Evaluating the Potential for Urban Agricultural Production in Madison, Wisconsin

Abstract:

Population growth and the widespread destruction of natural resources for increased food production are quickly becoming a global crises. Increasingly popular responses to these crises include urban agriculture and local food production, however the scale of each have yet to reach production levels of self-sufficiency within individual cities, and government aid to pursue these levels is lacking. Studies on food production potential within cities are only just beginning and have primarily focused on large post-industrial cities. This article attempts to determine the agricultural production potential of a mid-sized, Midwestern city by using four production practices atop various percentages of multiple land use types within the City of Madison, Wisconsin. Comparing our findings to national fruit and vegetable intakes, we have determined that Madison can meet its demand for fresh fruit and vegetable crops using methods of urban agricultural production and assuming ideal conditions and equitable distribution. We compare these results against the backdrop of Madison's current agricultural state and political ecology to contextualize our data, and compile our recommendations for expanding urban agriculture in Madison.

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Introduction

Climate change, population growth and large-scale urbanization present major challenges to global food production. The practice of urban agriculture is one strategy to mitigate these challenges that is already offering better access to healthy foods for low-income and minority residents than more traditional methods of food production. Thirty-eight percent of Earth's surface is currently utilized for agricultural production (Despommier 2010). As the human population of Earth continues to increase, resulting in more mouths to feed, the land area devoted to agriculture will need to increase as well. An increase in global agricultural land will undoubtedly threaten existing ecosystems such as tropical forests and temperate prairies as more land becomes cultivated. The majority of human population growth is occurring in cities around the world; the UN projects that by 2050, over 66% of the world will be dwelling in cities (U.N. World Urbanization Prospects 2014*)*. With a dramatic increase in urban population on the horizon, local communities will require new methods for food production within urban areas. In 2011, a team at The Ohio State led by Sharanbir S. Grewal, performed a study in Cleveland, Ohio to determine the agricultural self-reliance and food production potentials within the city, using a combination of several agricultural methods (Grewal et al. 2011). Others have implemented similar studies in several large cities, but as of yet, no study has specifically focused on smaller Midwestern cities. The following is an analysis of Madison, Wisconsin's agricultural potential for fruit and vegetable production within city limits.

Our research seeks to determine the City of Madison's potential fruit and vegetable crop production (kilograms/year) using yield data from (1) Madison community gardens, and from the following production practices distributed across North America: (2) conventional urban agriculture, (3) intensive urban agriculture, (4) hydroponics. Each production practice will be evaluated across three land use types as defined by the City of Madison's zoning code: (1) vacant/agricultural, (2) residential, (3) parks/open spaces, and (4) identified rooftops.

Literature Review

History of Urban Agriculture

Though it has received a recent spike in popularity, urban agriculture has been a prevalent part of global and domestic agriculture for hundreds of years. Throughout the twentieth century, urban gardens sprouted across the United States as a means to secure an adequate food supply during times of economic insecurity and war. During World War I, there were 5.3 million gardens, which in total produced approximately $525 million worth of food (Janik 2010, 23). This trend continued through the Great Depression and into World War II, with 20 million victory gardens producing 40% of total U.S. fresh vegetables at this time (Mok et al 2013, 24). While urban gardens fed citizens at home, they enabled the U.S. to send aid to the Allies overseas in the form of commercially produced food, namely grains, fats, sugars, and meats (Mok et al. 2013, 23-24). Governmental policies, propaganda, and the associated cultural shift that accompanied them undoubtedly helped the war effort and contributed toward victory (Janik 2010, 26). The state of Wisconsin heavily influenced this triumph with government and university leaders alike advocating for urban agricultural production and conservation efforts (Janik 2010). These historic periods demonstrate the ways in which urban agriculture can benefit the individual and a nation, and how urban agriculture can expand to meet shifting demands for food production, especially in response to crises.

Recent circumstances, like population growth, climate change, and large scale urbanization are again requiring populations to reconsider traditional agricultural methods. Eight-hundred million hectares, or 38% of Earth's landmass, is currently allocated for agricultural production in an effort to feed Earth's roughly 7 billion inhabitants (Despommier 2010). By 2050, the U.S. Census Bureau estimates the global population will surpass 9 billion, requiring much additional land be transformed for agriculture. The amount of arable land available is not evenly spread across the globe, and may not be adequate to fulfill the needs of the future population. South America and Sub-Saharan Africa retain 80% of their potential arable lands which are not currently used for agriculture, while South Asia, the Near East, and the rest of Africa only retain 10% (Germer 2011, 240). The costs to convert available lands in South America and Sub-Saharan Africa include the further destruction of their ecosystems, for example, forests which are vital to human and animal survival (Germer 2011). Additionally, much of this area would require highly intensive agricultural methods due to slopes, nutrient deficits in soils, and other constraints, ultimately making agriculture in these places economically and environmentally unfeasible (Germer 2011). Current agricultural practices in much of the world damage ecosystems through forest fractionation, erosion, flooding, and chemical and nutrient runoff (Despommier 2010). Allowing some of these cultivated areas to return to a more natural state would result in global benefits, including the potential to decrease the rate and magnitude of global climate change, improving water supplies, and reducing environmental threats to the integrity of many ecosystems and the constituent species of these ecosystems (Despommier 2010).

In 2008, an estimated 800 million people faced food insecurity globally. One year later, over one billion people were believed to be suffering from hunger and poverty throughout the world (Lee-Smith 2010, 486). Eight hundred million people already practice urban agriculture worldwide, proving that cities are viable spaces for agricultural production (Lee-Smith 2010). Considering that over 60% of the world's population is projected to be living in urban spaces by

2050, the expansion of urban agriculture will be a logical and considerable way to contribute toward global food production (U.N. World Urbanization Prospects 2014).

Benefits of Urban Agriculture

When one examines the workings of urban agriculture at a local scale, the list of benefits for those affected is unquantifiable. With regards to health benefits, gardening in itself is a form of exercise, and combined with a short walk or bike ride to and from a community garden can lead to weight loss and its associated benefits like lower cholesterol and lower systolic blood pressure (Armstrong 2000, 320). This can be a great way for less active or elderly people to stay physically healthy. Because gardens produce healthy fruits and vegetables, this gives access to and further promotes fresh, diverse and nutritious foods, which ultimately leads to a decrease in sweets (Armstrong 2000, 319). In fact, it has been shown that having a household member who participates at a community garden increases vegetable consumption to 4.4 times per day, compared to 3.3 for those who have none (Alaimo 2008, 96). The production of urban gardens provides food security, accessibility, and affordability, as well as self-reliance (Mok et al 2013, 24-25). In fact, many current efforts focus on low income areas, ethnic diasporas, and ‘food deserts’ that contain only convenience stores and gas stations as primary food suppliers, and do not often include fresh and healthy options (Mok et al 2013). This focus is vital, as these underprivileged areas regularly encounter the most barriers to healthy and affordable foods. The act of gardening also brings about many psychological benefits, such as stress relief (Mok et al 2013).

Community gardens have a tendency to develop bonds and even a culture between participants. They can bring together many people of different backgrounds, crossing racial, age, gender and class barriers to form one entity. Such interaction results in social development, a safe environment, and a sense of community and personal empowerment (Mok et al 2013, 24-25). There is often less vandalism and crime around community gardens, and strong reactions often occur when these spaces are converted for other means by landowners or local governments (Armstrong 2000, 320). Community gardens can also create a sense of place and value for residents, which often leads to meetings and social organization occurring in this space (Armstrong 2000, 319). This is especially evident for low income neighborhoods, as it has been shown that gardens are four times more likely to address unrelated neighborhood issues in these locations (Armstrong 2000, 320). The shift from vacant or unsightly lots to a community garden often increases property values across the entire area, meaning even those not participating can reap monetary benefits (Mok et al 2013, 22). According to the Food and Agriculture Organization (FAO 2015), urban gardening can also offer employment opportunities and a source of informal income with one job available for every 100 square meters of garden, a factor especially helpful in these underprivileged areas.

Because gardeners produce their food themselves, there are no middlemen or grocers, and food costs are subsequently lower (Mok et al., 2013, 22). Distant food producers and distributors are therefore not required to package, transport and store high quantities of food, which saves materials, money, and reduces carbon emissions, thus mitigating global climate change (FAO 2015). The rural system of farming currently loses 10-40% of global yields to spoilage after harvesting, and between 5-10% of food is wasted at the household level (Germer 2011, 239). Moving to a local system is not only more productive than rural farming by some measures, it simultaneously curtails these losses, and creates a connection between the individual and the food system (FAO 2015; Mok et al. 2013, 22). The individual-food production connection may translate to a lasting relationship with nature and gardening in the future (Lohr and Pearson-

Mims 2005, 476). Finally, urban agriculture helps clean up the local environment by increasing carbon sequestration, and soil decontamination (Edmonson et al. 2014, 886).

