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Sustainable Food Systems for Future Cities: The Potential of Urban Agriculture*

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Abstract: Populations around the world are growing and becoming predominately urban, fueling the need to re-examine how urban spaces are developed and urban inhabitants are fed. One remedy that is increasingly being considered as a solution to inadequate food access in cities, is urban agriculture. As a practice, urban agriculture is beneficial in both post-industrial and developing cities because it touches on the three pillars of sustainability: economics, society, and the environment. Historically, as well as currently, economic and food security are two of the most common reasons for participation in urban agriculture. Urban agriculture not only provides a source of healthful sustenance that might otherwise be lacking, it can also contribute to a household's income, offset food expenditures, and create jobs. Social facets are another reason for populations to engage in urban agriculture. A garden or rooftop farm is a place where people come together for mutual benefit, often enhancing the common social and cultural identity for city residents. Larger urban farms also participate in community enrichment through job training and other educational programmes, many of which benefit underserved populations. Finally, urban agriculture can play an important role in the environmental sustainability of a city. As a form of green infrastructure, urban farms and community food gardens help reduce urban heat island effects, mitigate urban stormwater impacts and lower the energy embodied in food transportation.

This paper will describe a multi-year study undertaken by the Urban Design Laboratory at the Earth Institute to assess the opportunities and challenges associated with the development of urban agriculture in New York City (NYC). The paper will present metrics on potential growing capacity within the City inclusive of both rooftop and land-based options, results from a survey of New York City based urban farmers that gathered information on the challenges and barriers to food production in NYC, with a focus on rooftop farming, and data from an environmental monitoring study on a commercial rooftop farm in Brooklyn. The paper will use the results of the multi-year study to provide insight into the potential role of urban agriculture to creating a more sustainable food system for New York City and cities elsewhere.

I INTRODUCTION

Populations around the world are growing, projected to increase to 9.3 billion by 2050 (USCB, 2012), and becoming predominately urban. Indeed, in 2011 the urban population in some of the world's developed regions, including the United States (US), surpassed over three-quarters of the total population (UNDESA, 2012). This growth in urban population is fueling the need to re-examine how urban spaces are developed and urban inhabitants are fed. One remedy that is increasingly being considered as a solution to unhealthy and/or inadequate food access in cities is urban agriculture. Urban agriculture is usually described as horticultural, agricultural, and farming activities carried out on small plots of land in and around urban centres, however some definitions also include animal husbandry (Enete and Achike, 2008; Graefe *et al.*, 2008; Vagneron, 2007). As a practice, urban agriculture touches on all three pillars of sustainability: economics, society, and the environment, as described below.

1.1 *Economic Benefits of Urban Agriculture*

Historically as well as today, community development, food security and economic security are three of the most common reasons for participation in urban agriculture. Urban agriculture not only strengthens social ties and provides healthful sustenance that might otherwise be lacking, it can also contribute to a household's income, offset food expenditures, and create jobs.

Food security is affected by both the 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 (Nugent, 2002). Food insecurity, or the lack of access to adequate food for an active and healthy life (Nord *et al.*, 2007) is not just a problem in the developing world, but in the United States as well (Enete and Achike, 2008; Nugent, 2002; Widome *et al.*, 2009). Food insecurity can be temporary or chronic (de Zeeuw *et al.*, 1999) and is associated with a variety of problems in adolescents, who are at higher risk than young children (Widome *et al.*, 2009). A perceived or actual need to improve food security and a lack of ability to rely of food from rural areas can result in the use of urban agriculture (Graefe *et al.*, 2008; de Zeeuw *et al.*, 1999), which has been shown to improve the quantity and quality of food available to low income urban households under a variety of conditions (Enete and Achike, 2008; Graefe *et al.*, 2008; Nugent, 2002; Widome *et al.*, 2009; de Zeeuw *et al.*, 1999).

