Renewable Agriculture and Food Systems: 27(4); 314–322 doi:10.1017/S174217051100038X

The role of green roof technology in urban agriculture

Leigh J. Whittinghill[1]* and D. Bradley Rowe[2]

[1]Department of Horticulture, Michigan State University, A224 Plant and Soil Sciences Building, East Lansing, MI 48824, USA.
[2]Department of Horticulture, Michigan State University, A212 Plant and Soil Sciences Building, East Lansing, MI 48824, USA.
*Corresponding author: whitti18@msu.edu

Accepted 15 July 2011; First published online 26 August 2011 **Review Article**

Abstract

Urban agriculture is a global and growing pursuit that can contribute to economic development, job creation, food security and community building. It can, however, be limited by competition for space with other forms of urban development, a lack of formalized land use rights and health hazards related to food contamination. The use of green roof technology in urban agriculture has the potential to alleviate some of these problems, without adversely affecting the benefits provided by urban agriculture. It would not only enable the use of land for development and agriculture, but may also facilitate the formation of formal space and water use agreements, and enable redistribution of ground-level resources among urban farmers. This could decrease the use of contaminated land and water at ground level and alleviate health concerns. Before green roof technology can be incorporated into urban agriculture on a larger scale, installation costs must be reduced, roof weight limitations should be assessed, and appropriate management practices should be developed which will ensure that the benefits of green roofs, such as energy savings and storm water management, are still provided to urban communities.

Key words: Eco-roof, local food production, vegetated roof, vegetables, community garden

Introduction

In recent years, the importance of green space in urban areas has been changing. A new vision of urban centers incorporates more green space, such as parks[1], and a more human-friendly environment mixing traditional urban centers of industry, commerce and residence with food production[2,3]. Implementation of this vision has been facilitated by the introduction of more environmentally friendly technologies and the introduction of policies and programs which promote their use[4–8]. One such technology being incorporated into development is green roofing.

Definition of green roofs

Green roofing is a technology enabling growth of vegetation on rooftops, effectively replacing green space lost during building construction. Conventional green roofs generally consist of a number of layers including a root barrier to prevent damage to the underlying structure; a drainage layer to facilitate the removal of excess water; a filter fabric to prevent the drainage layer from clogging with media; growing media; and vegetation[9]. Others may be composed of growing modules or vegetated mats. Green roofs vary in depth of growing media and vegetation, but are generally divided into two categories: extensive (those with <15 cm of media) and intensive (those with >15 cm of media)[7]. Extensive roofs are usually planted with ground cover or succulent species that require little maintenance after establishment, while intensive roofs can support herbaceous perennials, shrubs and even trees[9,10] but typically require continued inputs. Design and plant selection depend on the purpose of the project and the environmental benefits to be achieved. Uses of green roofs range from functional storm water and energy management roofs to park-like amenities open to the public, to food production.

Factors determining plant survival include media composition and depth[11,12], incoming solar radiation[13], climate and most importantly soil moisture[14–16]. Insufficient moisture can be remedied by altering media composition and depth or with irrigation if available. Growing media used on commercial green roofs are often engineered and comprise mostly lightweight materials such as heat-expanded slate or shale[9]. Media composition depends on manufacturer and available materials, but it is designed to be lightweight while maintaining the ability to support plant life. Organic matter content may vary and is beneficial for plant growth, but when it decomposes it may leach nutrients, resulting in runoff water-quality issues, and is inconvenient to replace. Economics dictates that substrate composition will depend on materials that are locally available and can be formulated for the intended plant selection, climatic zone and anticipated level of maintenance.

Benefits of green roofs

Use of green roofs in urban development has been shown to provide a number of benefits including reduced air and noise pollution, carbon sequestration, increased habitat and biodiversity, increased roof lifespan, storm water retention, energy savings and mitigation of the urban heat island[9,13,17–26]. Computer modeling predicts that an increase in green roof area, as could take place with the technology's incorporation into urban agriculture, will amplify these benefits[27]. Moreover, the introduction of green roofs to city development plans could promote infill development (the redevelopment of vacant areas within urban centers) and reduce spending on the development of new infrastructure such as roads and sewer lines[22]. Although infill development largely benefits municipalities and companies, expansion of the green roof industry would increase employment and economic growth in urban centers, benefiting populations that typically turn to urban agriculture.

Energy savings[28–31] and mitigation of the urban heat island[17,27,31–34] in particular have great practical benefit to poorer communities who are most likely to benefit from urban agriculture. Green roofs can reduce energy consumption of a building by 2 to 39%[29,30] and by between 12 and 87% for the top floor[30] during the summer. These reductions are primarily due to reducing the amount of direct solar radiation that reaches the roof and the amount of heat transferred into the building[28,31]. The extent of the reduction is dependent on the extent of vegetative cover on the roof[26,28,29], the existence of other insulation[30], the thickness of the green roof media, irrigation of the roof and climate[29]. Energy savings during the winter are negligible in warm climates, but can be seen in cooler climates[29,30]. Energy savings in very humid climates are also expected to be lower due to reduced evapotranspiration and the associated cooling effects[17].

