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# Will the urban agricultural revolution be vertical and soilless? A case study of controlled environment agriculture in New York City

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ABSTRACT

Controlled environment agriculture (CEA) is an emerging form of farming increasingly found in cities worldwide. Advocates promote CEA as the future of food production, arguing for its potential to address challenges ranging from climate change to food insecurity. Detractors state that CEA's narrow focus on high-end produce, along with its intensive capital and energy needs, limit its meaningful contribution to the urban food system. Over the last seven years, New York City has become an epicenter for urban CEA, offering planners an in-situ setting in which to evaluate its impact. The following case study examines the current state of CEA in New York City, its composition, requirements, and future. The authors identify CEA's relative contributions, which include providing a small number of green-sector jobs and increasing access to produce in low-income communities. In parallel, they question if CEA provides sufficient benefits to warrant public-sector support. Recommendations for cities considering CEA include critically analyzing its purported benefits; evaluating the environmental, economic and social potential of projects located on publicly-owned rooftops and land; and focusing incentives on nonprofit and institutional production that show clear community benefits.

## 1. Introduction

Over the last decade, urban and peri-urban agriculture (referred to as 'UA' in the following article) have received increased attention from urban planners (Hodgson et al., 2011; Kaufman and Bailkey, 2000; Mendes et al., 2008; MacRae et al., 2010; Nugent, 2000; Pothukuchi and Kaufman, 1999; Pothukuchi, 2004; Pothukuchi and Kaufman, 2000; Wekerle, 2004). Interest in urban agriculture has been spurred by a confluence of factors, most notably the demographic shift leading to two-thirds of the world's population becoming urbanized by 2050 (United Nations, 2012) and concerns about how this burgeoning populace will be sustainably fed (Steel, 2012; Thomaier et al., 2015; Weber and Matthews, 2008). Threats to future food provisioning are multifold, with environmental degradation due to industrial farming (Brown and Carter, 2003; Kissinger et al., 2012; Pothukuchi and Kaufman, 2000) and erratic weather precipitated by human-caused climate change two of the most urgent challenges. Together, these concerns have led to calls for a new approach to farming (Intergovernmental Panel on Climate Change, 2007), including re-envisioning cities as settings for production-level agriculture and emphasizing growing food more efficiently and closer to where a larger share of the world's population lives.

While the planning profession has long recognized the benefits of green space within the built environment (Lawson, 2005), planners have not historically championed the co-existence of commercial farming with city life. This is largely a byproduct of planners' pivotal role in developing modern zoning codes, which aimed to separate land uses incompatible with one another, among them industrial/manufacturing and residential housing.

The re-envisioning of agriculture as a beneficial urban land use is thus a relatively recent phenomenon, one that grew largely out of grassroots efforts by residents in low-income neighborhoods in the United States in the 1960s and '70s to put neglected vacant land back into productive use. Over time, their focus evolved into initiatives to increase food security and improve access to healthy food in places lacking grocery stores and supermarkets (Brown and Carter, 2003; Kaufman and Bailkey, 2000; Cohen, 2011; Reynolds and Cohen, 2016; Gordon et al., 2011; Saldivar-Tanaka and Krasny, 2004) and to the now-ubiquitous community gardening movement.

Although some planners initially questioned whether UA was the highest and best use of urban plots (Lovell, 2010; Mukherji and Morales, 2010), most professionals today are likely to support UA and

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acknowledge its benefits. In addition to increasing access to healthy food and improving food security (Nugent, 2000), its potential advantages include creating opportunities for millennial farmers to replace retiring rural ones (Gale, 2003; Rogus and Dimitri, 2015; National Young Farmers Coalition, 2017); reducing transportation, energy, and material expenditures along the supply chain (Blay-Palmer and Donald, 2008; Harrison, 2011; Weis, 2010); and improving the taste and quality of food by reducing post-harvest storage and handling (Gross et al., 2016).

Environmentally, UA has been associated with creating habitat for pollinators (Goddard et al., 2010); reducing the urban heat island effect (Susca et al., 2011); modulating microclimates and hydrology (Oberndorfer et al., 2007); productively redirecting wastewater, organic matter, and biosolids (Armstrong, 2009; de Zeeuw et al., 2011; Smit and Nasr, 1992); fixing atmospheric nitrogen (Herridge et al., 2008) and carbon (Beniston and Lal, 2012) that would otherwise contribute to climate change; and stemming farmland loss linked to peri-urban and suburban development (Haight et al., 2016; Pendall, 2003; Sorensen et al., 2018).

Socially, researchers have linked UA to strengthening social connections between farmers and consumers (Mincyte and Dobernig, 2016) and nature and people (McClintock, 2010; Turner, 2011); improving livability (Frumkin, 2003; Turner et al., 2004), health, and well-being (Joye, 2007; Ulrich, 2006); and adoption of plant-based diets (McCormack et al., 2010) that lower chronic disease risk (Boeing et al., 2012).

Concerns about UA have been raised, but these tend to be more limited in scope. Among them are introduction of disease and agricultural pollutants to the urban ecosystem (Smit et al., 2001); conflicts over land use (Schmelzkopf, 1995); and the unnecessary addition of complicated and maintenance-intensive systems to urban infrastructure (Susca et al., 2011).

Most planning studies of UA in the Global North have examined community-led, soil-based projects (Opitz et al., 2015). Recently, however, a new kind of farm has emerged in cities – generally commercial in nature, larger in scale, and more technologically advanced – that planners have not deeply studied. Found in cities as diverse as Tokyo and Jackson Hole, these farms have sparked great excitement in the popular press (Shute, 2007; Venkataraman, 2008; Frazier, 2017) as well as fierce debate among plant scientists and horticulturalists (Mattson et al., 2015; Buckler, 2009; Albright and de Villiers, 2008). These urban farms use soilless systems, such as hydroponics, aeroponics, and aquaponics, and are collectively referred to as controlled-environment agriculture (CEA). Distinguishing them further is the fact that, rather than being sited at ground level, these farms are often found in or on top of buildings, leading to their being dubbed 'plant factories' in Asia (Takatsuji, 1987) and 'vertical' (Despommier, 2005) or 'indoor' farms (Despommier, 2009) in the U.S. and Europe. As evidence of their growing dominance, the vertical farm market's size was valued at more than USD $2 billion as recently as 2016 and is estimated to grow 27% by 2024 (Global Market Insights, 2017).

### 1.1. Brief history of controlled environment agriculture

Soilless farms in which crops are grown exclusively in water were described as early as the Hanging Gardens of Babylon (Cornell University, 2012). The term 'vertical farming' first appeared near the beginning of the 20th century (Bailey, 2015), with 'hydroponics' following shortly thereafter (Gericke, 1937). In subsequent decades, advancements in lighting and plastics made greenhouses, where growing conditions could be controlled, more affordable for commercial farmers. Aeroponic experiments undertaken by NASA's Kennedy Space Center in the 1960s and '70s (Cornell University, 2012; Millam and Sharma, 2007), along with greater availability of LED lighting, further raised interest in controlled environment agriculture among a niche segment of home gardeners (Bridwell, 1972).

It was not until the last decade that CEA entered the mainstream. Much of the credit for that goes to Dickson Despommier, a professor of microbiology and public health at Columbia University, whose 'Vertical Farming Project' (2009) began as a class exercise, made its way to television (e.g., *The Colbert Report*), and eventually became a seminal book *The Vertical Farm* (Despommier, 2010). In so doing, he foreshadowed a tipping point in public interest and awareness about urban, vertical, and indoor CEA farming that continues to this day.

Despommier posited that while rural, soil-based farming was the historical norm, vertical and indoor urban farms offer the greatest potential for a rapidly urbanizing planet. Among the advantages he cites are their ability to maximize yields in small spaces; accommodate year-round production; reduce water usage, including contaminated runoff generated by commercial farms; eliminate the need for pesticides, herbicides, and fungicides; more effectively withstand pests, disease, and extreme weather caused by climate change; lessen reliance on fossil fuels; make healthier food accessible to low-income populations; lower greenhouse-gas emissions related to food transport; return land to its natural state; improve air quality; provide employment; and expand farming to non-arable regions.

Despommier's enthusiasm for urban CEA, however, is not universally shared, most notably among plant scientists, who have taken a more cautious view of the economic and environmental viability of his farm-in-the-city concept (Albright, 2011; Ilaslan et al., 2002; Mattson et al., 2015). Their concerns include indoor and vertical farming's significantly higher startup costs (Mattson et al., 2015) and CEA's comparatively higher energy demands, both in places with limited natural sunlight (Albright and de Villiers, 2008) as well as locations warm enough for year-round, soil-based growing (Barbosa et al., 2015). Some plant scientists also challenge CEA's promise of disease and insect-free growing, given that even the most well-maintained greenhouses are susceptible to powdery mildew, aphids, mites, and other pests (Brechner and Both, 2013).