The extent to which urban agriculture supplements household income is diverse and can be dependent on crop choice and the scale of production. Staples, such as rice, can provide income security for a household (Vagneron, 2007), but vegetables can often command higher market prices (Graefe *et al.*, 2008; Vagneron, 2007). Animal husbandry can also provide high profits (Graefe *et al.*, 2008; Nugent, 2002; Vagneron, 2007) through the sale of dairy products (Nugent, 2002) or manure as fertiliser (Graefe *et al.*, 2008). In some cases, only excess produce is sold (Graefe *et al.*, 2008; Vagneron, 2007) or urban agriculture is used to supplement inadequate household incomes (Enete and Achike, 2008; Nugent, 2002; Vagneron, 2007). In other cases, urban agriculture may be the only reported source of income for a household and plays an important role in alleviating poverty (van Averbeke, 2007; Graefe *et al.*, 2008). For households who do not sell produce, urban agriculture frees up funds for other uses (van Averbeke, 2007; Enete and Achike, 2008; Nugent, 2002; Vagneron, 2007). This can stretch the household budget, allowing for the purchase of other essential items (van Averbeke, 2007; Nugent, 2002) or increase economic freedom for women where household budgets are male-controlled (van Averbeke, 2007). Job creation through urban agriculture is also highly variable. In some areas, half of urban farmers employ workers (Graefe *et al.*, 2008). In others, urban farmers are too poor, or the employment market too fragmented to provide more than occasional or seasonal job opportunities (Nugent, 2002).

1.2 *Societal Benefits of Urban Agriculture*

Social facets are another reason for populations to engage in urban agriculture (van Averbeke, 2007; Nugent, 2002). A garden or rooftop farm is a place where people can come together for mutual benefit (van Averbeke, 2007; de Zeeuw *et al.*, 1999), often providing a common social and cultural identity for city residents (van Averbeke, 2007). Urban agriculture is commonly cited as a means of fostering community empowerment or as an opportunity for urban residents, particularly in underserved areas, to directly engage with food production and food procurement, which is increasingly seen as a social justice issue (Mees and Stone, 2012). Larger urban farms also participate in community enrichment programmes such as skills development, job training and other educational programmes, many of which benefit underserved populations. These programmes use the produce in cooking and nutrition lessons for residents, as is done at Seeds to Feed Rooftop Farm, in Brooklyn (SFRF, 2013) or the Growing Chefs programme, which offers educational programming in farming, gardening and cooking at numerous locations, including the Eagle Street rooftop farm (Growing Chefs, 2013). Programmes such as CORE/El Centro in Milwaukee also use urban farming as part of their healing therapies agenda and to help re-connect immigrant communities to their cultural roots, which value access to fresh, locally grown produce (Fredrich, 2013).

1.3 *Environmental Benefits of Urban Agriculture*

Finally, urban agriculture can play an important role in the environmental sustainability of a city. As a form of green infrastructure, urban farms and community food gardens can help reduce urban heat island effects, mitigate urban stormwater impacts, and lower the energy embodied in food transportation.

The Urban Heat Island (UHI), defined as higher mean temperatures in an urban area than the surrounding rural area (Alexandri and Jones, 2008; Getter and Rowe, 2006; Memon *et al.*, 2008), can lead to urban temperatures between 0.6˚C and 12˚C warmer than those of surrounding rural areas (Cheval, *et al.*, 2009; Memon *et al.*, 2010). Increasing the amount of vegetation in an urban area is one of the more popular methods of mitigating the UHI through altering the heat balance of a city (Akbari, 2002). Shading by vegetation blocks and redistributes incoming solar radiation and diffuses light reflected from nearby urban surfaces (Akbari, 2002; Alexandri and Jones, 2008) that would otherwise be reflected or re-radiated as sensible heat by urban surfaces (Memeon *et al.*, 2008). Evapotranspiration in vegetated areas acts as a heat sink and also results in lower ambient and surface temperatures than urban areas without vegetation (Akbari, 2002; Alexandri and Jones, 2008; Getter and Rowe, 2006). Unfortunately, many urban areas do not have much ground level land for additional green space, leaving rooftops as an important space for greening. Rooftop farms can help reduce local temperatures (Wong *et al.*, 2007) and when implemented on a city wide scale, could result in significant cooling of the urban environment (Bass *et al.*, 2003).