Green roofs have been shown to reduce ambient temperatures[31], an effect that is projected to increase with increasing roof surfaces and the inclusion of green walls (plants grown on walls using a variety of training and planting systems) in urban development[17,27]. Modeling predicts a corresponding reduction in urban temperatures and increase in thermal comfort[17,27]. The end result of reduced temperatures and therefore energy use is a reduction in the use of conventional air-conditioning[17,30]. This would benefit low-income neighborhoods for two reasons. Urban neighborhoods with higher summer temperatures than surrounding urban areas are correlated with lower incomes, higher poverty rates[32] and impoverished individuals aged 65 and older[33] in cities such as Phoenix, AZ and Philadelphia, PA. These individuals are more at risk to environmental hazards, such as extreme heat events, due to a lack of resources enabling them to cope with the hazards, such as air-conditioning[32]. Implementation of green roofs would not only reduce energy bills in such neighborhoods but also reduce the occurrence of extreme heat and the need to air-condition in the summer time, freeing up limited funds for other uses and improving the quality of life of individuals in these at-risk areas and populations.

Figure 1. Vegetable production on a green roof in East Lansing, MI.

Food production in an urban setting

Food production can be added to the benefits provided by green roofs[22,35] (Fig. 1) and expanded through the incorpoation of this technology into urban agriculture. Urban agriculture is defined as horticultural, agricultural or farming activities carried out on small plots of land in and around urban centers[36–38]. Individuals in urban centers around the world participate in urban agriculture for reasons, such as poverty, unemployment, food insecurity[2,39], high prices of market food, income or asset diversification and supplementary employment[2]. These motivational factors[2,3,36–41]; limitations such as land availability, land use and ownership rights, physical and economic access to inputs and potential food contamination[36–39,42,43]; and geographic and climatic factors unique to each urban center shape urban agriculture[2,3,36,38]. It is likely that a number of these limitations could be alleviated through the use of green roofs, while maintaining the benefits expected by urban farmers. Currently, policy is under reform in a number of cities worldwide resulting in accommodation for urban agriculture[3]. These policy changes present an opportunity and could be guided to include farming on green roofs and expedite the inclusion of green roofs and other alternative

https://doi.org/10.1017/S174217051100038X Published online by Cambridge University Press

technologies in urban farming with great benefit to urban populations.

Despite the possible benefits from incorporating green roof technology into urban agriculture, there are a number of potential issues that must be addressed. These include installation and maintenance costs, weight limitations, media composition and depth, cultural practices, potential water-quality issues of effluent and how food production would influence the other known benefits attributed to green roofs. These are not only factors that may limit the use of green roofs, but would also limit their viability for widespread use in urban agriculture. Further research and innovation may present solutions to these problems. The goal of this review is to examine some of the possible benefits and barriers to incorporating green roof technology into urban agriculture. In doing so, we shall first examine the current state of urban agriculture and then introduce potential benefits or limitations of using green roof technology. Due to the lack of published studies on the subject, we will also discuss future research needs. We have therefore divided the review into sections containing common themes; economic benefits and food security, economic barriers, access to resources and policy, human health and environmental health concerns.

Economic Improvement and Food Security

Economic development brought about by participation in urban agriculture comes in a variety of forms, including the supplementation of family income, job creation and freeing up funds previously used to purchase food. Crop choice and scale affect the extent to which urban agriculture contributes to the income of a household[2,37–39]. Rice, for example, is a staple in many parts of the world and can provide income security for an urban farmer's household[38], but production of vegetables may yield higher market prices[37,38]. Animal husbandry, another form of urban agriculture, can provide high profits[2,37,38], but may require much higher investments[38]. In some cases, social capital can be generated by a household, by giving away food that could not be sold[2]. The impact of urban agriculture on employment is highly variable, depending on the economic status of urban farmers[2,37]. For households in both developing and developed countries that do not produce for sale, or sell only their excess produce, urban agriculture frees up funds for other uses[2,36,38,39]. The prevalence of urban agriculture increases when poverty increases and when costs of purchasing food surpass that of growing it[2]. This can be an important measure in stretching household budgets, allowing for the purchase of other items[2,39] or some economic freedom for women where household budgets are male-controlled, as was found in Pretoria, South Africa[39]. In addition, economic concerns are an incentive for consumers who assume that purchasing local produce increases economic returns to local farmers through shortened supply chains and better market accessibility[40,41].

Figure 2. A community garden in Detroit, MI.