Limitations to Urban Agriculture

Though governments and communities recognize the potential benefits of urban agriculture and often encourage the expansion of such activities within cities, they cannot safeguard urban food production from challenges unique to urban environments. Pollution, resource limitations, inter-industrial competition for land, and the inability of city policies to encourage private gardens pose substantial risks to the expansion of urban agriculture.

Heavy human activity and the built urban landscape influence urban microclimates so that cities are often warmer compared to the rural areas surrounding them. This phenomenon is called the urban heat island effect and is the result of the thermal and reflective properties of materials typically used in urban construction and activities that generate mechanical heat and higher concentrations of atmospheric carbon dioxide (Wortman and Lovell 2013, 1287). The higher temperatures within a city can be detrimental to the quality and quantity of urban agricultural produce. For example, increased temperatures and carbon dioxide concentrations can accelerate the phenological development of certain plants which has been observed during early onsets on the spring season (Neil & Wu 2006, 244). These plants are subject to early flowering at a time when pollinators are not usually present to fertilize them, decreasing crop fertility and, ultimately, crop yields. Even when plant flowering and the presence of pollinators are synchronized, extreme temperature increases can inhibit photosynthesis through a number of mechanisms and, again, result in lower crop yields (Wortman and Lovell 2013, 1287).

Not only do the urban microclimates directly affect crop development, they also affect the availability of water resources and the ability of vegetation to efficiently utilize them. For example, increased temperatures result in a vapor pressure deficit. In other words, the dew point for the condensation of atmospheric moisture is greater, meaning less of this moisture is available to be utilized by plants. A greater vapor pressure deficit can lead to increases in plant transpiration and moisture stress, increased soil compaction and decreased levels of water infiltration (Wortman and Lovell 2013, 1288).

It becomes clearer, then, that if urban agriculture were to expand, so would the city's demand for water to maintain food production. In many cities, municipal water is the primary resource as most natural and human-made contamination has been filtered out. Urban agricultural activities do not require the use of potable water, but they do require water resources that, if used, would not pose risks to personal or environmental health. Where local governments allow them, rainwater harvesting barrels have been used to collected rainwater to be used as an alternative water resource for urban agriculture. Gardeners and farmers who use rainwater should take precautionary measures to reduce the risk of exposure to hazardous chemicals; collected rainwater, especially within the initial surface runoff of a rainstorm, is likely pick up contaminants from animal waste, airborne organic substances from decomposing materials and human activities (Wortman and Lovell 2013, 1288).

Additionally, since rainwater collects heavy metal contaminants and hazardous organic compounds from roofing materials and roads, the use of the initial surface runoff would increase the concentrations of these contaminants that are already prevalent in urban soils. The most threatening heavy metal contaminant is lead, which can be up to 100 times more concentrated in urban soils than in naturally-occurring soils in rural areas. The lead concentrations in urban areas are typically remnants of old vehicle exhaust and exterior house paint from decades ago, yet some lead pollution still occurs today as a result of various manufacturing processes (Wortman and Lovell 2013, 1284). Polycyclic aromatic compounds (PACs), on the other hand, are the result of the incomplete combustion of organic materials from car exhaust and industrial processes. PACs are a known carcinogen that can disperse in the soil and leach into groundwater. Because most crops are equipped with physiological mechanisms that limit their uptake of heavy metals and PACs, they are usually safe to consume even if planted in contaminated soils. The health risks posed by lead contamination of soils is the direct ingestion of said soils, which can inadvertently occur during agricultural practices such as dust inhalation and accidental ingestion of residual soil on skin and on the surfaces of produce. Because of this risk, growing and consuming root crops is inadvisable in some urban areas (Wortman & Lovell 2013, 1285).

Securing adequate water and soil resources is just one of several infrastructural issues to overcome before urban agriculture can be implemented at any scale. Some urban agricultural activities like high-tech rooftop farming and greenhouses require high capital inputs and labor-intensive maintenance. Consequently, the cost of implementing these methods would likely be compensated through increasing the prices of produce. A price increase would have disproportionate and adverse effects on food security and social justice goals since those in lower socioeconomic classes would be unable to access high-priced foods (Hallsworth & Wong 2013, 12).

These practices also bring into question the assumption that shorter transportation distances make urban agriculture more environmentally sustainable than conventional agriculture. The carbon footprint of these methods includes more than just food miles, taking into account fossil fuel combustion, the transportation of capital to these agricultural sites, among other factors contributing toward urban agriculture’s carbon footprint (Hallsworth & Wong 2013, 13). In order to determine urban agriculture's true ecological benefits and impact on the environment, a full life-cycle analysis for all infrastructure and agricultural commodities produced in a particular system would be necessary (Pearson 2007, 412-417).

Adequate funding of urban agriculture, especially for high capital and labor-intensive practices, is crucial for the viability sustained activity of all types of production practices. Cities often struggle to obtain funding for agriculture, especially those lacking assistance from nonprofit organizations or other institutions. (Hendrickson & Porth 2012, 42, 44). Additional conflicts occur within the political climate of urban agriculture, where outdated zoning ordinances and land-use policies must be navigated. Not only do many cities' policies limit where urban agriculture is allowed, they also restrict how much of a plot can be used for agricultural activity, production practices, and the economic viability of buying and selling produce grown on urban land parcels (Voigt 2011, 550, 553-4).

Even if a city has the intention of encouraging agricultural expansion within its borders, a lag declaration of this objective and updating ordinances and policies is experienced. The lack of adequate infrastructural support is symptomatic of a greater issue at hand. Cities that have goals for expanding agricultural activities often lack the power to actualize these goals. One reason is that cities lack the financial resources on their own to plan and build new agricultural operations, and they fail appeal to larger governmental bodies that could allocate part of their resources to their cause. This occurs more frequently in communities that aim to use urban agriculture as a means to generate food locally and promote local agendas, also known as the "localism movement", which consists of highly localized campaigns that focus on the self-improvement of the community welfare. As a result, this movement fails to garner the attention of large-scale political attention, which, as previously stated, may be necessary for the provision of infrastructural support (Morgan 2010, 345).

Climate of Urban Agriculture in Madison, Wisconsin

The City of Madison promotes urban agriculture with a variety of legal tools. As in any other municipality, zoning ordinances outline permitted uses of land within city limits. Zoning ordinances can act to promote, or to discourage, urban agriculture depending on how explicitly these activities are described in the ordinances. Areas zoned agricultural are primarily located on the city's periphery. With the exception of Racine, Madison is unique in that community gardening is explicitly defined in its zoning codes: in Madison, community gardening is only permitted in manufacturing zones (Kuhn 2009, 15). The fact that community gardening largely takes place outside of these zones brings to light a number of concerns. How the city views community gardening with respect to its zoning ordinances is unclear. Ambiguity in the enforcement of zoning laws exposes vulnerabilities in the security of gardens located outside of explicitly permitted areas.

Another important tool Madison planners use to promote urban agriculture is the City of Madison's Comprehensive Plan. Comprehensive plans are guides for short-term and long-term future land use decisions (Kuhn 2009, 9). Madison's comprehensive plan was revised by the City Common Council in 2011, when they stated their intention to convert 4% of the city's total land area to some form of urban agriculture by 2020. This number currently sits at 1.3% (Eanes 2012, 3). The city's plan contains 4 objectives, 11 through 14, that are considered directly related to urban agriculture. The Objectives are: (11) Encourage the preservation of farming operations within the city where it is economically feasible and compatible with surrounding land uses, (12) Identify areas on the city's periphery suitable for long-term preservation for diverse agricultural enterprises and community separation, (13) Promote the sale of foods grown in Dane County, (14) Protect existing community gardens in the City and establish additional areas for new community gardens (Comprehensive Plan, City of Madison, 6-16 - 6-18). Objectives 11 and 14 are of particular concern to our research.

Policies to achieve Objective 11 are: 1) Identify, map and maintain a database of agricultural operations in the city, and 2) Coordinate with Dane County to educate farmers with operations in the city about incentive programs that will help them continue farming or to sell their land to farmers with interest in smaller-scale agricultural operations such as farmette development and Community Supported Agriculture farming. Farmettes are small residential farms run by individuals earning most of their income from some other enterprise (McKelvie 2012). Policies to achieve Objective 14 include the following: 1) expand community gardening opportunities in the city; consider using the city's surplus property and parkland to do this, 2) strive to create one community garden site for every 2,000 households in the City, 3) design aesthetically pleasing community gardens appropriate to the neighborhoods where they are located, 4) extend leases of community gardens on City-owned property to five years, and 5) establish permanent community gardens on City-owned land or in city parks where possible (Comprehensive Plan, City of Madison, 6-16, 6-18).

Within the city there are 52 community gardens, with 2,992 plots, meaning the goal of one garden for every 2000 households has already been achieved (Smith & Harrington 2014, 76). Even so, these community gardens only provide access for less than 2% of Madison households. Homeowners have a much easier job producing food where they reside. Smith and Harrington in 2014 estimated there were around 45,193 home gardens within the city. This is a significant contribution to current production levels, as total food production from home gardens is over four and a half times that of community gardening (Smith & Harrington 2014, 76).