Urban vegetation, including agricultural space, can also be used in stormwater management. Its effectiveness at reducing stormwater runoff quantities and improving runoff quality is dependent on a number of factors. Green roofs can retain between 52.3 and 100 per cent of precipitation, reducing the amount of stormwater runoff (Czemiel Berndtsson, 2010; Getter *et al.*, 2007; Hathaway *et al.*, 2008; Rowe, 2011; VanWoert *et al.*, 2005). This has garnered them attention in municipal policy in cities such as Portland, Oregan (Liptan, 2005) as well as NYC. The ability of green roofs to improve runoff water quality is less clear. Green roofs release lower concentrations of heavy metals in runoff water than non-vegetated roofs (Czemiel Berndtsson *et al.*, 2006; Czemiel Berndtsson, 2010; Rowe, 2011), but have mixed performance with respect to nutrients, such as nitrogen and phosphorus (Czemiel Berndtsson *et al.*, 2006; Hathaway *et al.*, 2008). Fertiliser application to green roofs only increases the levels of nutrients in runoff (Czemiel Berndtsson *et al.*, 2006; Emilsson *et al.*, 2007; Rowe *et al.*, 2006). The effect of fertiliser on runoff water quality is one of the important environmental issues associated with rooftop agriculture and it is yet to be fully understood (Whittinghill and Rowe, 2012).

Urban agriculture can also lower the energy embodied in food transportation by reducing the number of miles food has to travel from the farm to the table. It has been estimated that food typically travels about 1,300 miles (2,080 km) from farm to table, a figure which could be reduced to 30 miles (49 km) for some foods if they were produced more locally (Peters *et al.*, 2009). Additionally, decreasing the distance that food travels can have a significant impact on reducing spoilage and therefore food waste; preliminary analysis has indicated that from an embodied energy perspective, decreasing food waste may be a more significant benefit of highly localised food distribution than fuel use (Ackerman *et al.*, 2012). Urban agriculture may also improve nutrient cycling through local recycling and re-use of organic and water wastes (de Zeeuw *et al.*, 1999), thereby reducing the ecological footprint of urban centers (Peters *et al.*, 2009; de Zeeuw *et al.*, 1999). Many rooftop farms rely on compost that is made from locally collected food scraps, including the Brooklyn Grange described in Section 2.3 (Ben Flanner, personal communication, May 24, 2012). In some cases, such as the Intercontinental New York Barclay hotel, these are food scraps from the kitchen of the building on which the farm is located (IHR, 2013).

II URBAN AGRICULTURE AND NEW YORK CITY

To provide insight into the potential role that urban agriculture could play in creating a more sustainable food system for today's evolving cities, the Urban Design Lab (UDL) at Columbia University's Earth Institute has undertaken a multi-year study of urban agriculture potential in New York City (NYC). The study has examined the food production capacity within the City (Ackerman *et al.*, 2011) as well as the challenges and barriers to urban faming, with an initial focus on rooftop farming. In addition, the study has undertaken some initial quantification of the environmental benefits and impacts of urban farming, again with an initial focus on rooftop farming. Findings to date in each of these areas are reported below.

2.1 *Potential Food Production Capacity Within New York City*

Understanding the capacity of urban agriculture to feed urban populations necessarily hinges on estimations of how much food can be grown within a city area. This is a critical assessment, in that the viability of urban agriculture and the degree to which it is afforded political and cultural support is, to some extent, dependent on perceptions of whether it can have a significant impact on local food availability and security.

In New York City, urban agriculture is already contributing to improved food security in many neighbourhoods. Community gardens across the city are providing food to members and supplying local food banks with their produce. Researchers at the Farming Concrete project estimated that 87,690 lbs of vegetables were grown on 67 gardens of the city's hundreds of community gardens in 2010 (Gittleman 2010). Urban farms such as Added Value Red Hook and East New York Farms have Community Supported Agriculture (CSA) programmes offering produce *Potential food production capacity within New York City* from their farms, while Eagle Street Rooftop Farm has a CSA which is supplemented with produce from a farmer in the Hudson Valley (this may be the first CSA in the nation to be at least partially supplied by a rooftop farm). Farms and community gardens are also selling their produce at farmers markets, in some cases onsite (such as with Added Value Red Hook, East New York Farms, La Finca Del Sur, Hattie Carthan Community Garden, and others), and the City is partnering with Just Food to establish five more farmers markets at community gardens. Many of these farmers' markets also host regional producers from outside the city. These examples provide evidence of how urban agriculture is acting as a catalyst for larger food system change by providing facilities and logistical support for regional producers to gain access to urban consumers. Many of these community farmers markets are in areas where conventional grocery stores are reluctant to locate due to concerns about neighbourhood income levels and demand.