Food security, the second major driver of urban agriculture, is affected by both quantity and quality of food available to a household. Even in locations where urban agriculture does not contribute significantly to employment, food security is of major concern to urban farmers[2]. Currently, food in the US must be shipped an average of 74 km (49 miles) to consumers in urban centers[41]. It has been estimated that under ideal conditions the agricultural products of the entire state of New York could not supply the agricultural needs of more than 55% of New York City[41]. This suggests that providing adequate food supplies for urban centers with growing populations may not even be possible on a regional scale, and costs associated with shipping may affect the food security of the urban poor. Producing agricultural goods within urban centers is one method of reducing the ecological footprint of urban centers[3,41] and ensuring urban dwellers, access to food. Food insecurity, or the lack of access to adequate food for an active and healthy life[17], is not just a problem in the developing world, but in the US as well[2,36,44] (Fig. 2). Food insecurity can be temporary or chronic[3] and is associated with a variety of problems in adolescents, who are at higher risk than young children[44]. A perceived or actual need to improve food security and a lack of ability to rely on food from rural areas can result in the use of urban agriculture[3,37], which has been shown to improve the quantity and

https://doi.org/10.1017/S174217051100038X Published online by Cambridge University Press

Figure 3. A herb garden on a green roof in Grand Rapids, MI.

quality of food available to low-income urban households under a variety of conditions[2,3,36,37,44].

Green roofs are already utilized to improve the economic circumstances and food security of urban farmers (Fig. 3). EcoHouse, in St. Petersburg, Russia is an example of a rooftop garden project which provides jobs to, and increases cash flow among, individuals living within the apartment complex[35]. The project also provides those residents with a reliable source of vegetables[35]. Another example is the green roof of the Fairmount Hotel in Vancouver, a portion of which is devoted to a kitchen garden, saving the hotel approximately $30,000 a year[22]. The rooftop garden on Earth Pledge's New York office is used not only as a source of food but also as a promotional tool for the group's organic local produce campaigns[4,22]. Similar community garden projects have been developed in other cities, such as the Multnomah County Green Roof Project in Portland, OR[45] and several community-scale gardens in Chicago, IL[46]. A green roof at Trent University in Peterborough, Ontario, is producing vegetables for a local restaurant, The Seasoned Spoon Café, which was started as a healthy fast-food alternative[47].

Economic Barriers

Economic barriers to urban agriculture include inadequate access to or knowledge about markets[2] and insufficient labor[2,27], inputs such as fertilizers[38], quality seeds[37] and credit or subsidy for startup costs or inputs[2,36–38]. These barriers are due to limited resources of urban farmers and will not be affected by the introduction of green roof technology to urban agriculture. An additional barrier introduced by the use of green roof technology is the cost of green roof installation and maintenance.

Installation of a green roof can be $32 m^{-2} more expensive than a conventional roof for roof structure alone[26]. Installation of green roof systems can vary from two to six times more expensive than conventional roof systems, depending on the design of the roof system[26]. Factors that impact the cost of a green roof include ease of access for installation, structural integrity of the building, type of drainage system, depth and composition of media, inclusion of an irrigation system and the use of a modular, mat or conventional built-up continuous roof system (C. L. Rugh, personal communication, February 5, 2010). Maintenance costs of a green roof also depend on roof design, as intensive roofs tend to require more care than extensive roofs. Maintenance of the roofing layers themselves is comparable to that of a conventional roof due to the longer lifespan of green roofs[26].

Tapping into incentive programmes, such as those used in Portland, OR[6] and Chicago, IL[5] which provide reductions in storm water removal fees and grants to help subsidize installation, may help. Other programmes, such as those geared toward improving the availability of fresh fruits and vegetables in urban centers and improving healthy eating habits in urban youth may also be sources of funding. It is also possible that locally made materials could be used to construct green roofs, reducing the cost of installation, but generation of policy promoting the use of green roofs and subsidizing their installation will be of greater importance in low-income areas than in high-income areas. Evaluation of locally available materials would also be necessary to determine both their suitability and their impact on green roof installation costs.

Access to Resources and Policy

Availability of land, especially land of adequate quality, is the main obstacle affecting urban agriculture[2,3]. Land scarcity and uncertainty in maintaining access to available land are due to competition with other development uses, primarily building construction[2,37,38]. These other uses are often more economically profitable and are therefore preferred by land owners[3,39,43]. Land use and investments in urban agriculture by urban farmers are impacted by resource use rights. Under current systems there are often no formal leasing agreements between land owners and urban farmers cultivating vacant lots[2]. Rights of urban farmers are often minimal[3], uncertain[43], and frequently transient due to changing land uses and termination of informal use agreements[39,43]. Lack of formal agreements over water use rights has led to conflict between municipalities and urban farmers[39].

Incorporation of green roofs into new development would increase the potential agricultural area and remove competition with urban development that reduces the willingness of urban farmers to invest in urban agriculture[2,38]. Currently, flat rooftops comprise as much as 85% of the roof area in downtown and commercial areas[20]. In larger urban areas, this could add up to a great deal of space and potential for productive use if these existing roofs were retrofitted into green roofs. Buildings must, however, have the structural integrity to support the added weight in a worst-case scenario, regardless of whether roofs are designed new or retrofitted[48]. Some existing roofs may not be suitable for retrofitting without incurring considerable costs in structural support. Many flat roofs have load capacities of only 146 $kg\,m^{-2}$ (30 ft^{-2}), which could be exceeded by as little as 7.6 cm (3 inches) of growing media[49]. This means that the flat roof area of existing buildings, which could be used for urban agriculture, is not accurately represented by the flat roof area of a city. More information on which roofs can support the additional weight of a green roof and the minimum depth of media necessary for agricultural production will enable more accurate estimates of how much roof area could be used. Despite these limitations, land owners could take advantage of this potential, enabling them to utilize more profitable development and then generate secondary profits through rental agreements with urban farmers.

