008). However, the low organic content means loamy sand has a relatively low water-holding (<20%) and nutrient capacity, which may not be suitable for vegetable production (Yu et al., 2013). Conversely, traditional containerized vegetable gardens use purpose-made substrates with high organic matter (>50%) to maximize water retention and vegetable yield (Hudson 1994). Therefore, in developing vegetable raingardens it is important to determine whether loamy sand raingarden substrates can satisfy the water and nutrient requirements of vegetable crops in addition to water quality outcomes.

Stormwater runoff usually enters a raingarden at the surface and then drains downward through the substrate, filtering pollutants (Davis et al., 2001; Hatt et al., 2007; Read et al., 2008). This might not be the optimal design for a vegetable raingarden, as watering needs to be managed efficiently to minimise plant water stress. In addition, the requirement to apply large quantities of supplementary irrigation water should be avoided so that the raingarden remains effective for stormwater runoff absorption. A potential solution is to invert the typical raingarden design so that, rather than runoff being applied to the surface, the raingarden is sub-irrigated with stormwater, delivering water below the root zone which then moves upwards through capillary rise. These garden beds are commonly known as wicking beds in Australia and as sub-irrigated planters in the USA, and have been shown to offer higher water use efficiency than surface irrigation (Ahmed et al., 2000; Incrocci et al., 2006; Santamaria et al., 2003). Sub-surface watering might also improve food safety in vegetable raingardens, as direct contact with runoff is minimized and pollutants can be filtered from the runoff water as it moves upwards through the substrate, before reaching plants (Tom et al., 2013).

The success of a vegetable raingarden will be determined by both its effectiveness at retaining stormwater and its ability to produce vegetables despite water limitations between rainfall events. To determine whether raingardens could be used to produce food and retain stormwater we undertook a greenhouse pot experiment using different substrates and methods of stormwater application. Two substrates were used; a loamy sand typically used in raingardens and a potting mix used in conventional containerised vegetable gardens but not normally in raingardens (FAWB 2009). There were two stormwater application treatments; 'sub-surface' and 'surface' application of water with water quantity based on average Melbourne summer rainfall. It was expected that vegetable growth (biomass, leaf area and root allocation) and yield would be greater in the potting mix than in the loamy sand due to greater water holding capacity, and that sub-surface stormwater application would maintain water availability between rainfall events and therefore have greater yield than surface watering due to reduced plant stress.

2. Materials and methods

The experiment was conducted in a non-temperature controlled greenhouse at the University of Melbourne's Burnley campus (37°49′44.22″S, 145°1′13.40″E) from September 2012 to February 2013. Melbourne's climate is characterised by cool, wet winters and dry, hot summers. Melbourne's mean annual rainfall is 648.4 mm (1855–2015), with 153.9 mm falling in summer months (Bureau of Meteorology, 2015). This was a very warm spring-summer period; mean daily maximum temperature in summer is 25.9 °C (January), however outdoor temperatures reached a maximum of 41 °C during the experiment, and daily maximum temperatures were ≥30 °C