To up-scale current urban agricultural activities to the point where NYC might be self-sufficient in supplying its fruit and vegetable needs, research by the paper's authors indicates that between 162,000 and 232,000 acres of land are needed (Ackerman *et al*., 2011). This figure does not account for the approximately 886 million lbs of tropical or warm-weather fruit consumed annually by New Yorkers, which cannot be grown locally (these warm-weather products represent 64 per cent of total annual fruit consumption by weight and 24 per cent of combined total annual fruit and vegetable consumption by weight). If all of the potentially suitable vacant land in the city (estimated at 4,984 acres) were converted to urban agriculture with an average growing area of 70 per cent of the lot area, the research estimates that this could supply the produce needs of between 103,000 and 160,000 people – depending on whether conventional or biointensive food yield figures are used. Although this is a substantial number of people, it falls well short of the population of NYC. Thus, while there is much more land potentially available than simply vacant lots, it is clear that NYC cannot strive to be anywhere close to self-sufficient in supplying its fruit and vegetable needs, much less all foods.

Although urban land availability precludes non-warm weather fruit and vegetable self-sufficiency for NYC, Ackerman *et al*. (2011) do show that for specific high value, healthy crops suited to urban farming, localised production is actually feasible from the perspective of land availability. While crops such as beans and potatoes need a great deal of land area and are not particularly well suited to small-scale, urban production, crops such as leafy greens and tomatoes may be grown in large quantities in urban areas. For dark green vegetables, for example, only 8,671 acres are needed to supply NYC using biointensive growing methods, and the approximately 360 million pounds of tomatoes consumed annually by New Yorkers could be grown on 8,260 acres. Furthermore, considerably less area would be needed for these vegetables to be grown hydroponically.

Considering the needs and resources of particular communities within NYC also adds a different dimension to the analysis. There are a number of NYC neighborhoods where a confluence of factors makes urban agriculture a particularly attractive and effective means of addressing multiple challenges. These include low access to healthy food retail, high prevalence of obesity and diabetes, low median income, and comparatively high availability of vacant and other available land. Not coincidentally, these factors are all correlated, and it is in these areas where urban agriculture could have the greatest impact on food security.

New York City neighbourhoods which fit the pattern of inadequate healthy food access, high incidence of diet-related disease, greater percentage of vacant land, etc., were found to include East New York, Brownsville, Crown Heights, Bedford-Stuyvesant, and Bushwick in Brooklyn, the Lower East Side and East and Central Harlem in Manhattan, and Morrisania, Claremont Village, East Tremont, and Belmont in the Bronx, among others. These are also neighbourhoods where the presence of many community gardens signifies community interest in and engagement with food production. In these neighbourhoods, urban agriculture could improve fresh food availability. For example, Brooklyn Community district 16 (Brownsville) has 58 acres of vacant land, which, if converted entirely to vegetable production, could produce as much as 45 per cent of the district's 85,000 residents' annual supply of dark green vegetables (broccoli, collard greens, escarole, kale, lettuce leaf, mustard greens, spinach, and turnip greens; this estimate assumes an average lot coverage of 70 per cent for growing area). This district also has an estimated 23 acres of green space on New York City Housing Authority (NYCHA) property, as well 14 acres of surface parking – converting some of this area to farming or gardening could increase the availability of fresh produce even further.