Development of flat roof space into agriculturally productive areas could facilitate formalization and standardization of rental, leasing or use agreements between land owners and urban farmers. Access to roof space is limited and would require urban farmers to negotiate with building owners to gain access to the green roof space. This would be a reversal of the current use of vacant lots for urban agriculture, whose absent owners are unaware of agricultural activities or unwilling to take measures to keep urban farmers off the land[2,3]. Although this could create problems for urban farmers if green roof owners are unwilling to rent the space due to zoning or building code issues that might arise[50,51], it could also empower urban farmers. Formal, legally binding use arrangements would grant urban farmers recourse should the green roof owner break the agreement. Such formal and empowering leasing agreements could also encourage farmers to increase investments in urban agriculture, increasing productivity and food security. Urban farmers with informal arrangements do not currently have this level of power and security[3,39,43]. Formalized rental and leasing agreements could easily be extended to include access to the buildings, water supply. This would be greatly beneficial to those farmers who have expressed willingness to pay for clean water where no clean water source currently exists[37], but will increase the costs of farming for most urban farmers. Rainwater collected from an unused portion of the roof may also provide an added source of clean water for irrigation.

There are, however, two additional potential outcomes of rental agreements for the use of green roof space. First is the exclusion from farming and water resources of resource-poor urban farmers unable to pay rent for green roof space. Second is the reallocation of ground-level space and water sources currently used by farmers able to pay for rental agreements. The former could result in greater problems associated with poverty and food security in urban areas, but the latter could grant a larger number of urban dwellers access to land and water and therefore the economic opportunities and additional food security provided by urban agriculture. If the latter is the outcome, it would mean a better quality of life for a greater number of urban dwellers. This will be of particular importance as populations become increasingly urban, both worldwide and in the USA[39,52,53], and doubts about the ability of rural areas to agriculturally support these growing urban populations also increase[39,41,44].

Human Health Concerns

Access to fertilizers is especially important as space limitations in urban agriculture require more intensive farming and greater fertilizer use per area than rural areas[36]. Often resource-poor urban farmers will use inexpensive and easily accessible fertilizers, such as manures or municipal wastes, which can lead to an increase in soil heavy metal and pathogen concentrations[36,37,42,54,55]. Heavy metal and pathogen contamination of food are the primary human health concerns associated with urban agriculture. Sources of contamination include soils in which crops are grown, water used for irrigation and air pollutants. In many cases, the land most readily available to urban farmers is contaminated with heavy metals from a variety of industrial and mining sources, which can lead to contamination of the agricultural products[40,42,54]. In addition, resource-poor urban farmers often cannot afford to pay for clean irrigation water even if a source exists[2,37,38]. Atmospheric deposition of contaminants during production, transportation and marketing of produce also leads to elevated levels of heavy metals[40,55–57].

https://doi.org/10.1017/S174217051100038X Published online by Cambridge University Press

The extent to which heavy metal contamination affects the safety of vegetables depends on several different factors, including the vegetable species, the part of the plant that is eaten and the type of heavy metal[54,55,57,58]. On average, fruit vegetables accumulate lower quantities of heavy metals than leafy or root vegetables[54,57,58]. Leafy vegetables are a major source of heavy metal dietary intake[55], due to high rates of translocation, transpiration and growth, as well as high surface area in close proximity to contaminated soil and irrigation splash[54]. High-surface-area vegetables, such as cauliflower[56], and those that spend more time in the field[57], are also known to accumulate higher concentrations of heavy metals through atmospheric deposition. Dietary intake of heavy metals can lead to accumulation in the human body because they are non-biodegradable[59], causing their negative effects to become apparent only after years of exposure[55,59]. Among resulting health problems are a variety of cognitive disruptions[59,60], nervous, cardiovascular[54,56,60], kidney, bone and liver[54,56] diseases, as well as cancer[59].

The use of green roofs in urban agriculture also has the potential to reduce health concerns. Green roofs have the potential to reduce use of contaminated land in urban agriculture due to the nature of their construction. In most cases, the media in which vegetables would be grown on green roofs are engineered instead of using local soils, and so initial contamination will be minimal. Green roof media are also less likely to accumulate heavy metals than ground soils due to their high permeability and low cation exchange capacity, which results in leaching of nutrients[61] and heavy metals[62] into runoff water. This tendency for leaching would reduce the likelihood of vegetable contamination on green roofs if contaminated sources of water or fertilizers are used. Rental and water use agreements will also facilitate more widespread use of uncontaminated water sources for irrigation. Atmospheric deposition of contaminants may also be reduced during the production phase. It has been suggested that distance from the source of pollutants impacts the extent of heavy metal contamination due to atmospheric deposition[56]. Most green roofs are several stories high, increasing the distance between crop production and such sources of pollution as major roadways and highways.

