A Methodology for Determining the Production Potential of Sustainable Urban Agriculture

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Abstract

Concern regarding the sustainability of the current food system has been rising for a variety of reasons. One proposed response to these issues is urban agriculture, which has been argued to reduce food miles, enhance gender equity, increase food security, provide employment, and other enhancements to the quality of urban life. This research asks a fundamental question: Is there sufficient land in and around urban areas to produce seven widely consumed vegetables in sufficient quantities to meet urban demand? Using GIS, policy analysis, and regionally specific vegetable yields for the Denver metropolitan region, we develop a replicable methodology to estimate the land base and production potential for urban and suburban areas using existing data. We conclude that the land base is adequate in Denver and Wheat Ridge, a contiguous inner-ring suburban community, to seasonally produce a large portion of fresh produce for seven widely consumed vegetables. The analysis includes backyard and community gardens as well as the possibility for more extensive production in schoolyards, landscaped office grounds, and city-owned lands such as parks and vacant land.

Keywords: urban agriculture, urban food systems, GIS

Introduction

Globally, concerns regarding the sustainability of the current food system are increasing, arising in part from continued population growth, increasingly large and dense urban populations, and the unfolding effects of climate change (de Zeeuw and Dubbeling, 2009). This, in turn, has prompted close examination of current food system from production to consumption (Soninno, 2009). In response to these issues, a number of alternative approaches to current agricultural production methods, farmland location, food processing, food quality, food security, and retail sale are developing. One such alternative is urban agriculture, defined broadly as the "the growing of plants and the raising of animals within and around cities" (RUAF, electronic document). Globally, urban agriculture is becoming more widely practiced and currently accounts for approximately 15% of the world's food production (FAO, 2010). Likewise, the U.S. has seen a rise in the popularity of urban agriculture, with cities throughout the country promoting it as a strategy for both encouraging the health and well-being of city residents, as well as increasing the environmental sustainability of cities (Hodgson, Campbell, and Bailkey, 2011). Despite its growing popularity, urban agriculture is not widely practiced in U.S. cities. Limited to pockets of activity consisting primarily of home gardens, community gardens, and small-scale community/neighborhood supported agriculture (C/NSA), these operations contribute relatively little to the overall food needs of a city. However, as cities take steps to facilitate the expansion of urban agriculture, there exists the potential for cities to become significant producers of food. Our research explores this potential by estimating how much could possibly be produced in an average sized U.S. city and neighboring inner-ring suburb.

Through our analysis of Denver and Wheat Ridge Colorado, we intend to demonstrate the production potential of urban agriculture in a contemporary urban and suburban setting.

Project Background

Urban agriculture is increasingly being seen as a strategy for meeting the food and nutritional needs of urban populations (Grewal and Grewal, 2012, Houston, 2005, MacRae, et al., 2010, 2012, Mougeot, 2005, 2006) and is considered a tool for achieving sustainability by addressing the social, environmental, and economic facets of food production. Urban agriculture can increase food security (Martinez, et al., 2010; Maxwell, Levin, and Csete, 1998) and enhances gender equity (Hovorka, 2006, Hovorka, de Zeeuw, and Njenga, 2009). Urban agriculture creates more environmentally sustainable cities by improving air quality, lessening the heat island effect and improving biodiversity (Broadway, 2009); recycling organic waste and preserving green spaces (Bryld, 2003); potentially reducing the need to ship fresh vegetables over long distances (Pirog, et al., 2001, Masi, Schaller, and Shuman, 2010).

Although urban areas are not typically thought of in terms of food production, agriculture has long been a part of the urban environment; there is historical and contemporary evidence suggesting it is possible to grow significant amounts of produce in urban areas. Historically, urban agriculture was utilized during times of economic depression and warfare when food production within the city provided a means to food security. Within the US, cities such as Detroit, Chicago, Boston, and Buffalo all had government supported garden programs by 1895 (Lawson, 2006). During World War I, the National War Garden Commission urged US citizens to take up backyard food production, termed “victory gardens,” to support American troops and send food overseas to a war torn Europe (Pack, 1919); the victory garden effort re-emerged during the Second World War. Articles published at the end of World War I estimated that over 300,000 pounds of fresh fruit and vegetables were supplied each week to the British Navy (Pack, 1919). Studies in Africa, Asia, and Latin America show that urban and peri-urban agriculture can produce a significant amount of food in modern cities, including vegetables and fruit, eggs, poultry, milk, pork (de Zeeuw and Dubbeling, 2009). Some outstanding examples of this include Havana, Cuba and Dakar, Senegal; urban and peri-urban production provides nearly sixty percent of Havana's vegetable needs and seventy to eighty percent of Dakar's vegetables (Gonzalvez Novo and Murphy, 2000; Mbaye and Moustier, 2000). Based on these cases, there is significant evidence supporting the idea that urban agriculture has the potential to contribute substantially to the food needs of urban populations.

