Uniting urban agriculture and stormwater management: the example of the "vegetable raingarden"

Paul J. Richards[1], Claire Farrell[1], Tim D. Fletcher[1] and Nicholas S.G. Williams[1]
[1]Department of Resource Management and Geography, University of Melbourne (Burnley campus)

Abstract: Stormwater runs off impervious urban surfaces at artificially high rates, and erodes and pollutes local waterways. Raingardens, as biofiltration systems, are garden beds that are designed to capture and filter runoff using sandy soils and resilient plants. For healthier waterways, the construction of raingardens is being actively promoted in many cities, including Melbourne. However, raingardens might have another significant benefit; as sites of food production, using captured stormwater (runoff) for irrigation. The use of stormwater is an increasingly popular practice for overcoming water scarcity issues, which can constrain home vegetable gardening and urban agriculture. Nonetheless, the use of raingardens for food production has not been explored and vegetables represent a significant departure from the types of plants that are conventionally used in these systems. We investigated the potential to produce vegetables in raingardens through a 5-month greenhouse (pot) experiment and a 1.5-year field trial. The results indicate that it is possible to produce adequate yield in raingardens and the function of raingardens in reducing urban runoff (in terms of discharge to waterways) can be retained. An infiltration-type raingarden, sized 7.5% of its catchment area, reduced both the volume and frequency of runoff by > 90%. However, "vegetable raingardens" must be designed and managed effectively. Design issues include the use of sub-irrigation to ensure food safety and limit plant stress, and choosing filter/growing media that sustains vegetable growth while meeting runoff management objectives.

Introduction: Water in Australian cities

Stormwater runs off the impervious surfaces of Australian cities at artificially high rates, which poses a significant threat to the health of local waterways. For example, large volumes of urban runoff can cause severe channel erosion and lead to a loss of habitat, as well as transporting elevated concentrations of pollutants (Paul & Meyer 2001). Water Sensitive Urban Design (WSUD) is a way of incorporating treatment of this runoff into urban landscapes (Denman, May & Breen 2006; Lloyd, Wong & Porter 2002). It has involved the design and installation of a wide range of technologies, including "biofiltration" or "bioretention" systems (Davis et al. 2009). These technologies improve runoff management by intercepting stormwater flows and restoring the flow regime closer to the pre-developed, natural level (Bratieres et al. 2008; Williams & Wise 2006).

In contrast to the large quantities of runoff in the urban landscape, the amount of water available from the traditional supply networks can be limited, particularly in times of drought. The water scarcity issues that affect many Australian cities are primarily caused by below-average runoff into urban water catchments (Edwards 2011). Melbourne, for example, has been affected by substantial decreases in rainfall since 1960 and some exceptionally severe droughts, the most recent lasting from 1997 to 2009 (Barker-Reid, Harper & Hamilton 2010). Water scarcity will become an even greater concern for Melbourne if long-term predictions of drier, hotter weather, as well as increasing consumption, are accurate (Edwards 2011; Howe et al. 2005). Many Australian cities have responded to water scarcity by implementing water restrictions, which require users (particularly households) to avoid or ration some uses of water. Such restrictions were in place in Melbourne for over ten years (Edwards 2011), but were lifted in December 2012 with the possibility of reinstatement during future drought periods. The most severe stage (Stage 4) included a ban on all outside watering, which significantly constrains urban food production. Urban food production is an important practice; traditional home vegetable gardening is often driven by economic motivations and cultural influences (Gaynor 2006), while a recent resurgence of interest in urban agriculture is a response to issues of environmental sustainability and food security (Barker-Reid, Harper & Hamilton 2010; Dixon et al. 2009).

The use of stormwater and wastewater, which is not limited by water restrictions, has become an important component of Melbourne's response to water scarcity (Barker-Reid, Harper & Hamilton 2010; Hatt, Deletic & Fletcher 2007; Misra, Patel & Baxi 2010). There is considerable opportunity for further expansion of stormwater reuse practices in urban food production, and for incorporation of urban food production into WSUD; at least on a small, non-commercial scale, as an extension of traditional home vegetable gardening. For example, green roofs are primarily used for stormwater management and other environmental benefits, but exploratory research has indicated that they could also be used for vegetable production (Whittinghill, Rowe & Cregg 2013). When it rains, such technology can both protect local waterways from the negative effects of stormwater and use this stormwater as a sustainable resource.