In addition to food contamination, concerns about urban agriculture include health problems due to improper handling of agrochemicals and urban waste, a potential increase in pests such as rodents and flies, which can contribute to the spread of diseases and the transmission of diseases from livestock to humans due to improper animal husbandry techniques[3]. Although these concerns may be avoidable through proper practices, they promote negative perceptions of urban agriculture. Formalized leasing agreements may provide greater oversight of agrochemicals and urban waste used in urban agriculture. Leasing agreements could include specifications for what, if any, agrochemicals or urban wastes can be used on the green roof, how they should be stored and used, and the consequences for the urban farmer if the specifications are not followed resulting in human injury or a health hazard. In some countries, organizations may already be in place which could monitor such agreements, such as the Occupational Safety and Health Administration (OSHA) in the USA. It is unlikely that the use of green roofs in urban agriculture will affect the keeping of large livestock, which would be impractical on rooftops.

Environmental Health Concerns

Despite the costs, urban farmers are currently producing vegetables on green roofs in natural soils and composts at a media depth of 30 cm or more. This practice potentially creates several problems, including the added weight to the roof, consistency of growing media, potential nutrient loads polluting effluent that discharges into our waterways from fertilizers and as compost decomposes, and the logistical practicality of adding compost every year on a roof several stories above the ground.

Water quality of runoff is another concern as nutrient leaching could cause problems downstream. Composition of the growing media is one aspect of this problem. Most commercial green roof media are formulated within the guidelines of the German FLL (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau) standards[63]. Years of experience have resulted in media that possess the chemical and physical properties to support plants, yet are lightweight, coarse enough to allow drainage at shallow depths, can be replicated and limit nutrient runoff when guidelines are followed. Natural soil is always variable and the addition of compost can lead to runoff quality issues. Even so, commercial green roof media generally contain about 15–20% organic matter which can result in nutrient loading[19,23,64]. Researchers in North Carolina[64] found that concentrations of both N and P decreased with decreasing percentages of compost in the media. These results emphasize the point that growing media can have an immense effect on the quality of effluent. In addition, applications of fertilizers and pesticides to ensure plant growth can be very detrimental to water quality[23,61]. This is especially true for soluble fertilizers applied in liquid form[61].

Studies performed on green roofs with conventional media have shown that nutrient leaching can initially be a problem, but overall, these media can have a positive effect on water quality[23,65]. The initial nutrient load likely is due to decomposition of organic matter that was incorporated into the original mix. Once established, and the organic matter reaches an equilibrium, vegetation and substrates can improve water quality of runoff by absorbing and filtering pollutants[23]. The effect of plants and their root systems was evident when effluent from an unplanted green roof containing media was shown to have higher concentrations and totals of N and P than effluent from planted roofs[65].

There is also the question of how much fertilizer is necessary to maintain agricultural productivity in green roof media. Experimentation has shown that non-succulents grown on green roofs require either additional organic matter in the media or fertilization[12]. The relatively high levels of fertilizer that may be necessary to produce vegetables could lead to high levels of nutrient leaching. This begs the question, are we trading the benefits of local food production for decreased water quality? If nutrient loading does turn out to be a problem, then green roofs could be coupled with other low-impact development practices such as rain gardens and bioswales (landscaping techniques designed to manage storm water), although these practices are not always possible in dense urban settings. This highlights the need to develop and use green roof growing media and cultural practices that minimize leaching of nutrients while still providing adequate physical and chemical properties for plant growth.

Conclusions

In addition to previously mentioned research needs, there are several areas where research on the use of green roof technology in urban agriculture is necessary before wide-scale use of the technology can be implemented. First, determination of what crops are suited to growth in green roof media will be necessary. Little is known about how growing vegetables on green roofs will impact the environmental benefits provided by green roofs. Many of the benefits are directly related to the amount of coverage achieved by the vegetation and the leaf area of the vegetation[66]. The coverage that would be achieved by vegetables will be very different than that of the ground covers and perennials traditionally used on green roofs because they are typically cultivated in rows. In addition, vegetable gardens would be replanted every year, whereas typical green roofs are populated with perennial species. Research on how this difference will impact energy savings and storm water retention, for example, will enable better assessment of this use of green roofs in areas where these benefits are of particular importance.

The effects of other environmental factors on crops, such as exposure to higher winds, should be determined for optimum crop selection. Although pollinators have been seen and kept on green roofs, an understanding of the efficiency and quality of pollination of vegetable plants on green roofs would enable better decision-making about which crops to grow and the necessity of bee keeping on vegetable-growing green roofs. Finally, economic evaluation of different crops may generate more information on how much economic impact this form of food production could have on both a small and large scale.

The incorporation of green roof technology into urban agriculture maintains the economic and food security benefits of urban agriculture, while eliminating some of the many difficulties faced by urban farmers around the world. The ideal case, where formalized use agreements with building owners and oversight by municipal authorities ensure greater space availability and healthier produce, is, however, only possible through the cooperation of all parties involved, something that may be difficult in areas where urban agriculture is viewed in a particularly negative light. The formalization of use rights required by use of green roof space by urban farmers represents an opportunity for farmers to achieve guaranteed access to quality land and irrigation water, providing security for their agricultural pursuits. For land and building owners, the formalization of use rights represents an opportunity to achieve greater economic success and some degree of oversight over the activities taking place. This combination of economic opportunity and oversight may have the added benefit of improving land and building owners' attitudes toward urban agriculture, which could expedite policy reform. Municipal involvement will enable new insights into the benefits of urban agriculture and understanding the ways in which its negative impacts can be minimized.