### 1.2. A case study of how CEA operates in New York City

Given the lack of consensus about urban CEA's economic, environmental and social impact, and the limited planning literature devoted to these farms, the authors embarked on a case study to examine how CEA is realized in a place where its footprint has grown tremendously over the last decade: New York City. The case study examines key categories relevant to planners: access to healthy, nutritious food; land use and real estate; employment; and environmental sustainability. Key research questions include: What is the state of CEA in New York City? How does produce grown using CEA methods contribute to the City's food and nutrition needs (e.g., increasing food access for low-income residents)? What are the land use and real estate requirements for CEA and what space is available for its expansion? How does CEA contribute to the City's economy, specifically in terms of providing employment? What is the potential for CEA to enhance sustainability efforts? In summary, this case study provides information about CEA practices in New York City that the authors believe other cities can use to inform their own approach to proposed CEA projects.

In the following section, we review the limited planning literature that references controlled environment agriculture within the context of UA. We then describe data collection methods used to understand this emerging sector in New York City with an emphasis on commercial growers. Next, we analyze the sector's impact vis-à-vis nutrition and food access, environmental sustainability, land use/location, and employment. We conclude with recommendations other cities may wish to consider when contemplating public policies or proposals related to CEA.

## 2. Controlled environment agriculture and city planning

As described previously, urban CEA has been hailed in the popular press as the future of farming (Frazier, 2017; Holden, 2017; Marginson, 2010). Enthusiasm includes its potential to use less water, pesticides, and herbicides than soil-based farms (Caplow, 2009; Astee and Kishnani, 2010); feed more people using less space (Gould, as cited in Brin et al., 2016); capture waste heat from buildings to reduce energy costs (Thomaier et al., 2014); reduce $CO_2$ emissions associated with long-distance transport (Rees and Wackernagel, 1996; Weber and Matthews, 2008); and grow crops in cleaner environments that reduce the risk of diseases such as E. coli (Orozco et al., 2008). Urban CEA has also been hypothesized to slow the loss of rural land to large-scale farming (Lehmann, 2010); provide a local alternative to imported food to increase self-sufficiency, especially in climate-threatened regions (Hodbod and Eakins, 2015; Rogers, 2017); stimulate green-sector employment (Jensen, 2015); and improve food access to low-income residents who live in areas labeled as 'food deserts' (Caldeyro-Stajano, 2004).

Simultaneously, urban CEA has been critiqued for being overly-optimistic (Hamm, 2015). Those who question it point to its high up-front capital costs (Bhanoo, 2014); the complexity of its profit model (de Nijs, 2017); the exposure of plants, even under cover, to pollutants, which can lead to contamination and health risks (Säumel et al., 2012; Alloway, 2004); and higher $CO_2$ externalities caused by 100% artificially lit systems, even factoring in energy costs associated with cross-country transport and crop loss due to shrinkage, which limit claims of environmental sustainability (Albright and de Villiers, 2008).

While planning research to validate UA claims has intensified in recent years, knowledge about the specific methods and technologies required for successful vertical, urban CEA have to date been largely theoretical (Januszkiewicz and Jarmusz, 2017) and only a handful of national and international studies have focused specifically on CEA within the context of urban planning (Januszkiewicz and Jarmusz, 2017).

One of the most extensive studies to include urban CEA is Thomaier et al.'s (2014) research on what she and her colleagues call Zero-Acreage Farming (ZFarming). ZFarming includes "all forms of food production related to urban buildings, including open rooftop farms, rooftop greenhouses, productive facades, and indoor farming on and in existing or newly built urban structures" (Thomaier et al., 2014, 44). Her study offers a useful overview of the ZFarming landscape in developed countries worldwide, but lacks an analysis of CEA's measurable impacts within the context of a particular cityscape.

Dimitri et al. (2016) conducted the first systematic study of UA at the farm level in the U.S. Using primary survey data, she and her colleagues found that of 315 respondents, 18% identified as operating vertical, 8% aquaponic, and 5% hydroponic farms, an indicator of CEA's growing presence nationwide. Dimitri also found that although the majority of UA operations had social aims, farms that used greenhouses, hydroponic systems, and high tunnels tended to be more profit-oriented and thus "reported higher sales than farms not using these types of structures" (Dimitri et al., 2016, p. 608). Similarly, she confirmed that "very large urban farms typically raise high-value crops, such as lettuce, in climate-controlled greenhouses through a hydroponic system (Dimitri et al., 2016, p. 608)." These crops compete on quality not price, and thus command higher prices at the retail level (Thomaier et al., 2015, as cited in Dimitri et al., 2016, p. 607–8). Beyond identifying where farms were located (i.e., on rooftops, in greenhouses, etc.), and examining the extent to which the primary farmer was able to "earn a living" (p. 608) from the farm, this research did not explore how many additional people UA farms employ or the nature of those jobs, leaving unanswered whether they are fulfilling on their promise of green-sector employment.

Another study (Ackerman et al., 2011) exploring UA's potential in New York City offers a window into land availability and land use requirements to meet the City's fruit and vegetable consumption demands. The authors determined that between 162,000 and 232,000 acres would be required to support New Yorkers' basic produce needs, not including tropical or warm-weather fruit. In parallel, they identified nearly 5,000 acres of vacant land suitable for growing, which they estimated could feed between 103,000 and 160,000 people "depending on whether conventional or biointensive food yield figures are used" (p. 195). Although acknowledging that the amount of land was insufficient to make New York City agriculturally independent, the authors speculated that for "specific high value, healthy crops suited to urban farming, localized production is actually feasible from the perspective of land availability" (Ackerman et al., 2011, p. 195). The authors cited "leafy greens and tomatoes" as examples of such crops, noting that "considerably less area would be needed for these vegetables to be grown hydroponically," (p. 195). Ackerman et al. were particularly optimistic about UA's potential to positively impact food security in neighborhoods with "low access to healthy food retail, high prevalence of obesity and diabetes, low median income, and comparatively high availability of vacant and other available land," (p. 195). Yet even this New York City-focused research barely mentions how using CEA versus soil-based production might change their calculations; given that the City had only one rooftop hydroponic farm at the time, the oversight is understandable.

The same limitation is found in research conducted by Nevin Cohen, one of the most prolific planning scholars reporting on New York City's UA landscape. In books he co-authored, among them *Five Borough Farm* (2012) and *Beyond the Kale* (2016), he mentions CEA as one of among many contributors to the City's diverse UA offerings, but its specific characteristics and contributions are not articulated because of commercial CEA's nascency at the time of his writing.

Gundula Proksch's recent book on UA (Proksch, 2017) offers a brief discussion of CEA. This includes a profile of architect Weber Thompson's conceptual design for Newark Vertical Farm, a mixed-use building incorporating commercial growing operations in Newark, New Jersey. The book provides important insights into UA generally, and points out the importance of land use laws and building codes to UA and CEA, but does not provide an in-depth evaluation of CEA as a distinct entity.

In sum, there is a dearth of information about indoor and vertical CEA in urban areas, particularly information that can help planners and policymakers understand its physical requirements and social, environmental, and economic impacts. This study, conducted between 2016 and 2018, addresses that gap with a case study in New York City that has applicability to other cities of similar diversity.

## 3. Research methods

This research was undertaken for Cornell University Cooperative Extension – New York City (CUCE-NYC) on the state of controlled environment agriculture in New York City and its relationship to youth workforce development.[2] Data was collected from publicly available sources, including federal, state, and municipal datasets (e.g., USDA, BLS); industry publications and reports (e.g., IBISWorld, ESRI); academic journals; articles in the popular press; and social media (e.g., blog, website posts). Information about the commercial sector was supplemented with data from a 2016 international survey of CEA businesses by Agrilyst, a CEA-focused software development company in New York City. Data about funding to CEA nonprofits came from information accessed through the website of The Foundation Center, a nonprofit that gathers and publishes information about philanthropy, charitable organizations, and the nonprofits they fund. To evaluate how New York City's public sector has supported CEA, the researchers identified capital and discretionary funding from the New York City Council's website as well as publicly available news reports about

[2] The focus of the entire study (Goodman, 2017) was to gather and analyze data to assess implications for CUCE-NYC in its teaching CEA to youth through its Hydroponics / Aquaponics / Aquaculture & Science, Technology and Sustainable Agriculture Education Program.

funding initiatives. Six interviews were conducted with representative individuals engaged in CEA in New York City, divided equally across the public, private, and nonprofit sectors. Data about land and building stock were assembled from publicly available sources and analyzed using geographical information systems software (ArcGIS).

## 4. Results

This research project yielded information about public support for CEA in New York City; the composition of the emerging CEA sector; and the location, land use, and real estate requirements of the industry and its capacity to grow. Additional information gleaned in this research highlights the range of CEA technologies, their sustainability, and the number and type of people employed in for-profit CEA ventures.