2.2 *Challenges and Barriers to Food Production in New York City*

The capacity of urban agriculture to meet certain food needs within a city also hinges on the ease at which urban faming can be practiced. To develop a better understanding of the challenges and barriers facing urban farmers, and to evaluate whether changes to policy or other systemic conditions could help alleviate such barriers, the UDL undertook a survey of NYC based farmers. The survey was informal and was administered to 22 individuals who are active in rooftop farming and gardening in NYC. Respondents were asked to identify challenges and barriers to the development phase (planning, design, construction) of a rooftop farm or garden, how they addressed these challenges, and whether they could think of broader solutions that would help mitigate or alleviate these challenges for them or other prospective farmers in the future. They were then asked a similar series of questions regarding the operation of rooftop farms and gardens (encompassing farm management, maintenance, etc.). This structure allowed for the differentiation between the barriers to entry for prospective rooftop farmers and gardeners, as opposed to the challenges encountered once a farm or garden has already been established – a distinction which was deemed to be important to identifying how potential policy incentives or solutions might best be targeted. Participants were free to identify as many challenges as they wished, as they were not asked to create a hierarchy; although some did so of their own volition, specifically referring to some issues as “primary,” “the major problem,” etc. Questions were left open-ended and follow-up questions were asked for clarification. Results were then transcribed, reviewed, and compiled, and common themes were identified.

Survey participants were identified using a variety of sources, including existing UDL contacts, the greenroofs.com database (GRC, 2013), and public information on recipients of tax incentives and green infrastructure grants. These individuals included 20 people with experience in the rooftop farming development process, which includes the planning, design, and construction phase, 7 people who have an oversight, management, or maintenance role on an active rooftop farm or garden, and 10 active rooftop farmers or gardeners (with many of the individuals filling multiple roles). Collectively, respondents participated in the development and/or operation of 13 rooftop farms and 19 rooftop gardens with a total growing area of over 150,000 square feet and a median growing area of 1,000 square feet (and with a total of approximately 100,000 additional square feet in the planning phase). Of the roofs, 13 use an intensive green roof system, 3 are extensive, while 15 involve some form of container farming or gardening (with some roofs including more than one type). Of these operations, 3 are in the Bronx (total 11,000 square feet), 11 in Manhattan (10,275 square feet), 14 in Brooklyn (86,400 square feet), and 2 in Queens (47,000 square feet) (none of the roofs are in Staten Island). Of the roofs, 4 are commercial rooftop farms, generating revenue primarily from sales to retailers, restaurants, and through farm stands and CSAs; 7 are projects on residential buildings intended primarily for use by multiple building occupants; 3 are non-profit operations staffed by volunteers supplying shelters or kitchens, 4 are on schools and meant primarily for educational purposes, 6 are on restaurants or hotels and used to supply commercial kitchens, and 6 are on private residences. Given the fact that rooftop farming and gardening is not a widespread activity in NYC, the study that was undertaken is believed to be fairly representative of this small but growing community. This is because a majority of rooftop food producing sites in NYC are in some way represented by the respondents, whether through people involved in design and construction or those who are responsible for day-to-day operations.

The range of topics raised by the survey respondents included: Regulation and Permitting; Tax Incentives; Green Infrastructure Grants; Rooftop Farm Siting; Funding; Roof System and Growing Media; Farm Maintenance and Labour; Access to Equipment and Materials; Climate and Pests; Information and Knowledge Dissemination on Best Practices; Community Outreach and Involvement. This wide range of topics is an indication of the complexity of rooftop food cultivation and the many challenges farmers encounter in their efforts to develop a successful operation. Nonetheless, the barriers mentioned in the survey can be broadly organised into four nested categories: at the highest level, rooftop farmers identified challenges that have to do with starting a small business in NYC, which many other types of businesses may face, such as securing loans and managing costs and labour requirements. The second category of challenges involves issues faced by small farmers generally, and includes such things as pest management and developing a viable marketing or distribution plan. The third category is specific to urban agriculture, incorporating the opportunities and constraints inherent in growing food productively in a dense urban setting. The last category, encompassing the majority of the problems identified, is specific to rooftop agriculture. These challenges included finding an appropriate site, securing the proper permits, financing construction, and managing and operating a farm or garden. Rooftop farms are both green roofs and farms, and some are commercial businesses while also attempting to demonstrate larger social and environmental benefits. These goals do not easily coincide, and many of the problems raised had to do with determining how to navigate this difficulty.