The "vegetable raingarden": Opportunities and challenges

Raingardens are another prime example of a WSUD technology that has the potential to be used for vegetable production, but this has not yet been tested. Raingardens, as biofiltration systems, are garden beds which are engineered, typically using resilient plants and sandy soils with low-organic content, to capture and treat stormwater that runs off roofs and other impermeable surfaces. The use of vegetables represents a significant departure from the plant species conventionally used in biofiltration systems, which tend to be perennial, native species selected for their capacity to survive the extreme wetting-drying regime in a raingarden, and their ability to remove pollutants from runoff (Read et al. 2008). In comparison to conventional raingarden plants, vegetables are generally much more sensitive to drought and over-watering, both of which can lead to relatively poor growth and yield, and ultimately plant death in severe conditions. Vegetables typically require significant irrigation to supplement rainfall, even in traditional growing systems. Water availability is therefore a critical issue in a vegetable raingarden. In order to adapt raingardens to function effectively as sites of vegetable production, there are several knowledge gaps and design issues that need to be considered.

Foremost among them is the method for delivering runoff water to the raingarden. Water usually enters a raingarden at the surface, but it might be preferable to "invert" a vegetable raingarden so that it is sub-irrigated. The use of sub-irrigation can offer higher water use efficiency than spray and drip irrigation, as demonstrated for tomato production (Ahmed, Cresswell & Haigh 2000; Goodwin et al. 2003; Incrocci et al. 2006; Santamaria et al. 2003). Sub-irrigation might also be beneficial for food safety, whereby pollutants can be filtered out of the runoff water as it moves upwards through the raingarden, before coming into contact with the plants.

The choice of soil type is another important issue. Typically, loamy sand or similar is used in a raingarden, primarily to improve the quality of urban runoff (Bratieres et al. 2008; FAWB 2009; Henderson, Greenway & Phillips 2007). However, the relatively low water holding capacity of sandy soil makes it generally not well suited to vegetable production.

Finally, there is a risk that modifying a raingarden for vegetable production will compromise its runoff management function. For example, a vegetable raingarden might be less able to capture urban runoff it is watered excessively, or if waterproof lining is required to maintain adequate soil moisture for vegetable production. Lining is also required if the raingarden is constructed close to a permanent structure, or if it is necessary to reduce the ingress of salt into the treated water, which is important in western Sydney and some other areas of Australia. Such lined systems are regarded as having poor hydrologic performance because they inhibit infiltration into underlying soils (Li et al. 2009), and fail to restore the baseflows that are lost following the creation of impervious areas.

Research project summary

Aims

We conducted a 5-month greenhouse (pot) experiment and a 1.5-year field trial (Figure 1) at the University of Melbourne's Burnley campus, to investigate water availability in a "vegetable raingarden" and its impacts on vegetable yield and runoff management. This included an assessment of: 1) irrigation requirements, 2) sub-irrigation relative to surface irrigation, 3) two soil types with different water-holding capacities (assessed in the greenhouse experiment only), namely a loamy sand used in conventional raingardens and a potting mix used in traditional containerized vegetable gardening, and 4) the ratio of inflow to outflow (assessed in the field trial only). The methods and results are described in Richards (2013). The field trial methods, including a parallel study on contamination risks, are also described in Tom et al. (2013).

Findings

The results indicated that the availability of water in a vegetable raingarden (sized ≤ 7.5% of its catchment area) can be suitable for the production of many common vegetables. Furthermore, to produce yield comparable to traditional vegetable gardens, the raingarden might not require any irrigation to supplement rainfall under the typical Melbourne climate. In the field trial of sub-irrigated raingardens, this was even the case in a drier than average summer, although only for a raingarden that was fitted with waterproof lining. We also tested an infiltration-type (unlined) raingarden; to maintain adequate soil moisture (> 10% volumetric SWC), this raingarden required supplemental irrigation regularly in summer, which was applied using a surface drip system. Nonetheless, supplemental irrigation could comply with all but the most severe of Melbourne's water restrictions, and is likely to have little or no negative impact on runoff management. Indeed, if supplemental irrigation is applied using collected stormwater (i.e. from a rainwater tank) rather than tap water, this increases the opportunity for reducing volumes of urban runoff. The vegetables tested in the greenhouse experiment (bean, beetroot, parsley and tomato) were able to tolerate the frequency and volume of average summer rainfall without supplemental irrigation. However, it is worth noting that, with climate change, Melbourne is likely to experience reduced rainfall and prolonged droughts, as well as more frequent extreme storm events (CSIRO 2007; Howe et al. 2005; Maunsell Australia Pty Ltd. 2008). These conditions would further increase plant stress in a raingarden.