### 4.1. A context of public support for CEA

In New York City, interest in sustainable food systems planning emerged in a context where there was limited but growing awareness in the U.S. of the value of urban agriculture among urban planners and local government officials (Brinkley, 2013; Campbell, 2004; Kaufman, 2004; Hodgson, 2012; Hodgson et al., 2011; Raja et al., 2008). Many New York City's officials have, over the past decade, expressed support for urban agriculture and its contribution to New York City's social, physical, and economic health (Adams and Espinal, 2017; Brewer, 2015; Mesa and Callahan, 2015). For example, after becoming Mayor, Bill de Blasio, in his signature *OneNYC: The Plan for a Strong and Just City* report (2014), noted that urban agriculture "plays a small but critical role in communities underserved by quality, affordable, fresh food," (Mesa and Callahan, 2015, p. 137). The report further states:

> Urban farming provides opportunities for residents to engage in growing local produce, educates children about nutrition, and offers training in food preparation, gardening, and retailing skills… We will study additional emerging urban agriculture opportunities, such as vertical farming projects, to activate underutilized light industrial space and offer related community programing. (Mesa and Callahan, 2015, 135)

Among public officials, Manhattan Borough President (BP) Gale Brewer and Brooklyn BP Eric Adams have been two of the more vocal supporters of urban agriculture generally and CEA specifically. In 2015, Brewer released *How Our Gardens Grow, Strategies for Expanding Urban Agriculture*, a report that outlined urban farming's benefits and offered recommendations for its expansion. In 2015, BP Adams initiated *Growing Brooklyn's Future*, a $2-million-dollar initiative to bring hydroponic urban farming to 12 high schools in Bedford-Stuyvesant, Brownsville, Canarsie, Cypress Hills, and East New York (Harney, 2016). In 2016, Adams allocated an additional $560,000 to support greenhouse education at four schools and announced plans to invest more than half of his Fiscal Year 2017 capital budget ($26 million) to improve science, technology, engineering and mathematics (STEM) education initiatives in nearly 150 schools across the borough (Harney, 2016). Adams has also spoken publicly, for example at Brooklyn Law's *Growing Greens in the Grid: The Future of Urban Agriculture in NYC,* about urban farming's potential to revolutionize the borough's relationship to food and the environment and create jobs in the biotech industry (Brooklyn Law School, 2017). Together with Councilman (CM) Raphael Espinal, Adams also introduced legislation calling for the New York City Department of City Planning to create a comprehensive urban agriculture plan to capitalize on the urban farming movement and use it to address community and youth empowerment, economic development, healthcare, and land use (Adams and Espinal, 2017). Although the plan has not advanced, an interim Local Law (Int. 1661-A 2017) has resulted in the creation of an official New York City urban agriculture website that serves as a landing page for interested farmers (City of New York, 2019).

Other New York City Councilmembers have also shown support for UA. The current NYCC Speaker Corey Johnson, as early as 2015, introduced a Local Law to amend the New York City Charter to create an urban agriculture advisory board. Other Councilmembers have provided discretionary and capital funding totaling over $2.6 million to support CEA projects, many in schools. Even the general public, through the NYCC's Participatory Budgeting (PB) process, has begun to weigh-in with its support; of 1,491 PB projects selected since 2012, 16 (1.07%) involved greenhouses and/or hydroponic gardening, representing $5,225,000 of $430,906,035 (1.21%) in total funding (The City of New York, 2018).

### 4.2. Composition of CEA in New York City

Over the last seven years, New York City has become home to six commercial CEA farm companies; five companies that sell, develop, or manufacture CEA technology or products; two restaurants that incorporate CEA as a signature feature; and one firm that specializes in CEA consulting, lobbying, and advocacy. A supermarket that maintains a hydroponic farm on its roof was the City's first, established as early as 1995. There are also six social service agencies that use CEA to grow food for low-income clients, five youth-focused CEA nonprofits, and 133 public schools that provide hands-on CEA learning, many in collaboration with a CEA nonprofit.

**Table 1**
CEA Producers and Affiliated Commercial, Institutional, and Community Farms and Gardens as of June 2018. (The number of farm locations each entity operates is indicated in parentheses.).

| Commercial Farms | Institutional Farms | Community Farms | Community Gardens |
|---|---|---|---|
| Edenworks (1)<br>Eli Zabar's Vinegar Factory (1)<br>Farm.One (2)<br>Gotham Greens (3)<br>Oko Farms (1)<br>Sky Vegetables (1)<br>Square Roots (1)[a] | University and school-based programs:<br>- Cornell University Cooperative Extension-NYC (26)<br>- New York City Public Schools with CEA farm project but no known nonprofit CEA Affiliation (17)<br>Nonprofits (many affiliated with CEA programs in schools)<br>- Green Bronx Machine (3)<br>- Harlem Grown (6)<br>- New York Sun Works (72)<br>- Seed Street (1)<br>- Teens for Food Justice (5) | Nonprofits (and affiliated nonprofits where produce is grown or distributed):<br>- Boswyck Farms[b] in conjunction with CAMBA, Child Development Center, Fountain House, Los Sures, Project FIND, Hamilton Senior Center (5)<br>- Project Farmhouse, a program of Grow NYC<br>- Oko Farms, in conjunction with the Northeast Brooklyn Housing Development Corporation | None identified. |

[a] Square Roots includes approximately 8 to 10 Freight Farm containers each operated by its own "Next-Gen Farmer".
[b] Although Boswyck Farms' owner relocated to California, the organization set up partnerships with the nonprofits listed above that are still in operation.

Using *Five Borough Farm*'s designated typologies (Cohen et al., 2012), which include Commercial Farms, Institutional Farms, Community Farms, and Community Gardens, the authors identified three of the four types among New York City's CEA farms and affiliated entities (Table 1).[3]

#### 4.2.1. Commercial farms

Commercial Farms aim to maximize crop performance to achieve profitability while sharing the broader UA community's social goals (Cohen et al., 2012). New York City's 10 commercial CEA locations (overseen by seven companies) are located across four of the City's five boroughs: Manhattan (n = 3), Queens (n = 2), and the Bronx (n = 1), with Brooklyn having the highest concentration (n = 4).

Produce grown at Commercial CEA Farms reaches consumers in a variety of ways. Gotham Greens has the widest distribution network, one that includes online retail, wholesale provisioning to mid-priced supermarkets, high-end grocers, and Zagat-rated restaurants. Edenworks has a narrower reach that includes select Whole Foods and mid-priced groceries (e.g., Foodtown). Square Roots initially hand and bike-delivered produce to its customers, but consumers can now buy its microgreens at 24 New York City grocers. Farm.One focuses on direct sales to restaurateurs, while Sky Vegetables offers online ordering for its grocery stores and has a vendor relationship with a restaurant in Connecticut. Eli Zabar sells his rooftop-grown CEA produce exclusively at his store, the Vinegar Factory.

#### 4.2.2. Institutional farms

Institutional Farms include those affiliated with hospitals, churches, prisons, schools, or public housing developments. Their primary mission is not food production, but they have goals UA supports (Cohen et al., 2012). There are 57 Institutional CEA locations in Brooklyn, 50 in Manhattan, 13 in Queens, 10 in the Bronx, and 1 on Staten Island, most connected to public schools. The seven associated nonprofits are based in Manhattan (n = 4), the Bronx (n = 1), and Brooklyn (n = 1); Boswyck Farms was in Queens before its founder relocated to California. Together they helped establish CEA's presence in over 130 New York City public schools. Among Institutional Farms, the most active is New York Sun Works, which has supported CEA projects in 72 New York City public schools (New York Sun Works, 2018). Except for Cornell University Cooperative Extension – NYC, which began offering CEA programs to youth in the 1970s, all others were founded in the last seven years.

While the researchers were unable to obtain a definitive list of produce grown at Institutional Farms, lettuce, herbs, and leafy greens were either reported by interview subjects or identified on organizations' websites. Institutional Farms based at schools often share their produce with students, with a smaller percentage donating excess to community partners such as food banks and homeless shelters. School-based CEA systems are sited either in classrooms or on rooftops as attached greenhouses. Our research estimates that some form of CEA programming is available at approximately four percent of New York City's 1,878 public elementary and/or middle schools and 11 percent of its 400 public high schools.

#### 4.2.3. Community farms

Community Farms are communal growing spaces operated by nonprofits that engage local neighborhoods in food production while providing social and educational programming (Cohen et al., 2012). Community Farms are located overwhelmingly in Brooklyn (n = 4), followed by Manhattan (n = 2) and the Bronx (n = 1). CEA can be found at six Community Farms run by nonprofits that serve low-income clients and one that serves as a demonstration indoor farm within the context of a public-facing education center (Project Farmhouse). A number of Community Farms were constructed by a CEA-focused nonprofit (Boswyck Farms) that trained receiving agencies to maintain them independently. The risks of this are evident in the fact that many later closed due to lack of succession planning following staff turnover.

The approximate amount of food produced on Community Farms is not readily available, but lettuce, herbs, and leafy greens are similarly found. CEA produce grown by Community Farms is primarily donated to clients.