Community gardens have typically emphasized providing food to areas where access to food security has become an issue. In Madison, an emphasis has been placed on locating gardens in low-income neighborhoods where home ownership is low and power over local land resources is limited. In Madison, these neighborhoods are mostly black and hispanic. There are around 14 community gardens in Madison's food deserts providing 1 garden for every 1,367 households in these areas; or 1 garden for every 3,243 individuals. At best only a marginal amount of food could be produced in these 14 gardens located in food deserts. For the 45,408 residents living in Madison's food deserts, community gardens will not have significant positive effects on food security or access to healthy food. Some doubt whether community gardening poses any real ability to improve food access and expand beyond a niche market at all (Hallsworth & Wong 2013, 11)

An interesting inverse correlation exists between the location of home gardens and the location of community gardens. Home gardening tends to occur in the exact opposite location as community gardening. Home gardening occurs in neighborhoods of single-family detached homes where the property tends to be owned by the tenant. Most single-family detached home owners in Madison and belong to a higher income class and are white. The demographics suggest that those with access to private property at home are more likely to use it for some form of food production. Because vastly more food is produced in home gardens than in community gardens, access to healthy food and food security could be addressed very effectively by expanding and emphasizing home gardening across the city.

Enabling those who do not own the land they live on to still cultivate home gardens where possible may provide more access to healthy food than trying to provide community gardens to a few individuals in these neighborhoods. This strongly suggests that those without the means to own their property are less able to provide home grown food for themselves and family. One garden per 3,243 individuals in the city's food deserts is a nice gesture at best. Coordination between land owners and city planners to make home gardening available to those who rent their property could be an important process in achieving the City's goals of improving access to healthy food and ramping up urban production.

Expansion of urban agriculture is limited by a city's available resources. This is true for both land and financial resources. Urban agriculture is, however a form of agriculture and policies to expand its implementation have been outlined in the 2014 Farm Bill. This is the largest source of federal aid to farmers and those with nutrition assistance needs, "which makes this omnibus legislation an ideal vehicle for promoting urban agriculture" (Mersol-Barg 2014, 282). Availability of federal funds would free up city resources and provide comfort for many opponents of urban agriculture as a burden on municipal funds.

Blaine et al. 2010 provided a profile of community gardeners in the City of Cleveland. Phone surveys were conducted with gardeners to collect demographic and characteristic data. Data on income, age, time gardening per week, and years gardening. were collected. This provides a baseline source of demographic information about who is participating in the communal urban agriculture. The City of Madison would for instance be able to identify where outreach programs would be most beneficial. Likewise a comprehensive profile of community gardeners seeks to locate those places most suitable for expansion, and those most at risk from outside forces. (Blaine et al. 2010, 11). Community Groundworks manages the Dane County

Community Garden network. The organization however does not keep personal information on gardeners. Individual community garden managers may have personal data on members however contacting them and collecting this data is not feasible at this time. Contacting each of Dane County's community gardens and obtaining data on individual gardeners in a comprehensive way turned out to be beyond the capabilities of this project. Future research on this subject should attempt to compile a detailed survey of the City's community gardeners.

Methods

In order to adequately answer our research question seeking to determine the city of Madison's production potential of fresh fruits and vegetables, we have developed an equation which employs the hypothetical utilization of various agricultural production practices atop multiple land use types. The results of this equation produce an agricultural production potential that is expressed in kilograms per year. The methodology we used to construct this equation and conduct our research was primarily based on the research of Sharanbir S. Grewal as presented in his 2011 article, "Can Cities Become Self-Reliant in Food?" In his study, Grewal attempts to determine the "percent self-reliance" of a post-industrial city using various land uses and methods of agricultural production. The setting of Grewal's research is Cleveland, Ohio and to determine the percent self-reliance of the city, he uses the following equation:

$$\textit{Percent Self Reliance} = (\textit{Area}) \times (\textit{Yield})\ \textit{Intake} \times 100$$

Similar to Grewal, we have overlayed different production practices atop different land uses in order to calculate fresh fruit and vegetable production potentials, however, instead of using *Percent Self-Reliance* as an indicator of the city's agricultural production, we have simply shortened the equation to measure Madison's agricultural production in kilograms per year. The primary equation used to estimate Madison’s agricultural production potential is expressed below:

$$Agricultural\ Production = (Area)\ x\ (Yield)$$

Equation Coefficients

Land Use Types (*Area)*

In our calculation, production potentials have been assessed using the area of three different land use types as surveyed by the City of Madison’s comprehensive plan (Comprehensive Plan 2006,) as well as partial data of non-residential rooftop areas. The on-the-ground land use types and their associated areas taken from the comprehensive plan and converted to hectares are indicated below:

Table 1. Depicts on-the-ground land uses and their areas in hectares as converted from the City of Madison’s 2006 Comprehensive Plan.

Land Use Type	Area (ha)
Agricultural & Vacant	3,063
Residential	5,318
Parks & Open Spaces	3,528

Because the City of Madison does not keep data on nonresidential rooftop areas, we collected rooftop area data from four Madison regions containing rooftops we have deemed suitable for rooftop agricultural production, specifically, hydroponic production practices (See Production Practices Section Below). These areas were selected for their abundance of flat-roofs and are easily recognizable regions within the City of Madison. These areas are shown in the locator map and adjoining table below:

Figure 1. Map of the selected regions of suitable rooftops for hydroponic agriculture in Madison, Wisc.

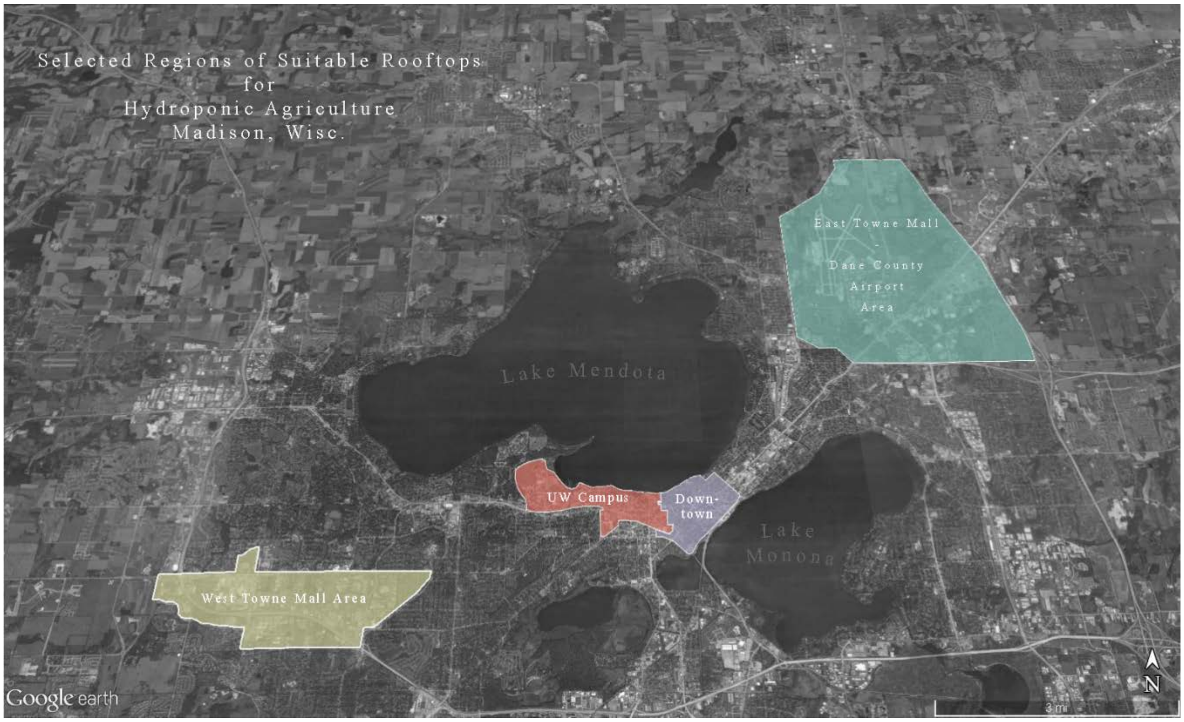


Table 2: Accompanies Figure 1 and lists the four selected regions of suitable rooftops, their area, and their location color key as indicated in Figure 1.