Figure 1: Field trial; two purpose-built, 3.3 m^2 raised garden beds were installed and plumbed as sub-irrigated "vegetable raingardens", receiving roof-water from an adjacent building with a tile roof. One of the raingardens was lined (top right of the photo), the other was of the infiltration (unlined) type. Adjacent to the two raingardens were two control gardens (foreground), representing traditional vegetable gardens.

The use of lining will affect not only irrigation requirements, and to some extent yield, but also the ability of the raingarden to reduce urban runoff. In the field trial, the infiltration (unlined) raingarden reduced both the volume and frequency of runoff by > 90%. Consistent with previous work (Davis 2008; Davis et al. 2009; Li et al. 2009), the raingarden that was lined was less effective, although it still captured approximately two thirds of inflow, which could be lost through evapotranspiration. The lined raingarden was most effective for rainfall events that were preceded by dry periods. Therefore, in the instances where lining is necessary, such as if the raingarden is built close (< 5 m) to a permanent structure, a lined raingarden would still provide satisfactory runoff management.

A sub-irrigated raingarden design offered no clear advantages over surface irrigation in terms of yield. In the greenhouse experiment, even when identical volumes of irrigation water were applied, yield with sub-irrigation was mostly similar to surface irrigation. In the field trial, the two raingardens received a large volume of rainwater from the roof during the monitoring period (> 33 kL in 1.5 years), but the sub-irrigated raingarden design did not convey this water effectively to the vegetable root zone, at least in the infiltration-type (unlined) raingarden. Consequently, for some vegetables, such as tomato and onion, yield was relatively low in at least one of the two raingardens, in comparison to two controls that represented traditional vegetable gardens. Nonetheless, sub-irrigation might be necessary to reduce the risk of contaminant transfer, particularly to leafy vegetables.

In the greenhouse experiment, the yield of vegetables was generally greater in the potting mix than in the loamy sand, apparently owing to its greater water-holding capacity, to the extent that loamy sand (as used in conventional raingardens) cannot be recommended for vegetable raingardens. To meet water quality objectives, a vegetable raingarden is therefore likely to require separate vegetation-supporting and filtration layers (as used in the field trial) rather than a uniform profile design, in which the vegetation and filter layers are combined (Hsieh & Davis 2005).

There was some variation in the yield of different vegetable species in both the field trial and greenhouse experiment. In the field trial, there was even variation within species; between varieties or between growing seasons (a total of 14 species, and up to three varieties of each, were tested). Nonetheless, although some were more prone to pest damage, no vegetable species or variety performed particularly poorly, and it seems that many common vegetables can be effectively produced in vegetable raingardens.

Design recommendations

An outcome of our project was an instruction sheet, published by Melbourne Water, for building a vegetable raingarden (Melbourne Water 2013). The recommended design is based on that of the field trial raingardens; sub-irrigated raised garden beds (although in-ground variations are feasible) with separate vegetation-supporting and filtration layers, plumbed to receive runoff water from a roof (Figure 2). It is expected that the sand layer will remove any pollutants that may be in the roof-water. In the field trial, the chemical and microbial contamination risk from the raingardens was no higher than the risk from a vegetable garden irrigated with potable (tap) water, and the roof-water inputs did not result in metal contamination of the soils, water or plants (Tom et al. 2013). It is recommended that wicks are installed to promote capillary rise of runoff water from the gravel layer into the soil layer (wicks were not used in the field trial). It is also recommended that the overflow system is positioned to allow the water level to rise close to the soil surface following significant rainfall.