Given these historical and contemporary precedents our study addresses a core question: in an average sized city and a contiguous suburban community, is there enough land available to grow sufficient quantities of certain widely consumed vegetables to fulfill the demand for urban populations? We examine production potential in terms of land that is geographically available and compare it to land that is available according to city policy, "practical space." To understand how production potential varies in different urban contexts, we consider two Colorado communities: the more densely populated city of Denver and the adjacent inner-ring suburb of Wheat Ridge. This enables us to compare how density, land availability, and city policy influence the production potential of urban agriculture.

Determining Production Potential

Our goal with this effort is to define the potential for urban agriculture at the macro-scale. Thus, when we discuss the potential for urban agriculture, we account for a wide range of possible urban spaces. An implicit assumption in our approach is that in order to realize the kinds of yields necessary from urban agriculture, commonly understood to be food production on small parcels of land, we include intensive production on larger tracts of land. For this reason, we consider nearly all available urban land, including backyard and community gardens, as well as larger, non-traditional tracts like parks, churches, schoolyards, brownfields, and office parks. However, absolute space is only one part of the picture. Being unoccupied does not in and of itself make land available for food production; zoning regulations set guidelines for land use in urban areas, designating permissible activities as well as prohibiting or limiting uses in other ways (Goldstein et al., 2011). For this reason, we explicitly include city policy as an influencing factor. While some geographic research has demonstrated the potential of food growing in urban areas using GIS and similar technologies (e.g., Brawley, 2010; Desjardins, MacRae and Schumilas, 2010; MacRae et al., 2010, 2012; McClintock and Cooper, 2010; McClintock et al., 2013; Peters et al., 2009; Mendes et al., 2008; Thapa and Murayama, 2008), the role of policy and its influence on where and how urban agriculture can be practiced has yet to be addressed. Until recently, most cities did not condone food production as a preferred method for urban land-use, so any exploration of urban agricultural potential must attend to land-use policy (MacRae et al., 2012). Furthermore, beyond city restrictions, guidelines defined by homeowners' associations may prove limiting as well, and needs to be considered in the context of specific site development.

Determining Production Potential

A number of other studies have also attempted to estimate the potential yield of urban agriculture, although our evaluation differs from these studies in significant ways. Grewal and Grewal's (2011) work is similar to ours and concludes that Cleveland has the potential to realize significant levels of food self-reliance. While they look at food production in a post-industrial city with high foreclosure rates and excess vacant land, our study considers a growing and economically vibrant city. McClintock and Cooper's (2010) study in Oakland, California are similar to what we have done here with one important difference: while they focused on what they call the "commons – land that is owned by public agencies and therefore a public resource" (McClintock and Cooper, 2010:1), we include all land both public and private. McClintock et al (2013) extended their original research by specifically examining the contribution of vacant and under-utilized lots to fresh vegetable production. We chose to include multiple categories of land type in order to gain a comprehensive estimate of the maximum production potential. Private property rights are strong in the western U.S. and food production on private property is clearly the land owner's prerogative. Food production on public lands, such as city-owned parks, is generally a land use not considered when the land was originally chartered, making its implementation a significant political feat. Despite the potential challenges associated with converting public land to areas for urban agriculture, we chose to still include public land in our study because it represents a sizeable amount of urban space. Redmond and Redmond (pers. comm.) have created models demonstrating that land around office parks, schools, in suburban housing developments and related areas can be shifted from non-food producing landscapes that incur high maintenance costs to landscapes that could profitably produce food.

Peters et al. (2009) also assessed production potential. Their study mapped the local agriculture potential and total food need of New York State. They selected a single diet plan, one which meets the requirements set forth by the USDA and is representative of the American diet. This food model included beef, eggs, and dairy, among other foods, and was used as a framework to examine the productive potential of New York soils and determine if local agriculture could be used to decrease food miles. Peters et al. (2009) illustrated the uneven distribution of production potential; some land spaces of New York State are more viable for agriculture than others, and thus some areas would be able to attain 100% in-state food sources, whereas areas such as New York City would not. Our study differs from this study in that we examined only fresh vegetable production in urban areas. Our intention was to illustrate that current policy and available urban land make it possible to offset food outsourcing of some of the most popular and more nutritious vegetables. Additionally, Urban Design Lab (UDL) at the Earth Institute at Columbia University (2011) conducted similar research regarding New York City's potential production capacity and benefits of urban agriculture. Accounting for both fruit and vegetables, the UDL researchers grouped vegetables by categories (dark green, orange, dry beans and peas, starchy and other) and fruits by types (tree fruit, grapes, berries, melons, warm weather/citrus) for ease of calculating both yields and the estimated land area for their production. Categorizing fruits and vegetables in this manner could lead to widely inaccurate estimations as, for example, orange vegetables of carrots, pumpkins and sweet potatoes do not provide the same amount (lbs) per square foot. Also, while UDL's study included NYC's ample rooftop space as well as land agriculture, we chose to forego rooftops as potential growing spaces from our study due to the variability of building structures and their suitability to support agriculture. UDL also considered urban agriculture's impact on city infrastructure, food deserts, energy use and waste reduction implications, all of which were beyond the scope of our research. One of the key findings from UDL's study of NYC was that urban agriculture, with its more intensive nature, has the potential to yield greater quantities of vegetables than current conventional methods of growing and while urban agriculture may not meet all the necessary production for the area it serves, it can greatly contribute to food security.