Selected Regions of Suitable Rooftops	**Rooftop Area (ha)**	**Location Color Key**
West Towne Mall Area	52.78	
UW Campus	80.10	
Downtown	27.01	
East Towne Mall - Dane County Airport Area	71.39	
Total Identified Rooftop Area	**231.28**	

To delineate selected rooftop regions and calculate rooftop area data from buildings contained within, we used the program Google Earth Pro. The selected regions of suitable rooftops: the West Towne Mall Area, UW Campus, Downtown, and the East Towne Mall and

Dane County Airport Area were all chosen due to their high densities of commercial, institutional and industrial buildings which often have flat roofs suitable for hydroponic production. Each region is of a different size, with the East Towne Mall Area by far encompassing the largest total area at 2,827 hectares. The smallest region was the Downtown Area which had an area of 199 hectares. The UW Campus Area and the West Towne Mall Area had areas of 267 and 687 hectares, respectively. Although these areas are not representative of the entire city of Madison, the rooftop areas found within each region and the agricultural production potential capable of occurring atop these selected rooftops, serves to provide a glimpse of what rooftops found within four major regions of the city could provide in terms of fresh fruits and vegetables.

After the four regions were delineated, we determined the total rooftop area found within each region. By altering the aspect of Google's landsat image, we were able to roughly determine each rooftop's pitch to see if it was sloped or flat. If flat, we utilized the ruler tool in Google Earth Pro to construct a polygon of each building's rooftop. We constructed polygons for every suitable building within each of the four regions, and summed these areas to produce an aggregate rooftop area value for each region (Table 2). It should also be noted that the landsat imagery available for the city of Madison on Google Earth Pro at the time of this study was taken in April 2013, and it is fair to assume that the rooftop landscape of each of the four regions has changed considerably over the course of two years.

(2) Production Practices (*Yield*)

The yield data we used in our calculation were averages taken from a total of seven sources cited in the Grewal article for conventional urban agriculture, intensive urban agriculture and hydroponic agriculture (Grewal 2011, 5). Madison garden yield data was obtained from home, community and educational gardens found within Madison by Smith and Harrington in 2014 (Smith & Harrington 2014). The yield data taken from the Grewal article was obtained from various researchers and urban gardens found across North America, reflecting varying climatic, soil and social conditions. The following is a table of the four agricultural production practices we used in our equation as well as their associated yields and sources.

Table 3. Agricultural Production Practices Associated Yields and Sources.

Production Practice	Yield (kg/ha/year)	Source (s)
Conventional Urban Agriculture	12,800	(Cleveland 1997) (Duchemin et al. 2008)
Madison Gardens	19,000	(Smith and Harrington 2014)
Intensive Urban Agriculture	62,000	(Duchemin et al. 2008) (Lane 1992) (McGoodwin 2009) (Cleveland 1997) (Dervaes 2009)
Hydroponic Agriculture	195, 300	(Bay Localize 2007)

The distinction between conventional and intensive urban agriculture lies between the two methods' relationship with inputs and labor, the latter receiving more of both, resulting in higher yields. Because our calculation of agricultural production potential is theoretical in nature, the distinction between both agricultural production methods and their associated yields may not need to be explicitly defined, but simply viewed on an ordinal scale with intensive urban agriculture incorporating more inputs by way of fertilizers, pesticides, high-yield strains, and human capital (Duchemin et al. 2008, 47). Despite their differences in intensity, both intensive and conventional urban agriculture, as well as Madison gardens, can all be defined as "traditional" methods of urban agricultural production in that they all use soil mediums.

Hydroponic agriculture can be broadly defined as a method for growing fruit and vegetable crops in a soilless medium (Bay Localize 2007, 3-16). Although there are many variations of hydroponic agriculture, the method is innovative in that it is significantly lighter than more conventional forms of agriculture, and is independent of regional soil fertility, rendering the method ideal for rooftop placement. The relatively of this production practice however, are its large water and nutrient requirements, necessities to plant growth which would otherwise be found in organic and inorganic materials found in agricultural soils (Bay Localize 2007, 3-16). Nonetheless, the Food and Agriculture Organization of the United Nations has produced numerous designs for sustainable water and nutrient distribution mechanisms to support hydroponic agriculture, which suggest world-wide support for the future of this method (Bay Localize 2007, 3-16). Its benefits, however can be clearly demonstrated in its extraordinarily high yield rates.

Data Calculation *(Agricultural Production)*

Agricultural production potential scenarios in kilograms / year were calculated after multiplying the defined area of singular land uses (agricultural and vacant, residential, parks and open spaces, and identified rooftop areas) with the yield rates of singular production practices (conventional urban agriculture, Madison gardens, intensive urban agriculture and hydroponic agriculture). Because it is wholly unrealistic to assume that 100% of any land use could be wholly devoted to crop production city-wide, each land use type has been multiplied against each production method four times, using 100%, 75%, 50%, and 25% of the land use area.

The receding percentage schema of cultivated land use was implemented because assuming that 100% of any land use is able to be cultivated is unrealistic for a variety of reasons including: agriculture's competition from other land uses such as residential and commercial development, soil contamination, geographic constraints and the necessity for ancillary agricultural features such as sheds, walkways and buffer zones. The 25 through 75 land use percentages as applied to the equation serve to accommodate these constraints, as well as to provide for more realistic production potential estimates. The four-percentage scheme was also included to allow city planners and agricultural researchers the ability to “mix and match” utilizations of different land use types at different cultivation percentages so that that total production potential for the city can be calculated using multiple land use types and production practices. Despite the division of the percentage schema into 25% groupings, we hope that the inclusion of each land use type’s area and each production practice’s yields will enable future researchers to construct their own agricultural production potential calculations using the same land use types and production practices, but at percentages of their choosing. Lastly, we believe that the four-percentage schema will provide future researchers with a wide range of estimates for adequate statistical data analysis.

Qualitative Methods

The qualitative component of our study serves to place the quantitative data results of Madison’s agricultural production potential within the context of the city’s unique political ecology, racial geographies, urban economy and environmental determinants. A qualitative analysis of Madison’s urban agricultural climate can be found in the literature review and discussion section of our paper. The literature review serves to specifically outline the benefits and shortcomings of urban agriculture, and provide insight to the practicality of the city and its citizenry attempting to meet agricultural potential. To broaden our understanding of the city’s agricultural policies, we conducted an interview with Mark Woulf, a representative of the Madison City Planning Commission to obtain an urban planner's perspective of Madison’s urban agriculture and specific details regarding agricultural policy and municipal efforts of encouragement (and discouragement). The results of this interview, as well as an in-depth analysis of Madison's social potential for urban agriculture can be found in the discussion section below.

Results

Table 4: Madison fresh fruit and vegetable production potential (kg/yr): The table below illustrates the total weight of fresh fruit and vegetable production in kilograms per year using different land use and agricultural production methods in Madison, Wisconsin. Percent (%) Cultivation refers to the percentage of each land use area (ha) devoted to agricultural production.

Production Method	Yield Rate (kg/ha/yr)	Land Use	25% Land Use Cultivated (kg/yr)	50% Land Use Cultivated (kg/yr)	75% Land Use Cultivated (kg/yr)	100% Land Use Cultivated (kg/yr)
Conventional Urban Agriculture	12,800	Agricultural & Vacant	9,800,512	19,601,024	29,401,536	39,202,048
		Residential	17,016,224	34,032,448	51,048,672	68,064,896
		Parks & Open Spaces	11,291,040	22,582,080	33,873,120	45,164,160
Madison Gardens	19,000	Agricultural & Vacant	14,547,635	29,095,270	43,642,905	58,190,540
		Residential	25,258,458	50,516,915	75,775,373	101,033,830
		Parks & Open Spaces	16,760,138	33,520,275	5,028,041	67,040,550
Intensive Urban Agriculture	62,000	Agricultural & Vacant	47,471,230	94,942,460	142,413,690	189,884,920
		Residential	82,422,335	164,844,670	247,267,005	329,689,340
		Parks & Open Spaces	54,690,975	109,381,950	164,072,925	218,763,900
Hydroponic Rooftop Agriculture	195,300	Identified Rooftops	11,292,558	22,585,117	33,877,675	45,170,234

Table 5: Madison fresh fruit and vegetable production per capita (kg/person/year). Data were obtained by dividing production potentials from Table 1 1 by 2014 U.S. Census estimates of population for Madison, Wisconsin. Results indicate the weight of fresh fruit and vegetables available to each person within the city of Madison assuming equal distribution.

Production Method	Yield Rate (kg/ha/yr)	Land Use	25% Land Use Cultivated (kg/person/yr)	50% Land Use Cultivated (kg/person/yr)	75% Land Use Cultivated (kg/person/yr)	100% Land Use Cultivated (kg/person/yr)
Conventional Urban Agriculture	12,800	Agricultural & Vacant	39.89	79.78	119.67	159.56
		Residential	69.26	138.52	207.78	277.03
		Parks & Open Spaces	45.96	91.91	137.87	183.83
Madison Gardens	19,000	Agricultural & Vacant	59.21	118.42	177.63	236.84
		Residential	102.81	205.61	308.42	411.22
		Parks & Open Spaces	68.22	136.43	204.65	272.86
Intensive Urban Agriculture	62,000	Agricultural & Vacant	193.22	386.43	579.65	772.86
		Residential	335.47	670.94	1,006.41	1,341.88
		Parks & Open Spaces	222.60	445.20	667.80	890.40
Hydroponic Rooftop Agriculture	195,300	Identified Rooftops	45.96	91.92	137.89	183.85

Table 6: Percent (%) demand as met by Madison's potential fresh fruit and vegetable production. Data was obtained by dividing per capita production potentials from Table 5 by the current fresh fruit and vegetable

demand in the United States of 149 kilograms / year as indicated by the USDA (USDA Fact Book 2002), and multiplying the results by 100. The results below serve to demonstrate Madison's ability to meet fresh fruit and vegetable demand based on the production potential per capita rates found in Table 5, expressed as percent.