2.3 *Environmental Monitoring of a Commercial Rooftop Farm in Brooklyn, NYC*

Financing the construction of a rooftop farm, especially a larger facility that has the potential to become commercially viable, was raised as a key concern by responders to the survey discussed above. Green infrastructure grants or tax incentives are both means via which rooftop farmers might access necessary finance, provided it can be demonstrated that rooftop farms have environmental benefits, most especially with respect to stormwater management. To date, however, few studies have quantified the impact of green roof farming practices on stormwater management issues, leading to lack of clarify on whether rooftop farms are even eligible for certain grants or tax incentives.

In order to address current lack of information on the environmental performance of urban rooftop farming, the UDL is engaged in monitoring the Long Island City Brooklyn Grange rooftop farm located at 37-18 Northern Boulevard. The rooftop farm was installed in 2007 and uses Rooflite® green roof media (Skyland USA LLC, Landenberg, PA) mounded into rows with a depth of 20-25 cm (8-10 in) and 2.5-5 cm (1-2 in) between row depth. The farm covers almost all of the 3,716 m^2 (40,000 ft^2) rooftop. A 281 m^2 (3,022 ft^2) watershed located centrally on the northern side of the building was selected for instrumentation to measure stormwater runoff quantity, while a second drainage basin located on the north-west corner of the farm was selected to monitor runoff quality. Non-vegetated areas of the roof include a stairwell, the central roof walkway made of gravel, and walkways between crop rows. The green roof is planted with vegetables, herbs and some flowers for cutting, including sunflowers. Irrigation is supplied to the plants through a drip irrigation line 3 times daily for 30-40 minutes, depending on weather conditions. Monitoring for water quality runoff at the farm began in January 2013, while monitoring for runoff quantity began in May 2013.

Preliminary results from the monitoring programme have focused on examining the water quality of runoff from the rooftop farm. Runoff water quality is determined from samples collected during individual storm events as runoff enters a rooftop drain. Rain water from the same storm is also collected for comparative purposes. To date, one irrigation water sample has also been gathered. After collection, the samples are taken back to the Heffner Laboratory at Columbia University and analysed for pH and electrical conductivity with an Accumet™ excel XL50 duel channel pH/ion/conductivity meter (Fisher Scientific, Hampton, NH), turbidity with a 2020we turbidity meter (LaMotte, Chestertown, MD), and colour and true colour with a DR/890 colorimeter (Hach, Loveland, CO). A portion of each sample is also stored in a freezer and will later be sent to Auburn University Soil Testing Laboratory (Auburn University, AL) for nutrient content analyses, including nitrogen and phosphorus.

Thus far, a total of 20 samples have been taken for water quality analysis. To compare the environmental impacts of the farm with that of a conventional green roof, the Brooklyn Grange water quality data were compared to data obtained from prior work that examined the quality of runoff from extensive sedum green roofs, as well as traditional non-vegetated roofs, installed on a variety of NYC buildings (Culligan *et al.*, 2013). Comparative findings to date are summarised in Figures 1 to 4.

The average pH of runoff from the Brooklyn Grange is slightly higher than that of rain from Manhattan and lower than that of rain from the Brooklyn Grange or runoff from the extensive sedum green roofs (Figure 1). The conductivity (Figure 2) and apparent colour (Figure 3) of runoff from the Brooklyn Grange are much higher than all other water sources, which are similar to each other. Sample true colour follows the same pattern (not shown). The average turbidity of runoff from the Brooklyn Grange appears higher than that of either rain source, but similar to runoff from both non-vegetated and extensive sedum green roofs (Figure 4). That runoff from the Brooklyn Grange has higher conductivity and true colour than runoff from conventional green roofs might indicate poorer runoff quality from the rooftop farm than a sedum green roof.

Figure 1: *Average pH of water sampled from Brooklyn Grange runoff (BKG), Brooklyn Grange irrigation (Irrigation)*, rain from a Manhattan Building (Rain121) and rain from the Brooklyn Grange (RainBKG). Runoff measurements from traditional non-vegetated roofs (non-vegetated), extensive sedum green roofs (green) and rain (rain) samples were collected from a previous study (Culligan et al., 2013).*