#### 4.2.4. Community gardens

Community Gardens are spaces on publicly-owned land or land trusts managed by local volunteers with the majority (80%) of space used for growing food. These gardens offer space for other activities, too, such as socializing (Cohen et al., 2012). The authors did not find any Community CEA Gardens in New York City, although Oko Farms operates a hybrid farm that sells produce and charges for aquaponics training to adults (Commercial CEA) while providing free and low-cost educational workshops and tours to youth on a publicly-owned GreenThumb lot.[4]

#### 4.2.5. Production, volumes, sale prices and revenues

Production data for NYC's Commercial CEA Farms is somewhat limited due to the small number of farms and the proprietary and competitive nature of the market. The data below is derived from responses to questions presented by the researchers to representatives from Commercial CEA Farms as well as an anonymized international survey of commercial CEA growers conducted by the NYC-based CEA technology firm Agrilyst, which provides data monitoring and analyses to the indoor farming sector. Agrilyst collaborated with the first author to formulate some of its questions and ensure the inclusion of ones relevant to this study.

Of the seven Commercial CEA Farms in New York City, the authors found that the most frequently grown crops were lettuce greens and herbs (Table 2). The widest range of produce was grown by a company that grows niche products for chefs (Farm.One). Two companies (Edenworks and Oko Farms) raise fish or seafood in addition to produce.

Argilyst's study found nearly similar responses from the seven Commercial CEA Farms it surveyed (Table 3).

*4.2.5.1. Production volumes*. Annual yields at New York City's Commercial CEA Farms are difficult to confirm and are based on company self-reports. To put their production volumes into context, the USDA reported the 2015 annual yield of head lettuce in the United States at 18.1 tons (36,200 lbs.) per acre. In contrast, New York City's Commercial CEA Farms report significantly higher yields.

Gotham Greens' Greenpoint location reports growing 50 tons (over 100,000 lbs.) on .34 acres (15,000 square feet) for an average annual

[3] *Five Borough Farm* studied just over 760 farming properties, of which three were commercial farms and one a CEA farm. The report's glossary further highlights the difficulty in drawing conclusions about New York City's current CEA landscape from this document: it references aquaponics, but does not include hydroponics, aeroponics, controlled environment agriculture, or vertical or indoor farms. Along with *Five Borough Farm*, the Design Trust for Public Space, in collaboration with gardeners, created a companion website, FarmingConcrete.org, designed to gather data from community gardeners and farmers about New York City's urban agriculture. At the program's height, from June to December 2012, 105 participants entered information about their garden or farm's harvest (e.g., yield by weight and volume, food grown, methods used) as well as social and economic impact (e.g., healthy eating, market sales). However, in the years since, the number of gardeners reporting information has dropped to one or two per year, and none reported using CEA.

[4] The GreenThumb Community Gardens program was initiated in the 1970s. The program involves the renovation of vacant lots by volunteers of all ages. The program provides support to over 550 community gardens in all five boroughs of New York City.

**Table 2**
Produce Grown by NYC Commercial CEA Farms.

| Type of Produce | # of Farms |
|---|---|
| Lettuce Greens (including arugula) | 6 |
| Herbs (including basil) | 5 |
| Other Greens (including brassicas, mustard greens) | 3 |
| Vine Crops (including tomatoes, cucumbers) | 3 |
| Microgreens | 2 |
| Fish or Shellfish | 2 |
| Flowers (incl. edible flowers) | 1 |
| Strawberries | 1 |
| Mushrooms | 0 |

**Table 3**
Produce Grown by NYC Commercial CEA Farms – Agrilyst Respondents.

| Type of Produce | # of Respondents |
|---|---|
| Greens | 7 |
| Microgreens/Herbs | 7 |
| Vine Crops | 3 |
| Flowers | 1 |
| Strawberries | 1 |
| Mushrooms | 1 |

yield of 150 tons (300,000 lbs.) per acre. At the company's Gowanus location, it reports growing 100 tons (over 200,000 lbs.) of leafy greens, herbs, and tomatoes on .46 acres (20,000 square feet) for an average annual yield of 217 tons (434,000 lbs.) per acre. At the company's largest location in Hollis, Queens, they report over 5 million heads of leafy greens on 1.37 acres (60,000 square feet). Assuming a weight of 8 ounces per head, this results in an average annual yield of 912 tons (1,824,000 lbs.) per acre.

Square Roots reports yields of 500 full lettuce heads per week in their Freight Farm containers. Based on their reported average weight of 4 to 7 ounces per head, each container could produce 4.46 tons (8,937 lbs.) per year or the equivalent of 607 tons (1,214,000 lbs.) per acre. Edenworks has recently reported average annual yields of 13 lbs. per square foot per year at their facility, the equivalent of 823 tons (566,280 lbs.) per acre (Kart, 2018).

*4.2.5.2. Sales and gross revenues.* Retail prices for CEA produce grown in New York City are much higher than like-kind items grown conventionally, locally, or even organically as shown in Table 4.

Our research found that lettuce grown by New York City-based Commercial CEA Farms is sold at a premium, likely making it unaffordable to middle- and low-income shoppers, even when it is carried in local supermarkets.

Annual gross revenues of New York City's Commercial CEA Farms were self-reported as part of the Agrilyst survey but not provided directly to these researchers. Although the authors cannot share segmented data due to the small number of respondents, we can report annual gross revenues ranging from $0-$9,999 to a high of $5M.

### *4.3. Locations, land use, and real estate*

Most of New York City's Commercial CEA Farms are between 8,000- to 15,000-square feet in total growing area, the equivalent of .18–.34 acres. In comparison, one of the state's largest hydroponic greenhouse companies, Intergrow in Albion, operates on approximately 60 acres (ca. 2,640,000 s.f.) in one facility and 10 acres in another, while Mastronardi Produce, owner of Backyard Farms, recently announced plans to build a 70+ acre facility in Oneida, New York, reportedly making it the largest built-at-once CEA operation in the U.S. (Schaulis, 2018). In total, approximately 3.09 of New York City's 193,689 acres (U.S. Census Bureau, 2010) are devoted to Commercial CEA, accounting for 0.0015 percent of the City's total land mass. In terms of specific locations, five of New York City's Commercial CEA Farms are on roofs. Three are inside buildings (Farm.One) or structures such as shipping containers (Square Roots). One is both on a roof and has an indoor space (Edenworks). Oko Farms is the only Commercial CEA Farm at ground-level.

#### *4.3.1. Example CEA real estate: the Pfizer building*

To gauge the lease rates paid by Commercial CEA Farms in New York City, the authors interviewed a broker and the owner of the Pfizer building, a site that has become home to a number of UA and related food and food tech businesses. The broker initially reported lease rates ranging from $32 to $40 per square foot (a 10,000 s.f. indoor farm would lease for $27,000 a month) with currently available spaces sized from 10,000 to 33,500 s.f.[5] A follow-up conversation with the owner revealed more flexibility. "If there's something compelling about a business," he said, he has offered "sweetheart deals" on rent and even free space in exchange for investing in a business. He made these arrangements with Brooklyn Grange, a soil-based rooftop farm, as well as Verticulture, which grew basil hydroponically before shutting its operations, and Tinyfield Farms, a rooftop hops producer.

#### *4.3.2. Suitable locations for CEA based on land cost*

In addition to already-established businesses, the authors sought to assess CEA's likely expansion in New York City by evaluating factors entrepreneurs typically consider, such as lease rates and spatial factors. The authors used *LoopNet*, a popular commercial real estate website, to ascertain average per square foot rates for industrial and manufacturing spaces that offer a minimum of 20,000 and maximum of 60,000 square feet sufficient for commercial growing and located within 10 miles of current Commercial CEA Farms. According to our analysis, indoor spaces suitable for CEA were easiest to find in the Bronx and Queens, whereas Brooklyn, Manhattan, and Staten Island had less appropriate spaces and at higher rates.

Table 5 highlights representative per square foot rates for industrial and manufacturing properties not only in New York City but also in Kearny, New Jersey, where Bowery Farms – a recent entrant to the regional CEA economy – is based, and Newark, New Jersey, where one of the country's largest CEA companies, AeroFarms, has its operations. Sample lease rates in both New Jersey cities were nearly half those in New York, even before accounting for tax and other incentives provided by the State of New Jersey and the Cities of Newark and Camden.

#### *4.3.3. Suitable commercial CEA farm locations based on zoning laws*

Zoning laws in New York City before 2012 viewed rooftop greenhouses as additional occupiable space that counted toward a building's calculable Floor-to-Area Ratio (FAR) and were therefore not permitted on buildings already at or near FAR (Ackerman et al., 2012). That changed when the Department of City Planning passed a Zone Green Text Amendment (New York City Department of City Planning, 2012) that encouraged the construction of new buildings and retrofitting of existing ones to make them more energy efficient and sustainable, including renovations that encourage UA. Among the provisions in the amendment benefitting CEA were allowing a rooftop greenhouse to be considered a "permitted obstruction," exempting it from a zoning district's FAR so long as it was: a) on a building without residences; b) used primarily for plant cultivation; c) less than 25-feet high; d) mostly transparent; and e) set back from the perimeter wall by six feet if it

[5] Electricity in the Pfizer Building is sub-metered, with each tenant responsible for his/her own use; the owner purchases electricity in bulk and sells it back to tenants without a markup. Heat is included and available 24/7, based on outside temperatures. A/C is included but provided only from 6 a.m. to 6 p.m. Monday to Saturday. No tenants use solar energy. Current tenants do not pay for water, but that may change.