Production Method	**Yield Rate (kg/ha/yr)**	**Land Use**	**Percent (%) Demand Met at 25% Cultivation**	**Percent (%) Demand Met at 50% Cultivation**	**Percent (%) Demand Met at 75% Cultivation**	**Percent (%) Demand Met at 100% Cultivation**
Conventional Urban Agriculture	12,800	Agricultural & Vacant	26.77	53.54	80.32	107.09
		Residential	46.48	92.62	139.45	185.93
		Parks & Open Spaces	30.84	61.68	92.53	123.38
Madison Gardens	19,000	Agricultural & Vacant	39.73	79.48	119.21	158.95A
		Residential	69	137.99	206.99	275.99
		Parks & Open Spaces	45.79	91.56	137.35	183.14
Intensive Urban Agriculture	62,000	Agricultural & Vacant	129.68	259.35	389.03	518.71
		Residential	225.15	450.29	675.44	900.59
		Parks & Open Spaces	149.4	298.79	448.19	597.59
Hydroponic Rooftop Agriculture	195,300	Identified Rooftops	30.2	61.69	92.54	122.74

Analysis (I):

Figures 2, 3, 4, 5: Dot plots depicting fruit and vegetable production potential using selected production practices atop four land use types: Parks & Open Spaces, Residential, and Agriculture & Vacant Land and Hydroponic Rooftops. The dashed red line represents the annual per capita consumption of fresh fruits and vegetables by Americans as obtained by the USDA (USDA Fact Book 2012

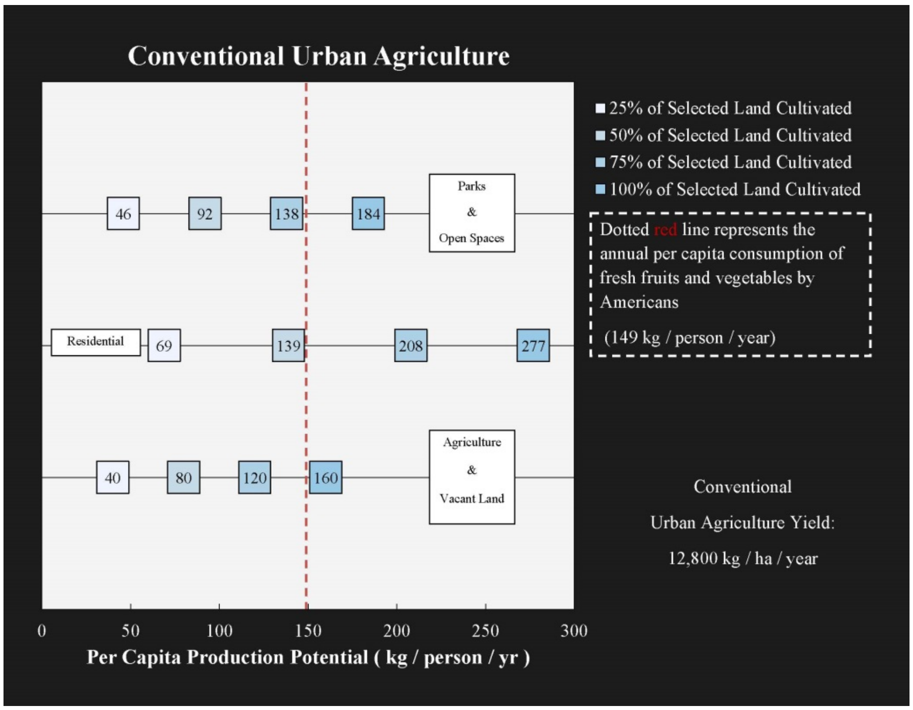


Figure 3:

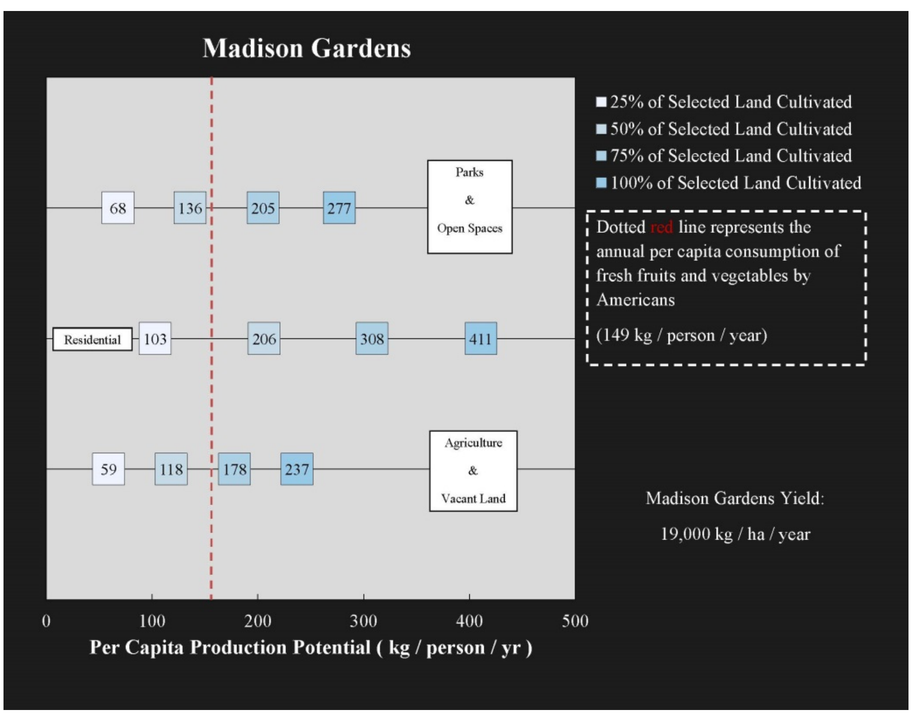


Figure 4:

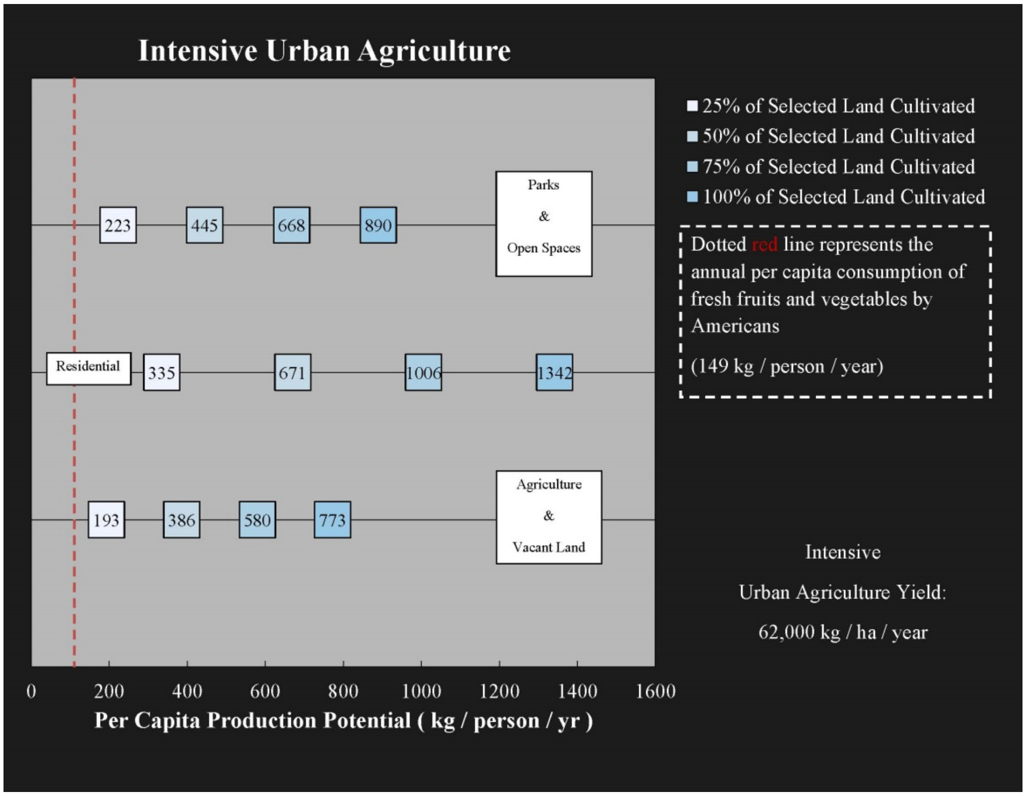
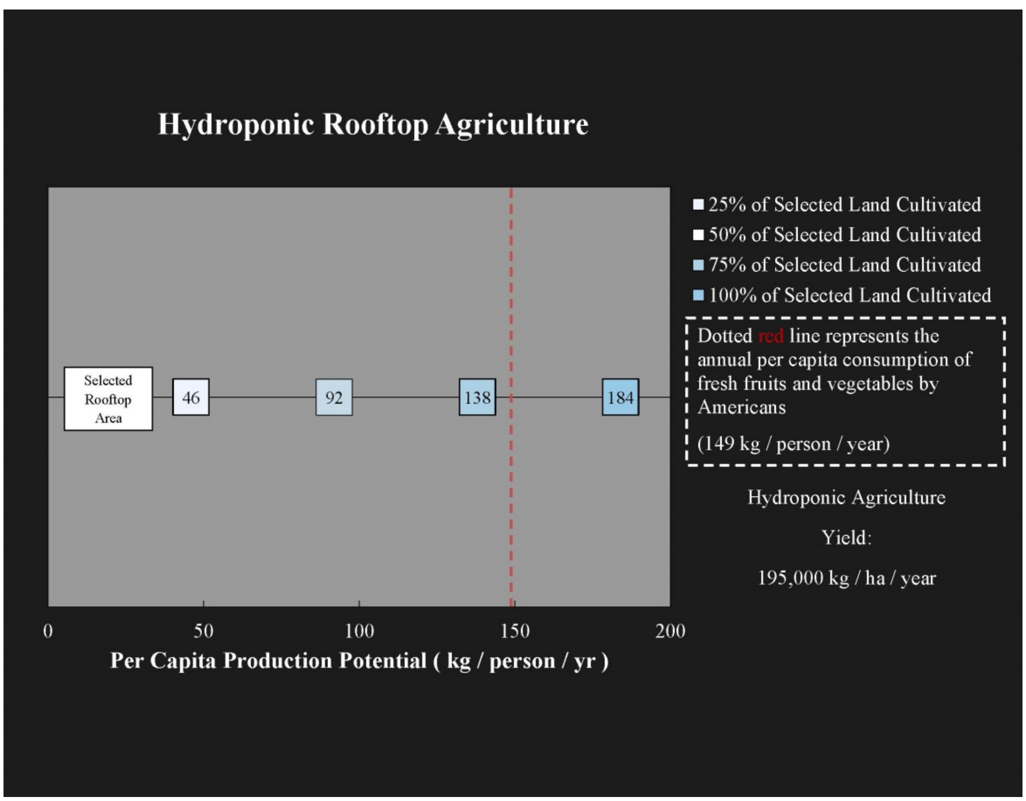


Figure 5:



Analysis (II):

To offer a demand benchmark for the statistics presented in Table 6 and Figures 2-5, we turn to data taken from the USDA's Economic Research Service of American per capita annual fresh fruit and vegetable consumption. The most recent data, which was compiled in a 2000 survey, concludes that the average American consumes 149 kilograms of fresh fruits and vegetables each year (USDA Fact Book 2002). When American fruit and vegetable consumption is paired with Madison fruit and vegetable production potentials under various land use and yield rate scenarios, as demonstrated in Table 6, the two values become directly related. Using this relationship we can begin to assess Madison's potential for meeting fresh fruit and vegetable demand through local, urban-grown fruits and vegetables. The percent demand equation was inspired by Grewal et al.'s percent self-reliance equation and is listed below, while the results of percent demand across each production practice and land use type can be found in Table 6 above.

$$Percent\ Demand = \frac{Madison\ Annual\ Fruit\ \&\ Vegetable\ Production\ Potential\ (kg/person)}{Annual\ Fruit\ \&\ Vegetable\ Consumption\ (kg/person)} \text{ x } 100$$

One shortcoming in our methodology is that the agricultural production potential scenarios we produced utilized only one land use type and production practice at a time. The exclusivity resulting from this shortcoming poorly reflects the practical methods the city might employ to produce enough fresh fruits and vegetables to meet demand. These practical methods would likely include the utilization of multiple land use types through multiple production practices. The table design is unable to represent the thousands of combinations the city may employ on a particular land use type together, but we believe that a savvy reader would be able to add production potentials from multiple scenarios to construct a more probable reality.

It should be noted that the demand benchmark of 149 kilograms is the per capita weight of fresh fruits and vegetables that Americans consumed in the year 2000, and may not be the weight of fresh fruits and vegetables that Americans *should* be consuming. According to a 2015 publication presented by the U.S. Center for Disease Control, only 24% of Americans are consuming enough fresh fruits, and only 13% of Americans are consuming enough fresh vegetables each year to be considered a healthy amount (Moore 2013). Therefore, the per capita fresh fruit and vegetable consumption weight of 149 kilograms is likely not enough to be considered healthy for the average person, and our application of 149 kilograms serves only as the demand for fresh fruits and vegetable weight per person. This being said, the World Health Organization (WHO) claims that a healthy diet includes at least 400 grams of fruits and vegetables per day, or 146 kilograms per year (Healthy Diet 2015). According to this statistic, the average American is actually consuming enough fruits and vegetables for a healthy diet.

The results listed above demonstrate the agricultural potentials of various land uses, levels of cultivation of said land uses, and the production practices applied upon them. These results are highly theoretical, and as described in the methods and discussion sections of this paper, were found by making a number of assumptions. Principally these assumptions were made regarding land quality, land values, the need for alternative spaces, and the availability of human and financial capital with little regard to the inherent vulnerabilities climatic variations impose on all types agriculture from year to year. Because of these various limitations to urban agriculture, it should be assumed that under almost no circumstances would 100% of cultivation of any land use type using any production practice be either physically or theoretically possible.

The inclusion of 100% cultivation scenarios solely reflects the absolute possibilities of a specific land use type and are located beyond the means of what is actually practical.

Percent cultivation aside, we have determined a number of land use type and production practice scenarios to be more likely implemented across the city than others. For example, it is much more likely that 75% of publically owned land, termed vacant and agricultural, will be converted to any form of agriculture rather than 75% of privately owned land, termed residential, being converted to agriculture. Therefore, we can assume that the privately held land defined as residential and identified rooftop areas are much less likely to be converted to agriculture than publically owned land, for we believe that neither the city nor any other organization has the right to force any landowner to cultivate any percentage of their landholdings. Cultivation atop these land uses must be conducted independently. Due to competing land uses such as commercial and residential development as well as the public's understandable desire to retain greenspace in parks and open spaces, it should be assumed that little more than 50% of agriculture and vacant land as well as parks and open spaces could reasonably be converted to agriculture. Despite these competing land uses, even small amounts of available land cultivated using methods such as intensive urban agriculture may contribute a sizable amount of fresh fruits and vegetables to the city’s population.

However, the results shown above do provide insight to the very real potentials a relatively obscure land use that is urban agriculture can provide. In a world where policy and personal action is largely justified by productivity and results, this study serves as a description of the results a widespread revolution in urban agriculture could provide. To see the materialization of these results, to any extent in the city of Madison, would represent a positive land use yielding a sustainable product that all can use.

Discussion

Project Limitations and Future Research

Resource and time constraints limited the scope of our research study, which was conducted over a period of four months. Consequently, we made several compromises to our methods, and a few necessary assumptions were made to facilitate the calculation of Madison potential fruit and vegetable production.

Official information pertaining to the City's rooftops was unavailable, so we collected data on flat rooftop areas within four well-known locations: the West Towne Mall area, the University of Wisconsin-Madison campus, downtown Madison, and the East Towne Mall/Dane County Airport area. These datasets are not representative of the total flat rooftop area in Madison, as we demarcated a select few locations. Additionally, the accuracy of our dataset is uncertain due to the following factors: 1) four different individuals located flat rooftops and calculated their areas from each region, and 2) we collected our rooftop data using Google Earth Pro software, which provided images from 2013. As a result, our data is based off of a former landscape and likely reflects outdated conditions. In the future, geocoding city-owned addresses using Google Earth software or directly observing rooftops across the city would ensure a greater accuracy of rooftop data. This measure would have an added benefit of determining the integrity of a building's structure so that only rooftops capable of supporting the weight of hydroponic systems are included in each dataset. Although Madison's building height restrictions has resulted in a shallow cityscape with relatively similar building heights, neighboring buildings or vegetation may still obstruct sunlight availability, which could limit agricultural growth on individual rooftops.

Time constraints also inhibited the conduction of in-depth research pertaining to the social climate and local attitudes toward increasing fruit and vegetable production in Madison. Interviews or surveys of key community garden members, academic experts, more city officials from a variety of departments, and Madison residents would have informed our understanding of the processes involved in expanding the City's urban agriculture in addition to the range of citizens' responses the City might expect from such a change. Because these interviews did not occur, we made the assumption that there was adequate citizen demand for locally-grown food markets to purchase from. Furthermore, we made the assumption that individuals have appropriate amounts of time, effort, knowledge, and capital to produce their own fruit and vegetable gardens.