Another consideration we examined is that the metropolitan statistical areas (MSA) covered in previous studies (e.g. Cleveland, New York City, Oakland) were not representative of the majority of MSAs in the U.S. A MSA is defined by the US Office of Management and Budget as a "large population nucleus, together with adjacent communities having a high degree of social and economic integration with that core…for the purposes of collecting, tabulating, and publishing federal data" (US Census Bureau, electronic document). We organized all 366 MSAs in the continental U.S. into quintiles based on the range of MSA population densities. The graphical results demonstrated a classic chi-squared distribution with over 90% of all MSAs falling into the first quintile (7.20 - 571 people per square kilometer [2.8 – 220 people per square mile]) and less than 1% falling into the fifth quintile (2262 - 2826 people per square kilometer [873 – 1,091 people per square mile]). Interestingly, both Oakland and New York City fall within the fifth population density quintile (most dense) whereas Denver, Colorado is in the first quintile (least dense). This finding suggests that previous estimations of "urban" or "local" agricultural production potential may significantly underestimate potential yields in the vast majority of MSAs in the continental United States.

Methods

SELECTION OF STUDY AREAS

We selected the neighboring cities of Denver and Wheat Ridge for their distinctive differences. Denver is a relatively densely settled city (compared to its surrounding suburban communities) with a 2010 population of 610,345 and a population density of just under 1,545 per square kilometer (4000 per square mile) (US Census, 2012). The most populous city in Colorado, Denver's limited land base gives it one of the highest population densities in the state. Surrounded on all sides by other cities, space constraints have left Denver with very few opportunities for annexation and expansion. Similarly, land use decisions over the last 30 years have significantly increased infill and population density during the rapid growth years from the 1970s through about 2007. Wheat Ridge is a neighboring city and inner-ring suburb to Denver with an agriculture background that, until recently, was characterized by many large lots of an acre or more (sometimes referred to as "horse properties"), in many cases with access to water from a system of irrigation ditches. While there has been considerable tract home and multi-family unit development over the last 30 years, there are still large areas of very low density giving parts of the community a decidedly more "rural" feel when compared to Denver. With a population of 31,030 and a density of approximately 1,252 per square kilometer (3,242 per square mile), Wheat Ridge is less densely settled than Denver (US Census, 2012). These two areas capture contrasting land-use patterns broadly representative of the greater Denver metro area and allow us to consider our results in terms of regional food production. Although not included in this study, it is important to note that the Denver metropolitan area is surrounded by agricultural land that gives rise to thriving community supported agriculture enterprises and adds considerably to the local food production potential.

LAND AVAILABILITY

Land availability was calculated using geographic information system (GIS) data available from the City and County of Denver (geographically the same area), the City of Wheat Ridge, and Jefferson County. Although Denver and Wheat Ridge share a political boundary, we discovered significant differences in GIS data quality and access between the two cities. The Denver dataset had more GIS layers than the Wheat Ridge dataset, which allowed for a more detailed assessment of Denver's urban vegetable production potential.

Land available for urban agriculture must be both geographically and practically available. By "geographically available" we mean land whose macro-level physical attributes render it useable. "Practically available" land refers to land that could be used for food production without changes in zoning or policy. We used a GIS subtraction method to calculate the total land in each of our study areas that was both geographically and practically available. The method began by calculating geographically available land as a subset to total land area according to Equation (1) where geographically available land (L_G) refers to that component of total land area (L_T) that is not classified as an impervious surface (I), tree canopy (T) or water feature (W). We selected these features because they represent the major macro-level attributes of land that is not available for agricultural uses. Furthermore, the three attributes are readily available as GIS data or are relatively easy to generate.

$$L_G = L_T - I - T - W \tag{1}$$

1. Impervious surfaces (I) are defined as areas that do not absorb water. The Wastewater Management Division of Denver developed an *impervious surfaces* GIS shapefile for Denver with the purpose of updating storm water billing information. This

layer was not available for Wheat Ridge. Instead, for Wheat Ridge we created an *impervious surfaces* layer by combining impervious surfaces from multiple GIS datasets into one continuous GIS layer, which included all building footprints, streets, sidewalks, driveways and parking lots.