**Table 4**
Price of Representative Greens at Manhattan and Brooklyn Retail Stores.

| BRAND | PRODUCT | RETAIL PRICE | PRICE PER POUND |
|---|---|---|---|
| **GREEN GRAPE PROVISIONS** | | | |
| Square Roots * Only Basil and Chives | 2/3-ounce chives / 1-ounce Genovese basil | $3.19 / $.99 | $77.28 / $15.84 |
| Gotham Greens | Butterhead Lettuce | $5.29 | $18.77 |
| Radicle Farm – CEA Farm, Newark, NJ | Chef's Blend Salad Mix | $5.29 | $15.87 |
| **WHOLE FOODS** | | | |
| Edenworks (NYC) | Microgreens | $4.99 | $39.92 |
| Gotham Greens (NYC) | Lettuce Mixes | $3.99 | $15.96 |
| Organic Girl (Salinas, CA) | Super Greens | $4.49 | $14.37 |
| Whole Foods 365 (CA) | Baby Lettuce | $3.99 | $12.77 |
| Satur Farms (local - Cutchogue, NY) | Mesclun Greens | $3.49 | $11.17 |
| "Live" Greenhouse Grown with Roots on (CA) | Upland Cress | $2.49 | $5.69 |
| Unknown Non-Organic (local - NJ/PA) | Red + Green Loose Leaf | $2.50 | $4.71 |
| **UNION SQUARE FARMERS MARKET** | | | |
| No NYC-based Commercial CEA Farms @ Union Square Farmer's Market | | | |
| Farm Dog Organic CEA-Grown Microgreens (local - Hamden, CT) | Mesclun | $5.00 | $32.00 |
| Keith's Farm (local - Port Jervis, NY) | Organic Red + Green Loose Leaf | $3.00 | $4.17 |
| Hawthorne Valley (local - Ghent, NY) | Red + Green Loose Leaf (Biodynamic) | $3.00 | $3.00 |
| S & S O Produce Farms (local - Goshen, NY) | Non-Organic Red + Green Loose Leaf | $1.50 | $2.09 |
| **TRADER JOE'S** | | | |
| No NYC-based Commercial CEA Farms @ 14$^{th}$ Street Store | | | |
| Trader Joes' Brand (Salinas, CA) | Spring Mix | $1.99 | $6.37 |
| Trader Joes' Brand (Monrovia, CA) | Wild Arugula | $1.99 | $4.55 |

NYC-Based Commercial CEA Farms Shaded.

**Table 5**
Sample Commercial and Manufacturing Building Lease Rates: New York City and Kearny and Newark, New Jersey, September 2018.

| Borough | | Total Square Footage of Sample Space | Lease Rate for Sample Space in USD as per s.f./per year |
|---|---|---|---|
| **Bronx** | Property A | 40,000 | $17.00 |
| | Property B | 40,000 | $15.00 |
| | Property C | 32,000 | $17.00 |
| **Brooklyn** | Property A | 20,000 | $28.00 |
| | Property B | 15,000 | $35.00 |
| | Property C | 16,000 | $21.00 |
| **Manhattan** | Property A | 86,000 | $25.00 |
| | Property B | 44,500 | $75.00 |
| | Property C | 8000 | $ 27.00 |
| **Queens** | Property A | 20,000 | $15.50 |
| | Property B | 30,000 | $22.00 |
| | Property C | 20,000 | $24.00 |
| | | 22,500 | $16.00 |
| **Kearny** | Property A | 29,100 | $8.00 |
| **Newark** | Property A | 62,400 | $5.75 |
| | Property B | 14,000 | $10.71 |
| | Property C | 121,500 | $7.87 |

exceeded the district's building height (New York City Department of City Planning, 2012, n.d.).

#### 4.3.4. Suitable commercial CEA farm locations on public land based on other criteria

New York City's Local Law 48 of 2011 mandated that City-Owned and Leased Properties (COLP) be evaluated by the City agency responsible for their disposition in terms of suitability for agricultural use. This determination must then be shared with the public, so that property suitable for UA can more easily be identified by interested parties and put to productive use. Table 6 summarizes August 2018 COLP data published by the New York City Department of Citywide Administrative Services to highlight available City-owned spaces potentially suitable for UA.

To determine if these sites were appropriate for Commercial CEA Farms specifically, the authors conducted a second analysis using criteria adapted from *Sustainable Urban Agriculture: Confirming Viable Scenarios for Production* (2012) by Kubi Ackerman and her colleagues at Columbia University. These criteria included sites with the following characteristics:

- Buildings built between 1900 and 1970 when codes mandated greater live roof loads (50 lbs./s.f.) to ensure structural stability;
- A rooftop footprint of at least 20,000 square feet to increase economically viability;
- No more than 10-stories high to be logistically feasible;
- Not a NYC Parks or GreenThumb property to allow for commercial use.

Based on these more conservative attributes, two COLP sites, both in residential zoning districts and constituting 135,334 s.f. (3.10 acres), were deemed suitable for Commercial CEA Farms. Rejected sites fell between 1,600 and 15,820 s.f. Although these locations could be outfitted with multiple 300-square-foot shipping container farms (i.e., the Square Roots model), the authors determined the likelihood of their being put to this use at ground-level was low.

#### 4.3.5. Suitable locations on vacant public land or private land or buildings based on other criteria

The website Living Lots (https://livinglotsnyc.org), created by the nonprofit 596 Acres, has conducted its own evaluation of vacant public- and private land potentially suitable for UA. Using their data, the authors identified an additional 151 sites potentially suitable for Commercial CEA Farms totaling 24,865,477 s.f. (571 acres), with the smallest at 20,000 s.f. (.46 acres) and the largest 8,117,815 s.f. (186.36 acres).

Finally, New York City's Primary Land Use Tax Lot Output (PLUTO) data was used to identify private buildings with rooftops — rather than ground-level space — adaptable for Commercial CEA Farms but not identified through COLP or Living Lots.

Table 7 summarizes the final tally of lots and buildings, while Fig. 1 situates these visually within the context of New York City's five boroughs.

In Ackerman's 2012 study, she and her colleagues looked at New York City's capacity for *all forms* of urban agriculture that could be pursued on unused and under-utilized space (e.g., New York City Housing Authority green space, surface parking). She found approximately 5,000 acres of potentially suitable growing space and estimated New York City's total land use needs for self-sufficient growing of non-tropical fruits and vegetables at between 232,215 and 162,139 acres

**Table 6**
Summary of Potentially Suitable Sites for Urban Agriculture in New York City from DCAS COLP Data, August 16, 2018.

| COLP Description – Potentially Suitable Categories | UA Suitable Sites Number / Square Feet / Acres |
|---|---|
| **Potentially** Suitable 1: *Site is available for a 4-year renewable license through the Parks Department's GreenThumb program contingent on program capacity* | 14 sites / 74,136 s.f. / 1.7 acres |
| **Potentially** Suitable 2: *Site is available on an interim basis (1- or 2-year license agreements that are potentially renewable) contingent on program capacity* | 0 sites |
| **Potentially** Suitable 3: *Site has specific instructions or conditions that limit its availability and/or use* | 15 sites / 234,809 s.f. / 5.39 acres |
| **TOTAL** | 29 sites / 308,945 s.f. / 7.09 acres |

**Table 7**
Land and Buildings Potentially Suitable for Commercial CEA Farms Using Ackerman's Sustainable Urban Agriculture Criteria.

| Data Source | # of Sites | Estimated Square Footage / Acreage |
|---|---|---|
| COLP Sites (per Local Law 48 of 2011) | 2 | 135,334 s.f. / 3.10 acres |
| Living Lots | 151 | 24,865,477 s.f. / 571 acres |
| PLUTO | 1,263 | 56,192,450 s.f. / 1290 acres |
| **TOTAL** | **1,416** | **81,193,261 s.f.** / 1864 **acres** |

based, respectively, on the USDA's figures for average annual yield per acre and that of "Bio-Intensive Low" growing methods.

Our analysis, focused narrowly on CEA, suggests an available 1,864 acres of land or roofs suitable for commercial production. Based on the reported average annual yields of the most productive Commercial CEA Farms in New York City, we estimate that 1,864 acres could produce 1.757B lbs. of dark leafy greens per year, far exceeding the 210M lbs. per year estimated by Ackerman as New York City's annual dark leafy green needs. Given a minimum requirement of 20,000 square feet for commercial CEA production – with 40 to 60K s.f. preferred – New York City would need 484 rooftops to meet its dark leafy green demand. According to New York City's Department of Design and Construction (2007), roofs account for 11.5% of the City's total overall surface area or roughly 944.3 billion square feet.