In the interest of time, we limited the scope of our research to four out of many agricultural production practices. We chose to exclude practices that are uncommon or are in the early stages of development, like underwater farming, and we excluded animal husbandry and grain crop farming because these practices require larger amounts of land than what is expected to be available in an urban environment. These exclusions allowed us to focus on fruit and vegetable production and the agricultural production practices that are most feasible to implement in Madison.

It should be noted that most people are unable to fulfill all of their nutritional requirements with fruits and vegetables alone, so our results are do not reflect a fulfillment of these requirements. An attempt to represent total food consumption within cities using the data from this study alone would be an impractical and poor reflection of a complete urban agricultural system.

A Realistic Take on Urban Agriculture in Madison

Up until this point, we have discussed Madison's potential fruit and vegetable crop production as it would occur under the following ideal conditions: 1) all areas included in our calculations were both physically suitable and accessible for each land use type and 2) fruit and vegetables were grown under ideal conditions and management techniques for each production practice. The yields presented in Table1 are a product of these assumptions and are not yet achievable due to several inevitable, but perhaps impermanent, limitations to expand or locate new sites for future urban agricultural activities. In order to describe a realistic annual potential for fruit and vegetable crop production, we begin to identify major limitations specific to Madison's physical, socioeconomic, and political climates. Throughout this process, we present several strategies to reduce, rid of, or avoid these limitations where appropriate.

Physical Limitations to the Expansion of Urban Agriculture

Southeastern Wisconsin has a mid-latitude climate and is subject to distinct seasonal changes. The growing season within this region is most limited during the winter months when mid-latitude cyclone tracks shift south, carrying warmer, moist air away from North America's continental interior. As a result, Wisconsin's temperate mid-latitude climate is characterized by a decrease in temperature and precipitation in the wintertime, and agricultural production is restricted to greenhouses. As springtime approaches, increases in daylight hours, temperature, and rainfall result in suitable conditions for agricultural production. Still, during these months, macroclimatic variations and microclimatic conditions associated with urban areas can limit Madison's agricultural activities.

The city of Madison's microclimate is influenced to varying degrees by the city's topographic relief, vegetation, lake effects, materials and density of the city's built environment, weather conditions, and the products of both past and present human activities. Madison experiences a mild urban heat island (UHI) effect, which results from a number of the previously listed factors. Although the intensities of UHI effects fall within different ranges depending on the season and time of day, strong UHIs are more common during calm, cloudless summer nights than on winter nights with similar conditions (Schatz and Kucharik 2014, 2379). This comparison indicates that a factor that remains consistent throughout the year, like Madison's geophysical climate and land cover, influences seasonal baselines for UHI intensities while more precarious factors, like weather, have smaller day-to-day influences on UHI intensities (Schatz and Kucharik 2014, 2382-83).

During the summertime, the local surface heating and temperature increases that characterize more intense UHIs may encourage rainstorm development, which could benefit urban crop growth and city water supplies. Increases in precipitation due to UHIs, however, are rare because both the influences on and effects of UHIs are typically inconsequential in a mid-sized city like Madison. Nonetheless, as climate change continues to influence global weather patterns, Madison could experience stronger UHIs and associated chronic issues like heat waves, which would adversely impact both agricultural activities and livelihoods of residents within the city. Looking ahead, urban planners may want to consider expanding the Madison's agricultural area as a means of mitigating strong UHI effects in addition to local food production. As a precursory measure, a comprehensive dataset could be collected to facilitate the identification of land parcels with suitable or near-suitable conditions for fruit and vegetable production. This information could be used to ensure the protection of these sites for agriculture or could assist in preparatory work to improve sites that have degraded as a result of external influences.

The soil quality present at any location is of particular concern in Madison due to the residual and ongoing contamination from industrial activities. As recently as 2007, environmental advocates including the Sierra Club have identified unregulated sources of industrial pollutants in Madison. Specifically, since the Charter Street Power Plant became active in the 1950's, enough pollutants have been discharged from burning coal that the establishment of agricultural sites in nearby areas is unlikely. The University-owned plant stored its coal supply in on-site open-air piles, which resulted in the contamination of rainstorm runoff when rain would come into direct contact with the piles. Runoff concentrations of hazardous heavy metals were so high that the facility often violated federal regulations on pollutant discharge (Midwest Environmental Advocates 2015).

Though the University of Wisconsin - Madison has responded by phasing out coal for natural gas as its primary fuel source, years of unregulated pollutant emissions across the city obscure the extent and spatial distribution of soil contamination. Ideally, the presence and concentrations of residual contaminants would be tested for in all land use type areas open to agriculture. A further assessment would determine whether use of these locations would pose substantial risks to human health. Because testing soil samples for contaminants can be costly, performing a site history analysis can provide an inexpensive means of narrowing down which pollutants to test for and where to test them. The following example is an especially useful to demonstrate what information is obtainable through this method, including extant issues that would prevent the establishment of a new agricultural operation.

Demetral Field is a recreational park located in Madison's East Emerson neighborhood. The extensive grassy area is sandwiched between industrial sites to the West and a residential area to the East and reveals only subtle indications of what the site had once been. Lying underneath Demetrial Field’s inviting exterior are the agricultural, industrial, commercial, and residential wastes that compose the now-decomposing twenty-eight acre sanitary landfill. Despite having planned for the landfill’s eventual transformation into a recreational park, planning problems arose after the wastes were sealed off in 1972 (Bemis 1982, 26).

While the problems occurring at Demetral Field are not unique for a sanitary landfill, they do inhibit the development of certain recreational activities and further development. First, the park had experienced different settlement rates ranging between six to eight inches annually as the wastes compacted and redistributed underneath the park over time. Differential settlement creates problems when building and then maintaining structures on the site, as demonstrated by the extensive damage to parking lot and tennis court facilities that have since been removed (Bemis 1982, 27). Additionally, the developers of the sanitary landfill did not install a liner to seal off the waste before covering up the dump, which allows groundwater to penetrate the top layer of grass and mix with the wastes. As a result, the groundwater leaches up contaminants before it eventually re-enters the city’s water source (Bemis 1982, 26).

The final problem, the problem that ultimately inhibits the establishment of urban agriculture at Demetral Field at any time in the foreseeable future, is the extensive gas leakage produced during decomposition of the wastes below. In the years following the landfill’s transformation into a usable park, hundreds of trees and shrubs were killed off due to the toxic leak. Park managers attempted to plant vegetation of different varieties at Demetral Field, but the only greenery that could survive was grass. (Bemis 1982, 27).

If the park’s primary source of contamination, the landfill, is to remain as such, the park will likely remain a grassy recreational space since further development is not only likely to fail, but it would threaten the safety of nearby residents. It should be noted that not all recreational sites overlaying different fill materials experience the same degree of problems and physical limitations to urban agriculture. For example, Omega Hills in Germantown, Wisconsin, is the site of a former stone quarry, which has since been covered and transformed into a park. The park managers have had success with planting a variety of vegetation types that have survived in the man-made grassy area (Bemis 1982, 33).

With these comparisons in mind, the usefulness of conducting a site history analysis is restricted to identifying the spatial and temporal existence of physical limitations. It is ultimately an insufficient tool to describe the extent of the risks posed by the limitations. They can inform decisions for future development, but several physical barriers such as soil, water, and air pollution, require empirical testing and direct observation in order to determine the actual suitability of a site for future urban agricultural use.

Land-Use Conflicts and Social Considerations

Madison is conveniently located within the Yahara Watershed, creating a barbell-shaped land area between Lake Mendota and Lake Monona. Despite the plentiful availability of freshwater this creates, an increase in the number of gardens within the city will dramatically increase the demand for clean water. Community gardens must fund their own water costs, even if located on city land. This is often accomplished through plot fees; however, increasing water costs present a new challenge. These high costs affect different regions at varying degrees, depending on average incomes.

Because many residents live in apartments or buildings that do not have lawns or allow for gardens, many community gardens are located on city-owned vacant spaces, and although there is low land use cost to gardeners, there is no guarantee in the lasting availability of these areas. Although the city attempts to deny leases for community gardens in locations identified for future development, this is not a perfect system. There have already been situations in which plots have been displaced and converted, for example the Hill Farms community garden which has been present on Madison's West side for 35 years has been ordered to vacate this past October in order to make way for a new office building (M. Woulf Interview, November 6, 2015). Because of the limited amount of vacant land in Madison, this situation is likely to repeat itself in the future. Placing gardens on existing parklands rather than vacant land can mitigate the uncertainty of extended leases on particular parcels, as these locations are less likely to be converted to agriculture. This however can lead to disputes over what activities should be allowed in different park locations. In addition to these issues, to limit unfair advantages in enterprises, the food produced in these city-owned spaces cannot be sold for profit, often leading to high amounts of waste if an excess is produced. This rule leads to yet another discrepancy between those who can afford to purchase the land and those who cannot, and does not provide a framework for low-income residents to help support themselves by participating in these practices.