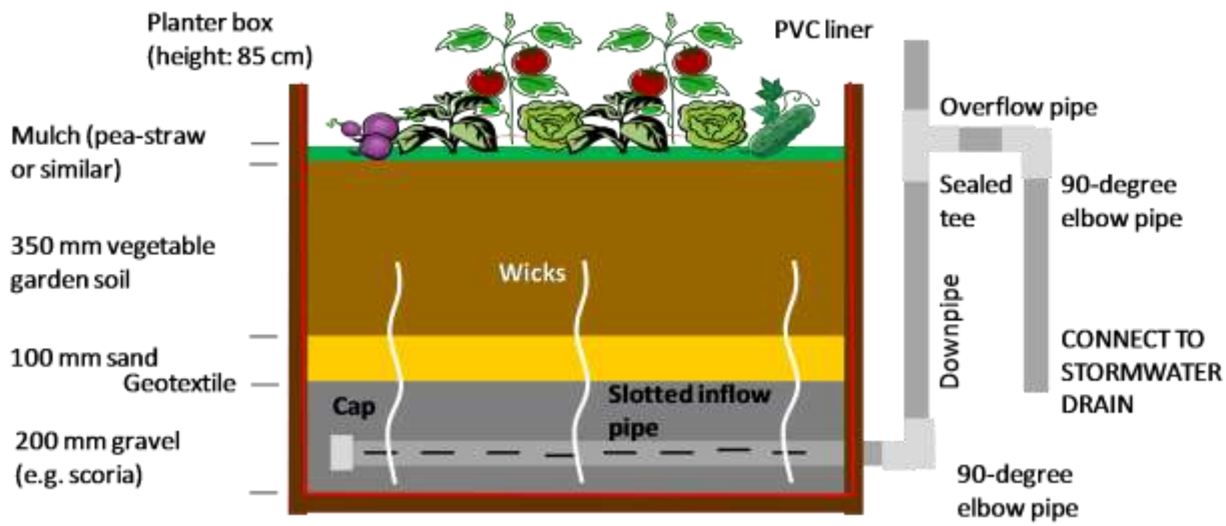

Figure 2: Design recommendations for a vegetable raingarden, following our research project.

Conclusion

There is considerable potential to unite urban agriculture and stormwater management through the construction of vegetable raingardens and similar systems. A vegetable raingarden can capture the large quantities of stormwater runoff in the urban landscape, and use this water to contribute to the important practice of urban food production. A greenhouse experiment and field trial indicated that, provided that it is designed and managed effectively, a vegetable raingarden can produce similar yield as a traditional vegetable garden while also effectively reducing urban runoff.

Acknowledgements

This research was funded by Melbourne Water, under the direction of Keysha Milenkovic. PJR was also supported by a Frank Keenan Scholarship from the University of Melbourne. TDF is supported by an ARC Future Fellowship (FT100100144). Minna Tom of Monash University assisted with the construction and maintenance of the field trial.

References

Ahmed, A.K., Cresswell, G.C. and Haigh, A.M. (2000) Comparison of sub-irrigation and overhead irrigation of tomato and lettuce seedlings, *Journal of Hort. Science and Biotechnology*, 75(3), pp. 350-4.

Barker-Reid, F., Harper, G.A. and Hamilton, A.J. (2010) Affluent effluent: growing vegetables with wastewater in Melbourne, Australia—a wealthy but bone-dry city, *Irrigation and Drainage Systems*, 24, pp. 79–94.