The process, though difficult, could be made easier through the establishment of policy friendlier to urban agriculture, incentive and subsidy programmes for the installation of green roofs and research into reducing the initial cost of green roofs and minimizing the inputs necessary for productive agriculture on green roofs. The resolution of these issues will further enable a future in which urban areas are greener and healthier places to live. This future could utilize ideas about development that incorporate green space in the forms of green roofs, parks or agricultural plots, enabling a closer connection with nature and the production of food with the benefit of increased food security, especially for the urban poor.

References

1 Nowak, D.J. 2006. Institutionalizing urban forestry as a 'biotechnology' to improve environmental quality. Urban Forestry and Urban Greening 5:93–100.

2 Nugent, R. 2002. The impact of urban agriculture on the household and local economies. RUAF Foundation International Workshop of Urban Agriculture: Growing Cities, Growing Food. Available at Web site http://www.ruaf.org.index.php?q=node/57 (accessed January 31, 2009).

3 de Zeeuw, H., Guendel, S., and Waibel, H. 1999. The integration of agriculture in urban policies. RUAF Foundation International Workship on Urban Agriculture: Growing Cities, Growing Food- Urban agriculture on the policy agenda. Available at Web site http://www.ruad.org/index.php?q=node/62 (accessed January 31, 2009).

4 Cheney, C. 2005. New York City: Greening Gotham's Rooftops. In M. Arpels, S. Chrisman, H. Sommerfield, J. Towers, E. Berkowitz, G. Brainard, and L. Hickey (eds). Green Roofs: Ecological Design and Construction by Earthpledge. Schiffer Books, Atglen, PA. p. 130–133.

5 City of Chicago, Department of Community Development. 2006. Green roof improvement fund. Available at Web site http://egov.cityofchicago.org/city/webportal/portalEntityHomeAction.do?entityName=Planning+And+Development&entityNameEnumValue=32 (accessed April 1, 2009).