These political and economic conflicts regarding gardening often hit substantially harder for the black populations in Madison. As most of the black population of Dane County lives within city limits, black residents in Madison fare much worse than white residents, and even black citizens in the United States at large. Unemployment in Dane County was 25.2% of blacks and 4.8% of whites in 2011, compared to the national average of 18% of blacks and 8% of whites (Race to Equity 2013, 7). The racial disparities in employment are one reason that over 54% of Madison's black residents are living below the poverty line, compared to 8.7% of whites in 2011 (Race to Equity 2013, 8).

Furthermore, racial minorities are far more likely to live in food deserts within Madison. These desert are defined as lacking access to retail grocery outlets within a mile of their residence, and often include low-income households and low rates of homeownership. The city is home to 45,408 individuals residing amongst 19,141 households within its food deserts. There are 14 community gardens located in these areas, however, that provides only one garden for every 1,367 households, making access to gardens limited, especially considering unequal distribution.

Alternatively, residential land is relatively equally distributed. Madison is home to over 45,000 home gardens on residential land, and while the land may be well distributed, access to private property is not. There is an inverse correlation between the locations of home gardens, and that of community gardens: community gardening tends to occur in neighborhoods with similar characteristics as food deserts, whereas home gardening is found in areas of higher income and homeownership levels, and the majority of properties are single-family detached homes. This brings to light an inequality with the ability to grow one's own food based on their income and in what sort of housing they reside.

Community gardens may also be difficult to establish. In 2013, controversy erupted over plans to establish a community garden in Brittingham Park. This project had the support of the mayor's office as well as members of the Bayview Community, a subsidized housing neighborhood adjacent to the park. This neighborhood is home to many elderly Hmong residents, some of which have lived in the area for over 35 years, as well as numerous other minority groups. The controversy stemmed from the residents living around Monona Bay's belief that the garden would be an eyesore and consolidate public lands into the hands of a few. For the first time in Madison's history, the City went against the suggestion of the alderman and moved forward with the project.

Even if public land is available it may not be suitable, as seen in the site history analysis of Demetral Field. If the field was not contaminated, it might serve as an ideal location for a community garden if local residents supported such a measure. This problem further emphasizes the importance of access to land at home, whether that land is owned or not. The fact of the matter is that landowners cannot be forced to allow gardening on their property, however, the City has fortunately incentivized developers to allow agriculture on their property. Developers may bypass building height restrictions if they provide agricultural rooftop space to tenants and according to Mark Woulf, this is already being done with the Gebhardt Development project being erected on the north side of the 800 block of East Washington Avenue (Mark Woulf Interview November 6, 2015; Van Enkenvoort, 2014).

As stated by Mark Woulf , director of Madison's Alcohol and Food Policy, the collapse of the United States housing bubble in 2008 had a relatively small impact on Madison's real estate market compared with post-industrial Midwestern cities such as Cleveland or Detroit (Mark Woulf Interview November 6, 2015). Madison has shown itself to be "recession-proof" due to the services provided by the University of Wisconsin Madison, and city, county and state governments that reside here. Consequently, Madison experienced lower rates of vacant land turnover during this time. Considering that the city's boundaries are not expanding, plans for future land redevelopment will likely favor non-agricultural land-uses. In other words, new urban agricultural operations will be limited in both scope and size. Proposals to expand Madison's agricultural activities will require strategic development in order to reduce risks associated with limited vacant land and competition for land-use.

Capital Limitations and Ways to Promote Urban Agriculture

As mentioned, many citizens within Madison live in underserviced communities. These populations often lack the resources necessary to initiate agricultural ventures. Every form of government, from local to federal, lists in some way the necessity to improve food security for people living in underserviced communities. Urban agriculture can serve as the perfect vehicle for achieving these goals.

The Farm Bill is the primary source of financial assistance available to farmers. Only recently, since 2008, has the Farm Bill included language meant to address issues of food insecurity in urban areas and began promoting the growth of various forms of urban agriculture. The primary source of nutritional assistance available to those in need has been the Supplemental Nutrition Assistance Program (SNAP), commonly referred to as food stamps. This program is the primary source of expenses under the Farm Bill, 76% for fiscal year 2015. Unfortunately funding for this and other social programs in the Farm Bill, Women, Infants, and Children (WIC) for example, are often the first programs to see budget cuts by congress. Conversely, subsidies for commodity crops generally stay the same or increase year to year.

The goal of SNAP is "to alleviate hunger and malnutrition … by increasing food purchasing power for all eligible households who apply for participation" (Food Research Action Center 2008, 1). In urban areas, however, those in need of increased food purchasing power are more likely to live in food deserts. These communities by definition do not have access to the types of food that would alleviate hunger and malnutrition and may only be able to access unhealthy processed foods within one mile of where they live. This can lead to increased rates of malnutrition, obesity and other chronic diseases which are more prevalent in low-income communities. This is an inherent flaw in the way hunger and malnutrition are addressed by the

Farm Bill. There are in fact ways the Farm Bill can be used to increase consumer control and truly alleviate hunger and malnutrition while also providing economic benefits to urban communities.

There are a number of programs under the Farm Bill available to would-be entrepreneurs to help in the process of beginning an agricultural enterprise. Since 2008, language in the bill has specifically addressed local food production as an important aspect of a well-rounded food system. The Specialty Crop Block Grant Program (SCBGP) provides funds to eligible projects that solely enhance the competitiveness of specialty crops. Specialty crops of interest to our research include fruits, vegetable, and nuts. This program intends to "ensure an abundant and affordable supply of fruits, vegetables and nuts." According to the USDA "developing regional and local food systems and improving food access in underserviced communities" increases the competitiveness of specialty crops (Mersol-Barg 2013, 304). Urban agriculture therefore is inherently eligible for such grants.

In Wisconsin, grants of $10,000 - $150,000 are awarded to projects that meet the aforementioned eligibility requirements. The state gives priority to projects that have the "potential to provide solutions that lead to measurable benefits to specialty crop growers and consumers." This emphasis on growers and consumers makes SCBGP perfect for initializing urban agricultural enterprises (Mersol-Barg 2013, 305). The 2015 allotment of funds to Wisconsin for this program was $1.4 million. Most of this was used for pest control and pollination research.

With an annual budget of $55 million, increasing to $85 million over the next three years, the SCBGP comprises a very small percent of the budget that is spent on nutritional assistance. Demand for these funds also far exceeds the supply. For instance, applications for the SCBGP in

California amounted to $65 million, four times the state's allotment and $10 million more than the national budget (Mersol-Barg 2013, 305). Although the amount of funding is being increased, it will still make up a small portion of total spending directed toward nutritional assistance.

The Community Food Projects Competitive Grants Program (CFPCGP) provides one time grants to private non-profit entities for community food projects designed to "meet the food needs of low-income people" and "promote comprehensive responses to local food-farm nutritional issues. This program is even more competitive than the SCBGP with an annual budget of only $5 million. The CFPCGP requires an applicant to match 100% of the award. While this ensures applicants are legitimate, it may price out lower income citizens. (Mersol-Barg 2013, 307).

The CFPCGP in particular focuses on low-income peoples and along with other programs could serve as a perfect vehicle for the promotion of urban agriculture. Expanding existing programs could serve to address some of the ultimate causes of food insecurity in ways that SNAP cannot. At present SNAP merely increases the purchasing power of its beneficiaries. As mentioned, those living within food deserts need more than purchasing power and must have the ability to access healthy and affordable foods in order to truly address malnutrition.

Conclusion & Future Recommendations

Without the timing and funding constraints we faced throughout this research there are a few tasks we would like to undertake in the future in order to achieve a more feasible interpretation of Madison's production potential. First, developing an extensive geospatial database of land use histories as well as individual parcel potentials would allow us to identify specific areas where agriculture is most capable of thriving. Second, a comprehensive home and community gardener survey would provide us and the City of Madison with the necessary information to identify who is and isn't participating in gardening in order to better guide future development plans. Third, a detailed cost analysis for all of the production practices discussed herein would enable us to outline the most efficient methods of food production in Madison. Finally, an analysis of funds from within the Farm Bill and any other sources of available financing would determine how the City can best implement projects in the most financially sound manner. Together these additions would help provide the City with the information necessary to implement an agricultural plan tailored to each viable parcel in a manner that maximizes economic and social benefits.

Using the agricultural production and percent demand equations, we have determined that the city of Madison is quite capable of supplying all of its fresh fruit and vegetable needs under a variety of scenarios. Although these scenarios reveal optimal production potentials assuming an ideal physical, political, social and financial climate, their results provide important insight into the ability of a single urban area to provide enough fresh fruits and vegetables to its citizenry without relying on outside sources. The adoption of any of these scenarios at any magnitude within the city of Madison would ultimately represent a positive transition to a more sustainable, healthy and verdant city.

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