Bratieres, K., Fletcher, T.D., Deletic, A. and Zinger, Y. (2008) Nutrient and sediment removal by stormwater biofilters: a large-scale design optimisation study, *Water Research*, 42(14), pp. 3930–40.
CSIRO (2007) *Climate Change in Australia - Technical Report*, CSIRO, Melbourne.
Davis, A.P. (2008) Field performance of bioretention: Hydrology impact, *Journal of hydrologic engineering*, 13(2), pp. 90–5.
Davis, A.P., Hunt, W.F., Traver, R.G. and Clar, M. (2009) Bioretention technology: overview of current practice and future needs, *Journal of Environmental Engineering*, 135, pp. 109–17.
Denman, L., May, P. and Breen, P.F. (2006) An investigation of the potential to use street trees and their root zone soils to remove nitrogen from urban stormwater, *Australian Journal of Water Resources*, 10(3), pp. 303–11.
Dixon, J.M., Donati, K.J., Pike, L.L. and Hattersley, L. (2009) Functional foods and urban agriculture: two responses to climate change-related food insecurity, *NSW Public Health Bulletin*, 20(1–2), pp. 14-8.
Edwards, G. (2011) Urban Water Management, in Crase, L. (ed.), *Water Policy in Australia: The Impact of Change and Uncertainty*, RFF Press, Washington, D.C., pp. 144-65.
FAWB (2009) *Adoption Guidelines for Stormwater Biofiltration Systems*, Monash University, Melbourne.
Gaynor, A. (2006) *Harvest of the Suburbs: An Environmental History of Growing Food in Australian Cities* (Perth, University of Western Australia Press).
Goodwin, P.B., Murphy, M., Melville, P. and Yiasoumi, W. (2003) Efficiency of water and nutrient use in containerised plants irrigated by overhead, drip or capillary irrigation, *Australian Journal of Experimental Agriculture*, 43(2), pp. 189-94.
Hatt, B.E., Deletic, A. and Fletcher, T.D. (2007) Stormwater reuse: designing biofiltration systems for reliable treatment, *Water Science and Technology*, 55(4), pp. 201–9.
Henderson, C., Greenway, M. and Phillips, I. (2007) Removal of dissolved nitrogen, phosphorous and carbon from stormwater by biofiltration mesocosms, *Water Science and Technology*, 55(4), pp. 183-91.
Howe, C., Jones, R.N., Maheepala, S. and Rhodes, B. (2005) *Melbourne Water climate change study: Implications of potential climate change for Melbourne's water resources*, CSIRO, Melbourne.
Hsieh, C-H. and Davis, A.P. (2005) Evaluation and optimization of bioretention media for treatment of urban storm water runoff, *Journal of Environmental Engineering*, 131(11), pp. 1521–31.
Incrocci, L., Malorgio, F., Bartola, A.D. and Pardossi, A. (2006) The influence of drip irrigation or subirrigation on tomato grown in closed-loop substrate culture with saline water, *Scientia Horticulturae*, 107, pp. 365–72.
Li, H., Sharkey, L.J., Hunt, W.F. and Davis, A.P. (2009) Mitigation of impervious surface hydrology using bioretention in North Carolina and Maryland, *Journal of hydrologic engineering*, 14(4), pp. 407–15.
Lloyd, S.D., Wong, T.H.F. and Porter, B. (2002) The planning and construction of an urban stormwater management scheme, *Water Science and Technology*, 45(7), pp. 1–10.
Maunsell Australia Pty Ltd. (2008) *Climate Change Adaptation Strategy*, City of Melbourne, Melbourne.
Melbourne Water (2013) *Instruction Sheet: Building a Raingarden, Vegetable Raingarden*, Melbourne Water Corporation, Melbourne.
Misra, R.K., Patel, J.H. and Baxi, V.R. (2010) Reuse potential of laundry greywater for irrigation based on growth, water and nutrient use of tomato, *Journal of Hydrology*, 386(1-4), pp. 95–102.
Paul, M.J. and Meyer, J.L. (2001) Streams in the urban landscape, *Annual Review of Ecology and Systematics*, 32, pp. 333–65.
Read, J., Wevill, T., Fletcher, T.D. and Deletic, A. (2008) Variation among plant species in pollutant removal from stormwater in biofiltration systems, *Water Research*, 42, pp. 893-902.
Richards, P.J. (2013) Hydrology of a vegetable raingarden; implications for vegetable yield and stormwater management, Master of Philosophy thesis, University of Melbourne.
Santamaria, P., Campanile, G., Parente, A. and Elia., A. (2003) Subirrigation vs drip-irrigation: effects on yield and quality of soilless grown cherry tomato, *Journal of Horticultural Science and Biotechnology*, 78(3), pp. 290–6.
Tom, M., Richards, P.J., McCarthy, D.T., Fletcher, T.D., Farrell, C., Williams, N.S.G. and Milenkovic, K. (2013), Turning (storm)water into food; the benefits and risks of vegetable raingardens (*Evaluation des performances et des risques d'un jardin de pluie potager*), in Bertrand-Krajewski, J-L. and Fletcher, T.D. (eds.) 8th International Novatech Conference, 23-27th June 2013 (Lyon, GRAIE).
Whittinghill, L.J., Rowe, D.B. and Cregg, B.M. (2013) Evaluation of vegetable production on extensive green roofs, *Agroecology and Sustainable Food Systems*, 37(4), pp. 465-84.
Williams, E.S. and Wise, W.R. (2006) Hydrologic impacts of alternative approaches to storm water management and land development, *Journal of the American Water Resources Association*, 42(2), pp. 433–55.