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Comparing the Costs and Environmental Impacts of Conventional and Controlled Environment Agriculture Leaf Lettuce Supply Chains[1]

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The Potential Benefits of Urban CEA Systems

The production of vegetables and fruits using controlled environment agriculture (CEA) in or near urban areas has received a good deal of media attention in recent years—and has also attracted a considerable sum of investment dollars. CEA operations (greenhouses, vertical farms and plant factories) enable year-round intensive production of vegetables by creating controlled environments that supply a balance of light, heat, CO_2 and water to optimize plant growth. The potential benefits of metro CEA include lower transportation costs, reduced product waste, and job creation but should also be weighed against potentially higher land, labor, water, and energy costs and compared with field-based production. CEA as an urban food production method, contributor to local food systems, and municipal investment strategy is yet to be fully assessed. Examples exist of commercially viable soil-based metro farms and apparently-successful metro-based greenhouse operations, but the financial feasibility of individual metro-based CEA enterprises (particularly plant factories), has not been systematically addressed by previous research. In a broader sense, the extent to which a city's demand for vegetables can be produced within its boundaries using CEA systems (that is, its scalability) is unanswered. To understand the potential of metro CEA, assessment of its likely economic, environmental and social outcomes is relevant. As a starting point, a supply-chain approach can be used compare the economic and environmental outcomes for conventional field-based and metro-based CEA production.

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[1] This is a short summary of Nicholson, C.F., K. Harbick, N. M. Mattson and M. I. Gómez. 2019. An Economic and Environmental Comparison of Conventional and Controlled Environment Agriculture (CEA) Supply Chains for Leaf Lettuce to US Cities, in E. Aktas and Michael. Bourlakis (eds.) *Food Supply Chains in Cities: Modern Tools for Circularity and Sustainability*. Palgrave, forthcoming May 2019.

Study Objectives and Methods

With financial support from the National Science Foundation (NSF[2]), our project compared the landed costs and selected environmental outcomes of conventional field-based and representative CEA supply chains for leaf lettuce to major wholesale markets in two US metropolitan areas (New York and Chicago). We used existing information on production and transportation costs to assess the total landed cost of 1 kg of lettuce from one cropping cycle of field-based production in the Salinas Valley of California, for a 0.40 ha CEA greenhouse and a similar-size CEA plant factory with year-round production at locations within the two metropolitan areas. Simulation modeling using American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) heat balance methods applied in the analysis of commercial buildings was used to assess energy use in the two CEA production systems. We quantified energy in natural gas for heating, electricity for CEA lighting and cooling and diesel fuel for transportation. Energy use was converted to CO_2 equivalents to assess Global Warming Potential (GWP) of the three systems. We also quantified water use.

Findings

Our analysis indicates that the total landed costs for CEA supply chains to provide lettuce to the Chicago and New York City metro areas are markedly higher than those with field-based production in California (Table 1). Lettuce produced and delivered from the greenhouse (GH) has a landed cost 158% to 163% higher than that of field lettuce from California, despite much higher transportation costs for the field-produced lettuce. Lettuce produced in a plant factory (PF) has a landed cost 153% to 157% higher than field produced lettuce. The differences between CEA supply chains and field production are smaller in the Chicago market (despite lower transportation costs from California) due to lower land values and lower rates per kWh for electricity.

In addition to the overall cost differences, the structure of costs for these supply chains are quite different. Field production costs are quite low and packaging (including harvesting) and shipment costs account for 67% to 70% of landed costs, whereas they comprise less than 12% of landed cost for GH and PF operations. For the CEA GH, labor and management, energy and structures account for more than 80% of landed costs, and transportation costs are minimal. Labor costs are notably higher for CEA supply chains, in part due to additional labor required for production, but also due to the administrative staff required for management and marketing that are typically lower and spread over much larger volumes for field-based operations. These results suggest that greater productivity of CEA GH labor and utilities—as well as locations that optimize trade-offs between land and transportation costs—will be necessary for costs to become more comparable between field and CEA lettuce supply chains.

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The environmental impacts of CEA lettuce supply chains other than water use often are larger than for field-based production (Table 1). CEA GH and PF have larger energy use and greenhouse gas emissions than field production. GH supply chains have markedly lower energy demand and GWP than PF supply chains in both studied locations, primarily due to the energy required for lighting and cooling. GH supply chains delivering to New York have estimated GWP only 3% larger than field-based supply chains, but the difference is much larger in Chicago due to higher energy use in production and longer transportation distances.

Summary

Our analysis of three supply chains to provide lettuce to two US metropolitan areas indicates that at present the lowest landed-cost option is a supply chain based on field production rather than GH or PF. Because the landed cost differences are larger (nearly double even in the "best case" scenario) this suggests that modifications to reduce the costs of CEA systems to the level of field production will present challenges. In addition, the studied configurations and locations of CEA supply chains operating within metropolitan urban areas may have higher energy use and GWP, although all the CEA operations analyzed used less water per kg of lettuce than field production. Although the configuration of a CEA supply chain will affect its environmental impacts, it is inappropriate to claim that "local" CEA supply chains for lettuce are broadly more environmentally friendly than field-based production, even when field lettuce is shipped long distances. Additional analyses of alternative scales, locations and CEA configurations as well as seasonal field-based production closer to metropolitan areas could provide further insights to supply chain actors. We note that urban CEA businesses can be profitable, despite higher costs, for production of leafy greens (such as micro-greens) that command a higher price for their characteristics, quality or freshness. Another component of our research project examines approaches to make CEA systems more energy efficient, which may ultimately lower environmental impacts and improve cost competitiveness.

Table 1. Landed Costs and Environmental Impacts for the Delivery of 1 Kg Lettuce to Wholesale Produce Markets in New York City and Chicago from Field-Based Production, a CEA Greenhouse and a CEA Plant Factory

	New York City Wholesale Market, Hunt's Point			Chicago International Produce Market		
	Field	GH	PF	Field	GH	PF
Landed Costs, $/kg	3.04	8.09	7.82	2.72	7.03	6.89
CED (MJ / kg lettuce)	18.52	23.83	42.52	14.24	29.19	44.74
GWP (kg CO2-eq / kg lettuce)	1.29	1.33	2.72	0.99	2.07	4.62
WU (liters / kg lettuce)	201.43	20.86	20.86	201.43	20.86	20.86

Note: *Field* indicates field-based production in Salinas Valley, California, *GH* indicates a CEA greenhouse in the same metropolitan area as the wholesale market, and *PF* indicates a CEA Plant Factory in the same metropolitan area as the wholesale market. *CED* is Cumulative Energy Demand, *GWP* is Global Warming Potential in kg of CO_2 equivalent and *WU* is water use.

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