2. Tree canopy (T) is defined as woody vegetation that shades the ground. Denver Parks and Recreation created a tree canopy layer for the city from images taken from the QuickBird 2 satellite using automated feature extraction from the near infrared band. This layer was not available for Wheat Ridge and we were not able to replicate Denver's method of tree canopy generation. To create a tree canopy layer for Wheat Ridge, we calculated the land area required to achieve a statistically significant sample (p=0.05). We then used ArcMap and a random selection script to generate a 100 ft x 100 ft grid over the city of Wheat Ridge and then to randomly select 10% of the 100 ft x 100 ft blocks. Next, a tree canopy outline was generated in each of the randomly selected blocks using aerial photographs. Since the tree canopy layer was generated through a random sample, we were able to scale up the total area of tree canopy across the city of Wheat Ridge. Generating a tree canopy layer is time consuming, and taking a random sample allowed for calculation of the tree canopy in a fraction of the time it would take to trace 100% of the trees.

3. Water features (W) include all permanently water-submerged land. Denver has two GIS layers for water that include: 1) streams and, 2) lakes and water bodies. The streams layer is a line file, which means stream width is absent. An average width of 50 feet was estimated and assigned to the streams and rivers, noting that no streams or rivers passing through the study area have particularly wide or flat floodways that might

otherwise have hosted agricultural activity in the past (see Tables 1 and 2). The two areas were combined to produce the total land occupied by water bodies in Denver. Wheat Ridge provided a polygon shapefile for water that included all streams and lakes from which we calculated total submerged land area.

Step two of the subtractive method calculated practically available land as a subset of geographically available land. This step began with a systematic review of each city's zoning code seeking to answer three questions:

- How does the zoning code organize the city's land area?
- Does the zoning code explicitly address urban agriculture?
- Does it distinguish between different types of urban agriculture?

Denver's zoning code organizes its land area by neighborhood context and then by zoning district. A neighborhood context describes the general character of a city area such as urban center, urban edge, suburban, etc. Each neighborhood context contains one or more zoning districts each of which offer explicit instructions on building form and character, minimum lot size, maximum building height, etc. (City & County of Denver, 2010).

Wheat Ridge's zoning code divides its land into twenty-two districts each with specific parameters for building height, number of structures, lot size, open spaces, permitted activities, etc. (City of Wheat Ridge, 2013)

The cities of Denver and Wheat Ridge have both recently modified their zoning codes to explicitly address urban agriculture and, generally speaking, make it more widely permitted.

Denver divides urban agriculture into three categories based on intended use: urban garden, plant nursery, and plant husbandry (City and County of Denver, 2010). The primary difference between the three categories is the intended final consumer (i.e. personal consumption or for sale to others). Land zoned to prohibit all three categories of urban agriculture is unavailable for urban production. Wheat Ridge divides urban agricultural activities into beekeeping, farmers markets, produce stands and urban gardens (City of Wheat Ridge, 2013). Since urban gardens is the only category related to vegetable production, we considered land zoned to prohibit urban gardens to be unavailable for urban production. It should be noted that all of Wheat Ridge's zoning districts permit urban gardens.

Our findings from reviewing the cities' zoning codes were compiled onto spreadsheets that listed all neighborhood contexts and districts and whether or not they permitted vegetable production. The spreadsheet data was then used to develop Equation (2) which shows the subtractive method for calculating practically available land for Denver and Wheat Ridge, where L_P is practically available land, L_G is geographically available land, and P_{GHN} is land where vegetable production is prohibited due to zoning restrictions for urban gardens, plant husbandry and/or plant nurseries.

$$L_P = L_G - P_{GHN} \tag{2}$$

As the final piece of step two, Equation (2) was used to create policy GIS layers that revealed the land practically available for vegetable production in Denver and Wheat Ridge. Our Denver policy GIS layers made one additional exclusion – the land area within and around Denver International Airport. The airport is surrounded by thousands of acres of open space, but highly fluid plans for future development made it impractical to include in our calculations.

To gain a more detailed view we further filtered for certain kinds of administrative and use categories including public schools, office parks and churches (data available only for Denver). For example, Denver Public Schools is one of the largest land owners in the city with many schools sitting on multi-acre sites, many office parks have large areas planted in maintenance-intensive Kentucky Bluegrass, and churches may engage their social mission through food production.