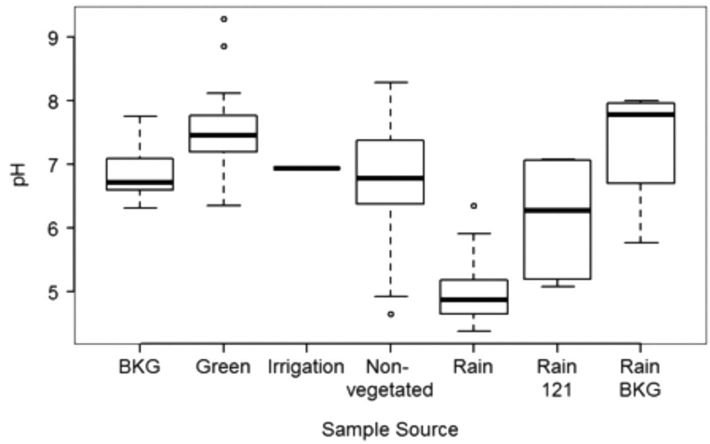


Figure 2: *Average conductivity of water sampled from Brooklyn Grange runoff (BKG), Brooklyn Grange irrigation (Irrigation)*, rain from a Manhattan Building (Rain121) and rain from the Brooklyn Grange (RainBKG). Runoff measurements from traditional non-vegetated roofs (non-vegetated), extensive sedum green roofs (green) and rain (rain) samples were collected from a previous study (Culligan et al., 2013).*

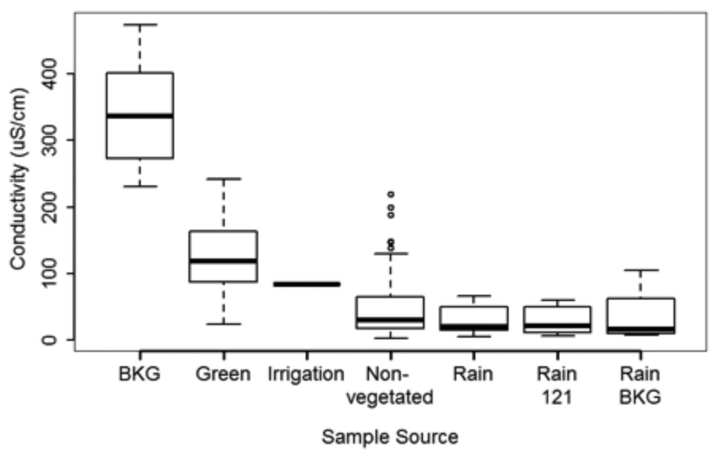


Figure 3: *Average apparent colour of water sampled from Brooklyn Grange runoff (BKG), Brooklyn Grange irrigation (Irrigation)*, rain from a Manhattan Building (Rain121) and rain from the Brooklyn Grange (RainBKG). Runoff measurements from traditional non-vegetated roofs (non-vegetated), extensive sedum green roofs (green) and rain (rain) samples were collected from a previous study (Culligan et al., 2013).*

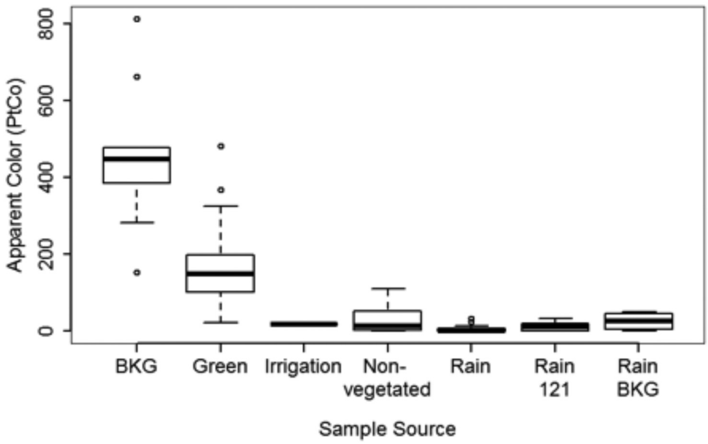
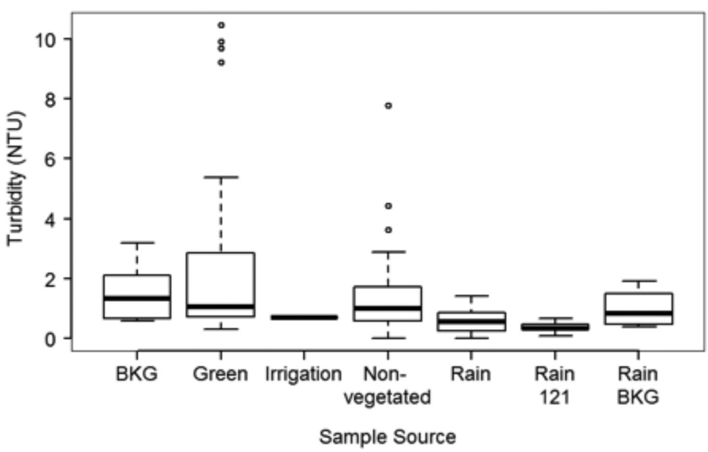