The estimated annual retail value of $1.75B in leafy green production, based on the current New York City retail price for CEA produce (average $34.00 per pound) is approximately $59.7B, while simply meeting the City's estimated 210M lbs. per year in dark leafy green demand equates to $7.1B in potential revenue.

### *4.4. Technology and sustainability*

Six of New York City's Commercial CEA Farms are on roofs and rely primarily on sunlight, with supplemental lighting used as needed; Gotham Greens is representative of this kind of farm. Four others are inside buildings or shipping containers and rely on LED or sole-source light exclusively (e.g., Farm.One, Square Roots). Aquaponic grower Edenworks grows both on a roof using sunlight and indoors using sole-source lighting. Oko Farms uses only sunlight.

Although Commercial CEA Farms were unwilling to disclose in full their back-end technologies, Gotham Greens appears to have the most advanced system. Its operations are controlled by a computer-operated weather station that monitors wind, rain, temperature, humidity, carbon dioxide, and light intensity (Collins, 2011). The data collected is then used to regulate irrigation pumps, greenhouse vents, exhaust fans, and shade curtains. Gotham Greens also maintains a solar array that generates 55 kW of energy, in keeping with the company's mission to operate sustainably with a small carbon and energy footprint. They, like many of New York City's other CEA companies, while not certified organic, use integrated pest management, beneficial insects, and other natural pesticides rather than chemical interventions to control weeds and insects (Gotham Greens, 2017).

### *4.5. Employment*

Six Commercial CEA Farms employ an estimated 150 people, with Gotham Greens the dominant employer (66%). The Commercial CEA sector broadly (i.e., including consulting and technology firms not included in this analysis, employ an additional 50 people). The number of employees at CEA companies other than Gotham Greens ranges from a low of three (Oko Farms) to a high of 19 (Square Roots).

The table below summarizes job titles at Commercial CEA Farms as found through their websites and verified through employees' Linkedin profiles (Table 8).

To estimate the wages of employees at New York City's Commercial CEA Farms, the authors matched CEA job titles to those outlined by the Bureau of Labor Statistics' Standardized Occupational Classification (SOC) system (Table 9). Jobs requiring forestry, agriculture, natural resources, and human science (FANH) or science, technology, engineering, or math (STEM) are highlighted because many Institutional CEA Farms seek to train youth for well-paid jobs in these fields. The wages cited are representative of like-kind workers in the New York-New Jersey metropolitan and nonmetropolitan region.. However the authors cannot verify that the exact same wages are paid to CEA workers in each respective SOC title.

The employment breakdown suggests that New York City's Commercial CEA Farms have created a diverse but limited number of green-sector jobs relative to New York City's total adult workforce. Likewise, while the percentage of FANH jobs appears to be relatively substantive (66%), the majority (83 out of 100) involve entry-level greenhouse workers who likely earn only slightly above minimum wage and require little agricultural knowledge. In contrast, higher-paying FANH and STEM jobs represent a much smaller percentage of job categories (11% each). This suggests that while it is virtuous for Institutional Farms to teach CEA to youth, the likelihood of their finding high-paying jobs in the CEA industry in the NY-NJ Metropolitan region is debatable. Employees may be needed in the regional and national CEA sector, particularly in the emerging cannabis industry (Goecker et al., 2015), but there is no evidence that youth are being prepared for this career path. More research is needed to support the hypothesis that CEA engagement in grade, middle, or high school leads to students pursuing FANH or STEM-related college degrees broadly.

## 5. Discussion

### *5.1. Access to healthy food*

The produce grown by Commercial CEA Farms in New York City contributes minimally to the estimated 40,76,000,000 lbs. of fruits and vegetables consumed annually by New York City residents (Ackerman et al., 2011) or the 19 billion lbs. of food that annually reach the City's 8.4 million residents, over 60 million annual tourists, and hundreds of thousands of commuters each day (New York City Economic Development Council, 2016).

There is also little evidence that CEA produce grown in New York City is addressing food insecurity and access issues that affect nearly three million New Yorkers, especially those in low-income communities

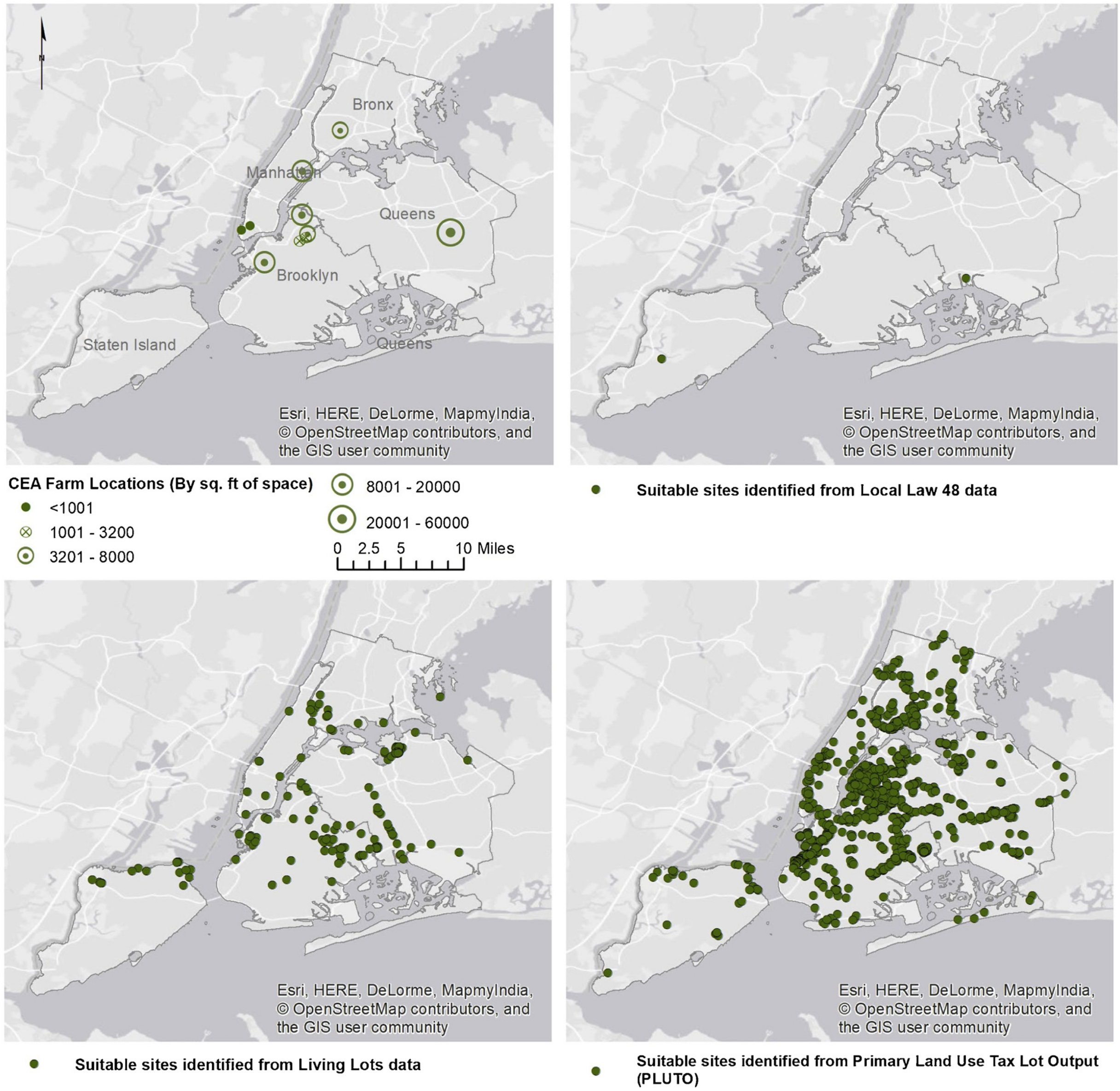


**Fig. 1.** Upper left panel: Map of existing Commercial CEA Farm locations. Upper right panel: Suitable sites identified from COLP, August 16, 2018. Lower left panel: Suitable sites identified from 596 acres' Living Lots. Lower right panel: Suitable sites identified from PLUTO, May 2018.