While parking lots, roof tops, and other "impervious surfaces" certainly have potential for urban agriculture, barriers including infrastructure, technical, biological, and economic constraints and possible remediation costs are such that we have excluded these conceivably large urban spaces from the analysis. Additionally, brownfield sites have been removed from our analysis. Brownfield sites are generally defined as former commercial or industrial properties having suspected or confirmed contamination that might exceed screening levels for human or ecological health. Affected media can include soil, surface water, groundwater, and man-made surfaces such as drywall or pavement. The customary due diligence standards for characterizing such sites for title companies and government entities include Phase I and Phase II site assessments prescribed by the International Organization for Standardization (ISO). Unless government entities become involved, only private parties may know site assessment information for a true brownfield site. Therefore, it is difficult to quantify the amount of land under a brownfield category. As an indication, brownfields that have participated to-date in state or federal assistance programs (excluding an unknown number of brownfield sites in private transactions) amount to 4,231 acres [1,712 hectares] in the City of Denver, and 9 acres [3.6

hectares] in the City of Wheat Ridge (CDPHE, pers. communication 2013). In order to determine the suitability of a site for urban agriculture it is important to first conduct soil tests for assurance that contamination levels, if present, are within safe ranges for food production due to the variability of urban soils and distribution of potential contaminants from industrialization, vehicle emissions, and other urban activities (Cachada et al, 2012, Nabulo et al, 2012).

FRESH VEGETABLE PRODUCTION ESTIMATE

Our research goal in calculating available land for urban agriculture was to understand how much food could be produced on that land. Rather than trying to calculate the total potential production of all potential foodstuffs, as this introduces a host of assumptions and complications (meat vs. vegetarian diet, grain production, etc.), we chose instead to illustrate production potential by selecting seven widely consumed, high nutrient vegetables and calculating the amount of land needed to meet the demand within two Colorado cities. These seven vegetables were chosen based on popularity (potatoes, tomatoes, carrots, and onions) and nutrient quality (spinach, tomatoes, carrots, bell peppers, and broccoli) and comprise approximately 80 percent of the total local fresh vegetable consumption (USDA ERS, 2011). Vegetable production data from several local sources were reviewed as the basis for selecting a representative yield (e.g., lbs. per unit area planted) for our calculations. These included data from the 2011 growing season of three gardens located in Denver of less than 1,000 square feet each (Fisher, pers. comm.); four growing seasons of a garden located in Louisville, Colorado of less than 5,000 square feet (Hearteye CSA, pers. comm.); and the Colorado State University Organic Farm Project located in Fort Collins, Colorado (electronic document). All reviewed sources represented similar production scales, practices, climate, altitude, and latitude and were qualitatively comparable. We selected a yield figure for each vegetable from the Colorado State University Organic Farm Project because they were most representative of average conditions and garden performance. Based on actual yield trends, we calculated an estimated potential contribution to the urban food supply for Denver and Wheat Ridge. Calculations were based on total yield per bed area (lbs/ft^2) for each of the 7 vegetables and converted to yield per acre and per hectare, standard agricultural units of measurement (see Tables 4 and 5).

This reference data set was chosen for this assessment because it most closely resembles growing conditions and practices found in an urban setting in Colorado Front Range communities (small scale, intensive organic production) and accounts for production losses. We used “store disappearance data” from USDA’s Economic Research Service (USDA ERS, 2011) to approximate consumer demand for each of our seven vegetables. This number is an underestimation as it does not include the small number of people who buy from farmers markets and CSAs, or who grow their own vegetables but we propose that it provides a reasonable approximation of demand given that the majority of the population buys their fresh vegetables through the corporate food system. Using the population of each city from the 2010 U.S. Census, we calculated the per capita consumption for each of the vegetables (see Tables 4 and 5).

Findings and Discussion

Our analysis illustrated that, in a city of relatively high population density like Denver, there is an adequate land base to satisfy a large portion of the city’s annual fresh vegetable demand during the growing season (Table 1). Not surprisingly, cities with lower population and density, like Wheat Ridge, proportionally have a still larger land base (Table 2) and have an even greater production potential. The main finding of this analysis is that there is sufficient land available, allowing cities the potential to produce large quantities of fresh produce, thus lending weight to arguments for more local/regional food production systems.

GEOGRAPHICALLY AVAILABLE*	(acres)	(hectares)
Total land area, L_T	73,935	29,920
Impervious Surfaces, I	-33,303	-13,477
Tree Canopy, T	-5,990	-2,424
Water features, W	-1,297	-525
Geographically available land, L_G	**33,345**	**13,494**
PRACTICALLY AVAILABLE	(acres)	(hectares)
Geographically available land, L_G	33,345	13,494
Vegetable production prohibited, P_{GHN}	-4,959	-2,007
Practically available land, L_P	**28,386**	**11,487**
* The area in and around Denver International Airport was excluded…		

Table 1: Denver land inventory using a Geographic Information System subtraction method. Geographically available land is land whose macro-level attributes suggest it could be utilized for vegetable production. Practically available land is a subset of geographically available land where vegetables could legally be produced under existing zoning ordinances.