Figure 4: *Average turbidity of water sampled from Brooklyn Grange runoff (BKG), Brooklyn Grange irrigation (Irrigation)*, rain from a Manhattan Building (Rain121) and rain from the Brooklyn Grange (RainBKG). Runoff measurements from traditional non-vegetated roofs (non-vegetated), extensive sedum green roofs (green) and rain (rain) samples were collected from a previous study (Culligan et al., 2013).*



III CONCLUSIONS AND RECOMMENDATIONS

There are distinct opportunities and challenges inherent in urban agriculture in NYC, which is the highest-density US metropolis with some of the nation's highest land values, making the prospect of farming in the five boroughs a demanding proposition. On the other hand, NYC has particular advantages: the economic and cultural robustness that serve to maintain high property costs are also associated with a high level of awareness, support and potential access to investment capital for projects that promote healthy food systems and sustainability. Specifically, urban farms are uniquely dependent on their surrounding communities to provide a strong customer base, and NYC's density, and diverse and vibrant food culture make for an attractive context for aspiring urban farmers. NYC's industrial and manufacturing areas are also highly suitable for rooftop agriculture due, in part, to access to re-development capital, a robust transportation network and adequate physical infrastructure. And despite what some might assume to be an inhospitable climate for agriculture, NYC's five boroughs have a rich farming history, with Queens and Kings Counties being among the most productive agricultural counties in the nation in the late 19th century, all before the advent of advanced season-extension techniques (Linder and Zacharias, 1999). In Manhattan, for several decades in the 19th century, the extensive squatter settlements were said to produce a large proportion of the produce consumed by the city (Plunz, 1990). Indeed, as with other urban areas, the demise of localised production only began with the advent of modern food transport technologies such as refrigerated rail boxcars, interstate trucking, and air freight, which successively promoted the nationalisation and then the globalisation of the food system.

Urban agriculture has great potential to help mitigate critical public health and environmental problems faced by NYC. The city suffers from higher than average rates of obesity and diabetes (Raufman *et al.*, 2007), which are correlated to inadequate access to fresh, healthy food retail (Morland *et al.*, 2006). This is relevant to the issue of urban agriculture because, as discussed in Section 2.1, the communities that suffer the most from diet-related disease and inadequate access to healthy foods are also the areas where much of the city's vacant land is located.

Urban agriculture is also part of a broader range of horticultural strategies that involve the creation of productive green space to directly address some of NYC's most intractable environmental problems, including those associated with urban stormwater management (Carson *et al.*, 2013) and mitigation of the urban heat island effect. Additionally, urban agriculture could decrease the environmental and economic costs of dealing with the City's waste stream by providing alternative means of disposing of organic waste through composting. Although urban farms could realistically process only a small percentage of NYC's compostable waste, as with other issues, the value lies in their potential as a catalyst for promoting shifts in consciousness and behaviour that could greatly amplify such, otherwise modest, impacts.

The solutions that urban agriculture offers to multiple problems in NYC, as discussed in this paper, are likely to be similar to those in other cities around the world, as are the hurdles to urban agriculture implementation. The work conducted by the authors of this paper indicates that these hurdles require urban policy amendments that would make it easier for urban farmers to obtain permits and undertake practices such as large-scale composting at their facilities, as well as further research that could lead to the development of best urban farming practices, including practices that reduce nutrient loading in the runoff from urban farms. Development of urban agricultural extensions at urban university centres is one way of cultivating the knowledge and expertise that could maximise the value of urban agriculture for city inhabitants.

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