**Table 8**
Employment at New York City's Commercial CEA Farms.

| Company | Publicly Available Job Titles at Commercial CEA Farms | # of Employees |
|---|---|---|
| Edenworks | CEO + Founder, Chief Design Officer + Co-Founder, Construction manager + Co-founder, CFO + COO, Farm Manager, VP of Agriculture, Senior Agricultural + Mechanical Engineer, Electrical Engineer, Product Manager, Nutrition + Food Safety, Data Scientist, Grower, *Freelance Sustainability Consultant* | 12 |
| Farm.One | CEO, Head of Operations, Head Horticulturist, Sales Manager, Engineering Manager, Shift Manager, Events Manager, *Systems Intern, Engineering Intern* | 7 |
| Gotham Greens | Co-Founder and CEO, Co-Founder and CFO, Chief Agricultural Officer, Assistant Plant Manager, Sales Manager, HR Manager, Director of Marketing + Partnerships, Hydroponic Grower + Greenhouse Manager, Customer Service + Logistics Manager, Food & Beverage Operations Director, Marketing Coordinator, Marketing + Brand Manager, Director of Finance, Data & Inventory Specialist, Marketing, Customer Service Representative, Greenhouse Assistant, Senior Facilities Manager, Greenhouse Assistant, Greenhouse Supervisor, Staff Accountant, Assistant Supervisor (Maintenance), Truck Driver, Pack house lead, Packer, Team Lead, Pack house lead, *Marketing Intern* [*The authors estimate that Gotham Greens employs an additional 73 individuals in unknown roles of which 50 are greenhouse workers] | 100* |
| Oko Farms | Co-founder/Farm Manager, Co-Founder/Aquaponics Designer, Operations Manager | 3 |
| Square Roots | Brand Manager, Operations Manager, Head of Programming + Recruitment, Farm Operations, Finance Manager, Farmer/Entrepreneur (6), Research and Development, Head Farmer, Farm Manager, CEO, Head of Community + Communications, Research + Development Engineer, Strategic Project Manager, Full Stack Developer, *Mentor (4)* | 19 |
| Sky Vegetables | Founders (3), CEO, Head Grower, Assistant Grower, Operations Director, Laborers/Farmworkers (2), Sales/Distribution Manager | 10 |
| Total | | 151 |

Jobs in italics represent positions of a consulting, mentoring, or short-term nature that may be unpaid or similar, such as internships.

**Table 9**
Job Roles at Commercial CEA Farms in New York City Matched to 2017 Metropolitan and Nonmetropolitan Area Occupational Employment and Wage Estimates.

| Standard Occupational Classification (SOC) Title | Role(s) at Commercial CEA Farm | # of People Employed in Role (s) | Mean Hourly Wage for Commensurate SOC Title |
|---|---|---|---|
| Farmworkers and Laborers, Crop, Nursery, and Greenhouse - FANH | Grower, Assistant Grower, Laborers/Farmworkers (2), Greenhouse Assistant, Greenhouse Assistant, Pack house lead, Packer, Team Lead, Pack house lead, Farmworker/laborers at Gotham Greens (73) | 83 | $16.24 |
| Farmers, Ranchers, and Other Agricultural Managers – FANH | Farm Manager, Head Grower, Farm Operations, Farmer/Entrepreneur (6), Head Farmer, Farm Manager, Assistant Plant Manager, Hydroponic Grower + Greenhouse Manager, Greenhouse Supervisor, Shift Manager | 14 | $37.12 |
| Chief Executives **50% of CEOs report STEM degrees* - STEM | CEO + Founder, Chief Design Officer + Co-Founder, Construction Manager + Co-Founder, CFO + COO, CEO, Founders (3), CEO, CEO, Co-Founder/Farm Manager, Co-Founder and CEO, Co-Founder and CFO | 13 | $121.67 |
| Marketing Manager | Product Manager, Brand Manager, Head of Community + Communications, Director of Marketing + Partnerships, Marketing Coordinator, Marketing + Brand Manager, Marketing | 7 | $93.94 |
| General and Operations Managers | Head of Operations, Engineering Manager, Operations Director, Operations Manager, Strategic Project Manager, Operations Manager, Senior Facilities Manager | 7 | $82.38 |
| Sales Manager | Sales Manager, Sales/Distribution Manager, Sales Manager, Events Manager | 4 | $96.31 |
| Computer and Information Research Scientists - STEM | Data Scientist, Research and Development, Research + Development Engineer | 3 | $65.50 |
| Soil and Plant Scientists - STEM | VP of Agriculture, Head Horticulturist, Chief Agricultural Officer | 3 | $32.97 |
| Financial Manager | Finance Manager, Director of Finance | 2 | $102.01 |
| Human Resources Manager | Head of Programming + Recruitment, HR Manager | 2 | $72.38 |
| Sales Representatives, Wholesale and Manufacturing, Technical and Scientific Products | Customer Service + Logistics Manager, Data & Inventory Specialist | 2 | $51.24 |
| First-Line Supervisors of Landscaping, Lawn Service, and Groundskeeping Workers - FANH | Assistant Supervisor (Maintenance), Shift Manager | 2 | $28.92 |
| Software Developer, Applications - STEM | Full Stack Developer | 1 | $56.55 |
| Electrical Engineer - STEM | Electrical Engineer | 1 | $51.97 |
| Mechanical Engineers - STEM | Senior Agricultural + Mechanical Engineer | 1 | $45.95 |
| Commercial and Industrial Designers - STEM | Co-Founder/Aquaponics Designer | 1 | $34.14 |
| Agricultural and Food Science Technicians – FANH + STEM | Nutrition + Food Safety | 1 | $22.95 |
| Bookkeeping, Accounting, and Auditing Clerks | Staff Accountant | 1 | $22.51 |
| First-Line Supervisors of Food Preparation and Serving Workers | Food + Beverage Operations Director | 1 | $20.56 |
| Customer Service Representatives | Customer Service Representative | 1 | $20.15 |
| Light Truck or Delivery Service Drivers | Truck Driver | 1 | $18.59 |
| **Total Jobs** | | 151 | |
| **Total FANH Jobs with Greenhouse Workers** | | 100 | |
| **Total FANH Jobs without Greenhouse Workers** | | 17 | |
| **Total STEM Jobs** | | 17.5 | |
| **Percent of FANH Jobs with Greenhouse Workers** | | 66% | |
| **Percent of FANH Jobs without Greenhouse Workers** | | 11% | |
| **Percent of STEM Jobs** | | 11% | |

New York-Jersey City-White Plains, NY-NJ Metropolitan Division.

(NYC Department of City Planning, 2008). Whether this is because locally grown CEA produce is too expensive, not available in enough neighborhood grocery stores, or for reasons not yet identified, requires further study.

The produce grown in Commercial CEA Farms in New York City also tends to be of only moderate nutritional value (e.g., lettuce, basil) and therefore contributes only minimally to the goal of elected officials supportive of UA to increase New Yorkers' consumption of healthy fruits and vegetables, especially those at-risk of obesity, diabetes, and related chronic health diseases.

Anecdotal reports from Institutional and Community CEA Farms suggest they are more successful at providing a wider range of produce to low-income consumers (Amu, 2017), which is why we posit that Institutional and Community CEA Farms offer the greatest potential for expanding year-round access to healthy food in these communities. Further study of production and consumption in these settings is needed to support this hypothesis.

### 5.2. Location and land use requirements of CEA

In mapping the location of New York City's Commercial CEA Farms, we found the majority in and near low-income communities where industrial space can still be found affordably, due to the exodus of traditional manufacturing businesses. These under-utilized spaces have also allowed CEA companies to negotiate favorable lease rates with sympathetic owners. And although even cheaper spaces exist in other cities in the Tri-state region, many Commercial CEA Farms still want a New York City address because of the marketing and logistical advantage of being able to service high-end customers and restaurateurs within hours rather than days.

In a parallel effort, New York City's elected officials have passed legislation to stimulate the use of public land and buildings for UA production generally, though not CEA specifically. These policy initiatives include Local Law 48, which helps the public find City-owned and leased (COLP) space to farm; Local Law 50, which encourages City agencies to purchase produce from New York State vendors; and the Zone Green Text Amendment, which relaxes zoning to allow for higher FAR for rooftop greenhouses. Such policies, however, have had little impact on the sector's growth, in part because the City has still failed to adopt a comprehensive agricultural plan to streamline the process through which Commercial CEA Farms start and expand. Funding and technical assistance to allow Community and Institutional Farms to grow at production scale for the communities they serve is also urgently needed, according to some anecdotal reports from nonprofit producers (correspondence with Elise Long, Gowanus Sky Farm, January, 2019).

While Local Law 48 makes it easier for the public to find properties suitable for growing, the database has no relationship to the map of vacant public and private land created by 596 Acres nor the niche sites (e.g., NYCHA green spaces) identified in *The Potential for Urban Agriculture in New York City* report by Ackerman, et al. (2011) at The Urban Design Lab. As such, finding land, buildings, or rooftops suitable for commercial CEA production remains unwieldy at best, with the actual acreage – somewhere between the 1,864 acres we identified and the 5,000 acres noted by Ackerman – anyone's guess. This points to the need for more dialogue between CEA entrepreneurs and politicians to ensure alignment around needs and goals and improved documentation of land and buildings, based on factors relevant to CEA, such as hours of sunlight, infrastructure (e.g. elevators, roof load), and opportunities for alternative utility schemes (i.e., capturing building waste heat).