GEOGRAPHICALLY AVAILABLE	(acres)	(hectares)
Total land area, L_T	6,495	2,628
Impervious Surfaces, I	-2,697	-1,091
Tree Canopy, T	-1,052	-426
Water features, W	-179	-72
Geographically available land, L_G	**2,567**	**1,039**
PRACTICALLY AVAILABLE	(acres)	(hectares)
Geographically available land, L_G	2,567	1,039
Vegetable production prohibited, P_{GHN}	-0	-0
Practically available land, L_P	**2,567**	**1,039**

Table 2: Wheat Ridge land inventory using a Geographic Information System subtraction method. Geographically available land is land whose macro-level attributes suggest it could be utilized for vegetable production. Practically available land is a subset of geographically available land where vegetables could legally be produced under existing zoning ordinances.

A finer-grained analysis by land use types is important because different kinds of land-use and ownership have different land-use patterns, political priorities, expectations for their land, and present unique challenges and opportunities. Table 3 lists examples of Denver's land-use categories; available data did not permit similar analysis for Wheat Ridge. These numbers are indicative of the types of large urban land spaces that could be used for food production. As noted above, city-owned parks represent an obvious large land base that could produce large quantities of food but park managers and users may have significantly different priorities. Recent discussions in Denver over expansion of the zoo and the possibility of a homeless persons' encampment have made it clear that any proposal calling for large scale vegetable production on park lands would likely meet with very stiff opposition.

On the other hand, privately owned land may provide unique opportunities for urban agriculture. Many churches, for example, have a strong social mission and those with sufficient land base may consider using some of their land for urban agriculture. Similarly, office parks face massive landscape maintenance expenses that could be offset if some part of that land were generating income through food production instead of generating costs through lawn maintenance (Redmond and Redmond, pers. comm.). Denver Public Schools is one of the largest landowners as well as one of the largest consumers of fruits and vegetables in Denver. Many schools are situated on multi-acre lots, only part of which is used for playgrounds, sports fields, and related activities; the rest is often under several inches of pea gravel to reduce maintenance costs. While there are hosts of political, policy, and organizational difficulties facing the use of school properties for food production, “school garden” is a well-established concept, thus “school agriculture” may gain acceptance, much as community gardens have since their resurgence in the early 1970s. Several Denver Public Schools are piloting programs to determine if organic food production on school property is practical.

Finally, city-owned properties, such as abandoned building lots, are uncommon in fast growing cities like Colorado but represent a significant land resource base in many urban centers. Midwestern cities, in particular, have been exploring the agricultural potential of abandoned urban lands as both food producing areas and redevelopment opportunities (Broadway, 2009; Grewal and Grewal, 2012). Here again, Denver has begun experimenting at its Sustainability Park (electronic document), which is a full city block in a redevelopment area north of downtown. It was developed as a showcase for sustainable urban design and is home to a number of neighborhood supported agriculture (NSA) operations. These are important efforts to demonstrate production potential as well as costs and infrastructure needs (e.g. water).

City & County of Denver							
Land Category	**Total Area**		**Non-Useable**		**Potential for Ag**		**Vegetable Demand Satisfaction**
[-]	acres	hectares	acres	hectares	acres	hectares	percent
DPS (Denver Public Schools)	1,730	700	676	274	1,054	427	39%
Parks	4,947	2,002	1,304	528	3,643	1,474	134%
City-Owned	8,066	3,264	1,836	743	6,230	2,521	229%
Churches	381	154	246	100	135	55	5%
Hospitals	467	189	243	98	224	91	8%
Residential	20,409	8,259	11,064	4,477	9,345	3,782	344%
Total Land Required to Satisfy Demand					**2,717**	**1,100**	

Table 3: Land availability by category in Denver and the amount needed to meet the demand for 7 vegetables. Using Denver Public Schools to illustrate: DPS owns 1730 acres of which 676 are occupied by building, play structures, ball fields, etc. leaving just over 1000 acres that have farm potential. That amount of land would satisfy 39% of total demand for the seven vegetables listed below in Tables 4 and 5. Parks and City-Owned land are non-overlapping categories.