6 City of Portland, Environmental Services. 2009. Ecoroof incentive program. Available at Website http://www.portlandonline.com/bes/index.cfm?c=44422& (accessed April 1, 2009).
7 Kula, R. 2005. Green roofs and the LEED™ green building rating system. In Proceedings of Third North American Green Roof Conference: Greening Rooftops for sustainable communities, Washington, DC, May 4-6, 2005. The Cardinal Group, Toronto, p. 141–153.
8 Liptan, T. 2005. Portland: A new kind of stormwater management. In M. Arpels, S. Chrisman, H. Sommerfield, J. Towers, E. Berkowitz, G. Brainard, and L. Hickey (eds). Green Roofs: Ecological Design and Construction by Earthpledge. Schiffer Books, Atglen, PA.
9 Getter, K.L. and Rowe, D.B. 2006. The role of extensive green roofs in sustainable development. HortScience 41(5):1276–1285.
10 Dvorak, B. and Volder, A. 2010. Green roof vegetation for North American ecoregions: A literature review. Landscape and Urban Planning 96:197–213.
11 Getter, K.L. and Rowe, D.B. 2009. Substrate depth influences sedum plant community on a green roof. HortScience 44(2): 401–407.
12 Rowe, D.B., Monterusso, M.A., and Rugh, C.L. 2006. Assessment of heat-expanded slate and fertility requirements in green roof substrates. HortTechnology 16(3):471–477.
13 Getter, K.L., Rowe, D.B., and Cregg, B.M. 2009. Solar radiation intensity influences extensive green roof plant communities. Urban Forestry and Urban Greening 8(4): 269–281.
14 Durhman, A.K., Rowe, D.B., and Rugh, C.L. 2006. Effect of watering regimen on chlorophyll fluorescence and growth of selected green roof plant taxa. HortScience 41:1623–1628.
15 Emilsson, T. 2008. Vegetation development on extensive vegetated green roofs: Influence of substrate composition, establishment method and species mix. Ecological Engineering 33:265–277.
16 Monterusso, M.A., Rowe, D.B., and Rugh, C.L. 2005. Establishment and persistence of *Sedum* spp. and native taxa for green roof applications. HortScience 40(2): 391–396.
17 Alexandri, E and Jones, P. 2008. Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates. Building and Environment 43:480–493.
18 Barrio, E.P.D. 1998. Analysis of green roofs cooling potential in buildings. Energy and Buildings 27:179–193.
19 Berndtsson, J.C. 2010. Green roof performance towards management of runoff water quantity and quality: A review. Ecological Engineering 36:351–360.
20 Carter, T. and Jackson C.R. 2007. Vegetated roofs for stormwater management at multiple spatial scales. Landscape and Urban Planning 80:84–94.
21 Getter, K.L., Rowe, D.B., and Andresen, J.A. 2007. Quantifying the effect of slope on extensive green roof stormwater retention. Ecological Engineering 31:225–231.
22 Loder, A. and Peck, S.W. 2004. Green roofs' contribution to smart growth implementation. In Proceedings of 2nd North American Green Roof Conference: Greening rooftops for sustainable communities, Portland, OR, June 2-4, 2004. The Cardinal Group, Toronto, p. 8–24.
23 Rowe, D.B. 2011. Green roofs as a means of pollution abatement. Environmental Pollution 159(8–9):2100–2110.
24 Saiz, S., Kennedy, C., Bass, B., and Pressnail, K. 2006. Comparative life cycle assessment of standard and green roofs. Environmental Science Technology 40(13):4312–4316.
25 VanWoert, N.D., Rowe, D.B., Andresen, J.A., Rugh, C.L., Fernandez, R.T., and Xiao, L. 2005a. Green roof stormwater retention: Effects of roof surface, slope, and media depth. Journal of Environmental Quality 34:1036–1044.
26 Wong N.H., Tay, S.F., Wong, R., Ong, C.L., and Sai, A. 2003. Life cycle cost analysis of rooftop gardens in Singapore. Building and Environment 38:499–509.
27 Bass, B., Krayenhoff, E.S., Martilli, A., Stull, R.B., and Auld, H. 2003. The impact of green roofs on Toronto's urban heat island. In Proceedings 1st North American Green Roof Conference: Greening Rooftops for Sustainable Communities, Chicago, IL, May 29-30, 2003. The Cardinal Group, Toronto.
28 Fang, C.-F. 2008. Evaluating the thermal reduction effect of plant layers on rooftops. Energy and Buildings 40:1048–1052.
29 Sailor, D.J. 2008. A green roof model for building energy simulation programs. Energy and Buildings 40:1466–1478.
30 Santamouris, M., Pavlou, C., Doukas, P., Mihalakakou, G., Synnefa, A., Hatzibiros, A., and Patargias, P. 2007. Investigating and analyzing the energy and environmental performance of an experimental green roof system installed in a nursery school building in Athens, Greece. Energy 32: 1781–1788.
31 Wong, N.H., Tay, S.F., and Chen, Y. 2007. Study of thermal performance of extensive rooftop greenery systems in the tropical climate. Building and Environment 42:25–54.
32 Harlan, S.L., Brazel, A.J., Prashad, L., Stefanov, W.L., and Larsen, L. 2006. Neighborhood microclimates and vulnerability to heat stress. Social Science and Medicine 63: 2847–2863.
33 Johnson, D.P. and Wilson, J.S. 2009. The socio-spatial dynamics of extreme urban heat events: The case of heat-related deaths in Philadelphia. Applied Geography 29:419–434.
34 Memon, R.A., Leung, D.Y.C., and Chunho, L. 2008. A review on the generation, determination and mitigation of Urban Heat Island. Journal of Environmental Sciences 20:120–128.
35 Arpels, M., Chrisman, S., Sommerfield, H., Towers, J., Berkowitz, E., Brainard, G., and Hickey, L. 2005. Building case studies. In M. Arpels, S. Chrisman, H. Sommerfield, J. Towers, E. Berkowitz, G. Brainard, and L. Hickey (eds). Green Roofs: Ecological Design and Construction by Earthpledge. Schiffer Books, Atglen, PA. p. 24–102.
36 Enete, A.A. and Achike, A.I. 2008. Urban agriculture and urban food insecurity poverty in Nigeria: The case of Ohafia, south-east Nigeria. Outlook on Agriculture 37(2):131–134.
37 Graefe, S., Schlecht, E., and Buerkert, A. 2009. Opportunities and challenges of urban and peri-urban agriculture in Niamey, Niger. Outlook on Agriculture 37(1):47–56.
38 Vagneron, I. 2007. Economic appraisal of profitability and sustainability of peri-urban agriculture in Bangkok. Ecological Economics 61:516–529.
39 van Averbeke, W. 2007. Urban farming in the informal settlements of Atteridgeville Pretoria, South Africa. Water SA 33(3):337–342.
40 Hu, X. and Ding, Z. 2009. Lead/cadmium contamination and lead isotopic ratios in vegetables grown in peri-urban and mining/smelting contaminated sites in Nanjing, China.