Although the earlier identified 1,864 acres for CEA sounds promising in relation to the City's identified produce needs, continued and steady increase in new CEA businesses like the one to date seems unlikely. This is because, despite the success of a small number of well-capitalized and environmentally innovative early entrants, Round II CEA companies will face increasing pressure from peri-urban Commercial CEA Farms (i.e., Bowery Farms in Kearny) that pay lower lease rates, oversee more real estate, and have received significantly more venture capital, tax incentive, and grant funding that bolster their ability to operate at greater economies of scale (Friedman, 2014). Additionally, while early entrants such as Gotham Greens benefitted from leveraging New York State Energy Research and Development Authority (NYSERDA) funds to innovate their systems and reduce energy costs (Puri and Caplow, 2009), newer CEA companies such as Farm.One cannot, given their reliance on less sustainable sole-source electric and LED lighting. As an example, when Farm.One recently expanded to a second location, it did so by soliciting individual, private investors. Finally, future companies will face more hurdles finding affordable space, due to gentrification pressures. Thus, while vacant roofs exist in New York City, it is unclear for how long they will remain affordable if challenged by luxury residential uses.

### 5.3. Environmental sustainability

Commercial CEA Farms on roofs, which rely on the sun as their primary light source, perform well according to measurements of environmental sustainability, while those that use LEDs are not as energy efficient, even when compared to conventional, soil-based farms growing similar items (Barbosa et al., 2015). Community and Institutional Farms that use less capital-intensive lighting (i.e., high-pressure sodium) have a lower carbon footprint, but questions remain about even their environmental benefits as compared to simpler growing methods. For example, while soil-based rooftop farms such as Brooklyn Grange mitigate urban heat islands and reduce stormwater runoff, the same cannot be said of rooftop CEA greenhouses or indoor farms, even ones that use solar arrays. Likewise, while CEA farms use less water, pesticide, and fertilizer than soil-based farms in places such as California, there is little evidence that siting Commercial CEA Farms in New York City is necessary, especially when rural and peri-urban ones can accomplish the same more efficiently. Furthermore, suggesting that locally grown CEA is preferable because it reduces greenhouse gas emissions from long-distance transport is highly dependent on underlying assumptions (e.g. diesel versus pick-up trucks) (Theurl et al., 2014; Albright and de Villiers, 2008; Purcell and Brown, 2005) and not always supported in reality.

As Albright and de Villiers (2008) note in their extensive study comparing energy and $CO_2$ emissions for fresh produce imported into New York State compared to the same grown locally, CEA makes most sense in regions with favorable climates where less supplemental heat and light is needed. Beyond that, the environmental advantages begin to shrink.

In the end, whether more of New York City's vacant roofs and/or land are used for Commercial CEA Farms will likely be driven primarily by whether market demand for the "fresh" and "local" produce segment grows (Bowman, 2017) or, more radically, whether New York City redefines "local purchasing" so that public institutions (i.e., schools, prisons, hospitals, and senior centers) are required to buy more produce from New York City-based Commercial CEA Farms rather than farms across New York State.

### 5.4. Employment

Commercial CEA Farms in New York City provide a small number of green-sector jobs, but this is overshadowed by the dominance of a single employer (Gotham Greens). Likewise, while Gotham Greens generates a noteworthy number of entry-level farming positions (i.e., packing and handling), their estimated pay rate is below what has been deemed a living wage for a city as expensive as New York (Glasmeier and Massachusetts Institute of Technology, 2018). More concerning, as evidenced by a recent automation grant Gotham Greens received from NYSERDA (Governor's Press Office, 2016), is the possibility of even these jobs being eliminated in order to lower costs and increase efficiency. In contrast, the number of positions the local industry has created for higher-level FANH and STEM positions is small, a concern given the large number of youth being trained at Institutional and Community Farms purportedly for these jobs. While one hopes that CEA engagement increases youth interest in FANH and STEM careers broadly, this has not yet been confirmed.

In contrast, retirement trends in the *national* greenhouse, horticulture, and farming industries do suggest a need for new workers – and a dearth of graduates to fill them (Goecker et al., 2015). More promising, but less understood, is whether small pockets of future CEA jobs might be created in New York City from new residential developments incorporating rooftop or indoor CEA as an amenity (Yemi Amu, 2017). The legalization of medical and recreational marijuana, which will create job opportunities for farm managers with greenhouse experience, may be another avenue for employment. For now, Community and Institutional Farms may offer the most diverse range of jobs, despite their small size, and in teaching and direct service positions less likely to be replaced by automation.

### 5.5. Recommendations

Given that Commercial CEA Farms are unlikely to replace a significant portion of a city's produce now sourced from California, Arizona, or Florida, local governments considering whether to support CEA projects through funding or policy mechanisms should first educate themselves about the technology these farms use, whether crops are of high nutritional value, if prices are affordable to low- and middle-income consumers, and how many living-wage jobs will be created.

Cities should also recognize that, due to high startup costs, Commercial CEA Farms will likely focus primarily on recouping their investment by growing high-value crops for wealthy consumers (e.g., lettuce and basil) rather than nutritional produce priced for low-income residents (e.g., spinach and kale). Produce grown by Community and

Institutional Farms are better positioned to get healthy food into the hands of those who need it, but require more financial and technical assaistance to ensure their longevity. Depending on their scale, some Commercial CEA Farms may also add revenue to a city's tax base.

To the extent that cities must decide which types of CEA farms to support, those on roofs, in glass buildings/greenhouses, or on the ground that rely on solar rather than single-source lighting should take precedence. Funding for school-based projects should be done following a cost-benefit analysis of the educational opportunities afforded by capital-intensive rooftop greenhouses as compared to simpler and cheaper soil-based farms, even if the latter cannot be used year-round, to ensure the outlay is warranted.

CEA farms located in cities with high land values are best sited on roofs, so as to free street-level space for residential or commercial purposes. However, in cities where land values are low, greenhouse production at ground-level could be a viable alternative to extend growing seasons. Supplemental greenhouse lighting is still necessary in cities with fewer days of sunlight, but placing these farms outdoors on the ground will at least better connect them to local communities.[6] More research is needed to determine if vertical farms, such as those operated by Aerofarms in Camden and Newark, which re-purpose derelict manufacturing buildings and are made possible through generous tax incentives, are justified in terms of the public benefits they offer.

In terms of profitability, rural and peri-urban CEA businesses are likely more viable than those in city centers due to lower operational costs and greater economies of scale. As such, cities may wish to consider whether offering companies large tracts of land or vacant buildings at town edges is more deserving of public funds. Gotham Greens' recently announced plans to open a 100,000 square-foot farm in Baltimore inside a 3,100-acre global logistics center that affords "access to deepwater berths, railroads, highways and storage space," is indicative of the larger footprint these companies need to be competitive (Vegetable Growers News, 2018). For planners encountering businesses that demand tax incentives or other benefits as a condition of doing business, the right response may be to require that a meaningful percentage of hires include unemployed and underemployed individuals in the identified communities, that businesses guarantee living wages for entry-level workers, and that unsold greens be donated to food banks or shelters.

## 6. Conclusions

While Commercial CEA Farms are predicted to grow in economic and physical prominence in cities worldwide (Wood, 2017), planners and policymakers need to look closely at what the vertical, rooftop, and indoor agricultural revolution means for their specific context. Urban agriculture has a substantial track record of positive environmental and social benefits, however CEA in its present form does not fit neatly into these earlier incarnations and its additive value to the urban landscape may be less visionary than the popular press would have policymakers and the public believe. That CEA has grown in New York City over the last seven years is the result of factors specific to that metropolis, including a large population with segments that are well to-do, easy access to investors, and built infrastructure such as large manufacturing buildings in need of new tenancy. Significantly, the substantial base of CEA nonprofits and entrepreneurs thas have advocated for and received public support has helped the sector advance, if modestly, in ways it may not have been able to do otherwise.

Whether to publicly incentivize and support CEA in other cities with a different built environment, infrastructure, and regional economy is an assessment planners and policymakers should consider carefully in consultation with university horticultural departments and cooperative extension offices that can serve as important thought partners. This article also outlines methods of suitability analysis that planners can use to evaluate available buildings and land for their capacity to support the requirements the CEA sector requires.

Beyond CEA's economic viability for any individual entrepreneur is determining how a Commercial, Institutional, or Community CEA Farm contributes to the health and well-being of food-insecure and economically challenged communities. Based on data gathered for this study, CEA appears most beneficial when carried out by Institutional and Community Farms that have demonstrated efficacy with soil-based growing and now want to expand to year-round production focused on nutrient-rich produce. For CEA to contribute to the sustainability of cities will require continual striving for good governance in reducing environmental and energy impacts of production and ensuring that public sector policies remain focused on supporting populations most in need. CEA may be touted as an exciting set of technologies with great promise, but it is unlikely to offer a panacea for social problems or an unqualified urban agricultural revolution.

[6] One example is a prototype Community CEA Farm (Grow-A-Lot) developed by a multi-stakeholder consortium for the Clinton Foundation to test the feasibility of small-scale greenhouse growing on vacant land that has not yet been implemented.


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None.

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