City & County of Denver
Population: 610,345 people

Vegetable	Yield		Store Disappearance (ERS 2011)		Denver Vegetable Demand (consumption)		Area Required (Production)		Area Available	Vegetable Demand Satisfaction
[-]	lbs./ acre	kg/ hectare	lbs./ (person * year)	kg/ (person* year)	lbs./year	kg/year	acre/ year	hectare/ year	acres [hectares]	["x" times more than demand]
Broccoli	21,780	24,394	5.6	2.5	3,417,932	1,550,348	157	64	28,386 [11,487]	181
Carrot	52,272	58,545	7.2	3.3	4,394,484	1,993,304	84	34	28,386 [11,487]	338
Bell Pepper	12,937	14,489	8.6	3.9	5,248,967	2,380,891	406	164	28,386 [11,487]	70
Potato	13,068	14,636	35	15.9	21,362,075	9,689,674	1,635	662	28,386 [11,487]	17
Spinach	19,604	21,956	1.7	.77	1,037,587	470,642	53	21	28,386 [11,487]	536
Onion									28,386 [11,487]	
Tomato	26,136	29,272	16.4	7.4	10,009,658	4,540,306	383	155	28,386 [11,487]	74
Total Land Required to Produce Vegetable Demand: All Vegetables							**2,717**	**1,100**	28,386 [11,487]	**10.45**

Table 4: City and County of Denver Production Potential for Seven Select Vegetables

City of Wheat Ridge

Population: 31,030 people

Vegetable	Yield		Store Availability (store disappearance)		Wheat Ridge Food Demand (consumption)		Acre Requirements		Area Available in Wheat Ridge	Food Demand Satisfaction
[-]	lbs./ acre	kg/ hectare	lbs./ (person * year)	kg/ (person* year)	lbs./year	kg/year	acre/ year	hectare/ year	acres [hectares]	"x" times more than demand

Broccoli	21,780	24,394	5.6	2.5	173,768	78,819	8	3	2,567 [1,039]	321
Carrot	52,272	58,545	7.2	3.3	223,416	101,339	4	2	2,567 [1,039]	642
Bell Pepper	12,937	14,489	8.6	3.9	266,858	121,044	21	8	2,567 [1,039]	122
Potato	13,068	14,636	35	15.9	1,086,050	492,623	83	34	2,567 [1,039]	31
Spinach	19,604	21,956	1.7	.77	52,751	23,927	3	1	2,567 [1,039]	856
Onion									2,567 [1,039]	
Tomato	26,136	29,272	16.4	7.4	508,892	230,829	19	8	2,567 [1,039]	135
Total Land Required to Produce Vegetable Demand: All Vegetables							**138**	**56**	**2,567 [1,039]**	**19**

Table 5: City of Wheat Ridge Production Potential for Seven Select Vegetables. The number in the last column…

The relatively small amount of land required to produce our seven vegetables (Tables 4 and 5) illustrates the considerable production potential for urban agriculture. The entirety of Denver's demand for the 7 selected vegetables is met on less than 10 percent of available, useable land and only 5 percent of available, useable land in Wheat Ridge. Even allowing for the simple and obvious fact that much of this land will obviously not be suitable or available for production, the very considerable "buffer" allows us to think in terms of urban agriculture on a much larger scale than has been done to date.

Based on this analysis, we conclude the available land base is not a significant barrier for urban areas to meet their own fresh vegetable demand and invest the necessary social and political capital for policy and infrastructure changes to support urban agriculture. Having established that there is sufficient land in an urban area to grow significant amounts of food, key discussions going forward are: what should be grown? What about grains? What about animals? We based our calculations on vegetable production, because vegetables are relatively simple to grow in urban spaces and would require minimal to no change to infrastructure, zoning, or policy. Vegetable (and fruit) production can easily be integrated into urban landscapes in ways that animals are not; also, plant producers are not confronted with the kind of waste control issues inherent with animal husbandry. Similarly, grain production is not practical in an urban context as it is most efficiently grown extensively rather than intensively, requiring large tracts of land.

It is here that regional or "foodshed" discussions become important. Urban and rural agriculture can be complementary rather than dichotomous; urban areas can more easily accommodate the production of perishable products, while livestock and staple crops are better suited to rural production (van Veenhuizen and Danso, 2007). Colorado is a large, diverse state with tremendous agricultural production. Within 200-250 miles of most Front Range population centers nearly all non-tropical foods can be produced in quantity: grazing animals on the eastern plains and in the mountains, wheat and irrigated corn on the plains, fruit on the western slope and vegetable production throughout.

In our examination of urban agriculture's production potential, we acknowledge that the calculations are at a macro-scale level. Going forward, understanding land management and production potential of a given space is an important step in designing a food program that addresses the environmental, social, and economic pillars of sustainability. To achieve these goals for theimplementation of urban agriculture, these spaces must also address the needs of the city's occupants and the food producers. This includes taking into account the economic potential, compensation for land space, and other expenses associated with food production (Kiminami and Kiminami, 2006). Similarly, if urban agriculture is to be viable over the long term, urban growers must be able to produce in quantities that realize a reasonable profit. Currently, local food producers and other small-scale efforts lack the economies of scale necessary for efficiency. The return of producing on a small plot land may not be sufficient to cover production costs; farmers must be able to find a reasonable venue to sell their products as driving from market to market is neither efficient nor sustainable. The marginal returns of small-scale production will be an important issue to address in moving forward in constructing a local food source. These economic and sustainability issues will be important to address; our research has simply initiated an imperative first step by assessing production potential of urban agriculture. Understanding production potential is a prelude to sustainable development and economic viability.