Bulletin of Environmental Contamination and Toxicology 82:80–84.
41 Peters, C.J., Bills, N.L., Lembo, A.J., Wilkins, J.L., and Fick, G.W. 2009. Mapping potential foodsheds in New York State: A spatial model for evaluating the capacity to localize food production. Renewable Agriculture and Food Systems 24(1):72–84.
42 Agbenin, J.O., Danko, M., and Welp, G. 2009. Soil and vegetable compositional relationships of eight potentially toxic metals in urban garden fields from northern Nigeria. Journal of the Science of Food and Agriculture 89:49–54.
43 Thornton, A. 2009. Pastures of plenty?: Land rights and community-based agriculture in Peddie, a former homeland town in South Africa. Applied Geography 29:12–20.
44 Widome, R., Neumark-Sztainer, D., Hannah, P.J., Haines, J., and Story, M. 2009. Eating when there is not enough to eat: Eating behaviors and perceptions of food among food-insecure youths. Research and Practice 99(5):822–828.
45 King, J. 2004. Multnomah County's green roof project: A case study. In Proceedings of 2nd North American Green Roof Conference: Greening rooftops for sustainable communities, Portland, OR, June 2-4, 2004. The Cardinal Group, Toronto.
46 Coffman, R.R. and Martin, J.F. 2004. The sustainability of an agricultural roof garden. In Proceedings 2nd North American Green Roof Conference: Greening Rooftops for Sustainable Communities, Portland, OR, June 2-4, 2004. The Cardinal Group, Toronto.
47 Blyth, A. and Menagh L. 2006 From rooftop to restaurant – A university café fed by a rooftop garden. City Farmer, Canada's Office of Urban Agriculture. Available at Web site http://www.cityfarmer.org/TrentRoof.html (accessed April 19, 2010).
48 Rowe, D.B. and Getter, K.L. 2010. Green roofs and roof gardens. In J. Aitkenhead-Peterson and A. Volder (eds). Urban Ecosystems Ecology. Agronomy Monograph 55. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, WI. p. 391–412.
49 Kortright, R. 2001. Evaluating the potential of green roof agriculture. Urban Agriculture Notes. City Farmer, Canada's Office of Urban Agriculture. Available at Web site http://www.cityfarmer.org/greenpotential.html (accessed December 21, 2010).
50 Dillion, R.M. 2010 Urban gardeners versus zoning laws. Associated Press February 16, 2010. Available at Web site http://www.csmonitor.com/The-Culture/Gardening/2010/0216/Urban-gardeners-versus-zoning-laws (accessed April 15, 2010).
51 Sutton, S. 2009. City in the sky: Harnessing the potential of urban rooftops. Presentation at the 7th North American Green Roof Conference: Greening Rooftops for Sustainable Communities, Atlanta, GA, June 3-5, 2009.
52 UNDESA. 2007. World urbanizations prospects, 2007 Edition. United Nations Department of Economic and Social Affairs (DESA) Population Division – Population estimates and projections section. Available at Web site http://www.un.org/esa/population/unpop.htm (accessed September 29, 2009).
53 U.S. Census Bureau (USCB). 2009. International data base: Total midyear population for the world: 1950–2050. Available at Web site http://www.census.gov/ipc/www/idb/worldpop.php (accessed October 3, 2009).
54 Zhuang, P., McBride, M.B., Xia, H., Li, N., and Li, Z. 2009. Health risk from heavy metals via consumption of food crops in the vicinity of Dabaoshan mine, South China. Science of the Total Environment 407:1551–1561.
55 Srinivas, N., Rao, S.R., and Kumar, K.S. 2009. Trace metal accumulation in vegetables grown in industrial and semi-urban areas: A case study. Applied Ecology and Environmental Research 7(2):131–139.
56 Sharma, R.K., Agrawal, M., and Marshall, F.M. 2009. Heavy metals in vegetables collected from production and market sites of a tropical urban area of India. Food and Chemical Toxicology 47:583–591.
57 Voutsa, D., Grimanis, A., and Samara, C. 1996. Trace elements in vegetables grown in an industrial area in relation to soil and air particulate matter. Environmental Pollution 94(3):325–334.
58 Yang, Y., Zhang, F.S., Li, H.F., and Jiang, R.F. 2009. Accumulation of cadmium in the edible parts of six vegetable species grown in Cd-contaminated soils. Journal of Environmental Management 90:1117–1122.
59 Arora, M., Kiran, B., Rani, S., Rani, A., Kaur, B., and Mittal, N. 2008. Heavy metal accumulation in vegetables irrigated with water from different sources. Food Chemistry 111:811–815.
60 Chimbira, C. and Moyo, D.Z. 2009 The effect of single and mixed treatment of lead and cadmium on soil bioavailability and yield of *Brassica napus* irrigated with sewage effluent: A potential human risk. African Journal of Agricultural Research 4(4):359–364.
61 Emilsson, T., Czerniel Berndtsson, J., Mattsson, J.E., and Rolf, K. 2007. Effect of using conventional and controlled release fertilizer on nutrient runoff from various vegetated roof systems. Ecological Engineering 29:260–271.
62 Berndtsson, J.C., Emilsson, T., and Bengtsson, L. 2006. The influence of extensive vegetated roofs on runoff water quality. Science of the Total Environment 355:48–63.
63 FLL (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau). 1995. Guidelines for the Planning, Execution and Upkeep of Green-Roof Sites. Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau, Bonn, Germany.
64 Hathaway, A.M., Hunt, W.F., and Jennings, G.D. 2008. A field study of green roof hydrologic and water quality performance. Transactions of American Society of Agricultural and Biological Engineers 51(1):37–44.
65 U.S. Environmental Protection Agency. 2009. Green roofs for stormwater runoff control. EPA-600-R-09-026. USEPA, Washington, DC.
66 Heilman, J.L., McInnes, K.J., Gesh, R.W., Lanscano, R.J., and Savage, M.J. 1996. Effects of trellising on the energy balance of a vineyard. Agricultural and Forest Meteorology 81:79–93.