There are many other factors and potential limitations that would need to be addressed for each parcel of land on which agriculture is proposed. While both Denver and Wheat Ridge have recently changed their zoning codes to enhance the possibilities of urban agriculture, other cities in the Denver metropolitan area still have restrictive zoning that inhibits any agriculture of scale or the keeping of food producing animals, generally chickens, ducks, pygmy goats, and honey bees.

Agriculture requires considerable infrastructure (soil amendment, irrigation, fencing, etc.), often with high upfront costs. This raises two important issues: First, it is hard to justify this kind of investment in the absence of long term contractual access to a parcel; urban agriculture should not be considered a temporary land use until a more lucrative activity is identified for any given parcel. Denver Urban Gardens, the organization that develops and maintains the majority of community gardens in Denver, will not accept a parcel unless it is guaranteed access for at least 10 years, having suffered the loss of several valuable, mature gardens because land owners chose to develop the land (Buchenau, pers. comm.). This is particularly acute in the urban core where land is relatively scarce and values are high. Some discussions focus on integrating food production into the urban landscape rather than thinking of it as a separate enterprise (e.g., Nasr, MacRae, and Kuhns, 2010; Redmond and Redmond, pers. comm.). The policy and land use discussions in Midwestern cities that have large tracts of abandoned and/or city-owned land will be very different from those in cities like Denver that are still growing in population and where land values are high and use is fluid; very high density cities, such as Chicago, New York, and San Francisco, will face still other issues. Second, we are defining urban agriculture as just that: agriculture, with the intent that growers can expect to make a profit by producing food, whether full or part time. As business enterprises, larger urban agriculture endeavors will require access to credit, financing, insurance and other financial services (Meyer, et al., 2011, Thilmany and Sureshwaran, 2011). In a similar vein, traditional agriculture has benefitted tremendously from government sponsored extension services. To date, relatively little effort has been devoted to developing extension services for small-scale and urban agriculture though Denver had an "Urban Agriculture Education Coordinator" for two years. Models on how this kind of extension service might be structured are being developed (Robotham and McArthur, 2001).

Determining Production Potential

Individual parcels of course have to be evaluated for their suitability for agriculture: soil fertility, parcel history, sun exposure, slope aspect, and the possibility that some degree of remediation may be necessary; in the dry west, access to water for irrigation is essential. Within the city limits, access to city water is relatively straightforward and the city has developed a range of mechanisms to sell water to users in areas without conventional taps (e.g., meters and pressure regulators installed on fire hydrants). In outlying areas (e.g., peri-urban and suburban areas) access to water may be more complex. Some areas of Wheat Ridge still have functioning irrigation ditch or well-water systems, which may provide water to select agricultural lands.

In a highly seasonal environment like the Front Range of Colorado, seasonality is a critical concern for any consideration of urban agriculture. Consumer demand is relatively constant all year, yet the growing season in Colorado is necessarily seasonal. Without season extension technology the expected harvest period is roughly limited to April through September. With the emergence of reasonably inexpensive technologies that extend the growing season (e.g., high tunnels, hoop houses) the harvest period can stretch from February through November with the possibility of year-round production of some vegetables in favorable locations. Further afield and more complex, urban areas produce huge quantities of waste heat (power plants, methane flares in waste treatment facilities and landfills, oil refineries, etc.) that conceivably could be captured to heat green houses in high solar insolation areas like Colorado.

Conclusion

Determining Production Potential

Our analysis shows that cities like Denver and Wheat Ridge have enough available land to produce quantities of fresh vegetables sufficient to meet a large portion of consumer demand, at least seasonally. Is it possible to become fully self-sufficient in vegetable production? Cities could realistically expect to offset fresh produce trucked in from elsewhere by as much as 25%, as has been illustrated by other cities (Masi, Schaller, and Shuman, 2010). This has important implications for the sustainability of food sources. Major issues still loom: In order to be a sustainable business venture, urban agriculture must be lucrative; profitability has yet to be demonstrated in this region. Arguably, due to health and environmental issues, food production in urban areas should be based in organic principles. Also, the resulting produce must be affordable and accessible to the poor as well as more affluent consumers. Having demonstrated that there is adequate land for producing a significant amount of a number of fresh vegetables, we can now turn to the larger policy and infrastructure questions that need to be addressed in order to develop a sustainable, urban food system.

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