Comparing resource use for tomato production on urban, peri-urban and rural farms in Georgia, USA

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Abstract

The large-scale urbanization of the global population has created convoluted and often inefficient food supply chains, where food is brought from rural areas across the world into cities. These food supply chains are vulnerable to shocks and stresses, as seen with the COVID-19 pandemic. These stresses are only expected to increase with the effects of climate change. Farmers are being pressured to grow more food for a growing global population whilst conserving natural resources. Thus, there has been increased effort to promote local agriculture to build food self-sufficiency in cities. However, the sustainability of different scales of local agriculture, such as urban versus regional production, is unclear. This study evaluates different types of local food production in Georgia, USA by examining yields, resource use, material use, and transport distances to final sale for tomato production. Organically managed urban (n=1), peri-urban (n=3), and rural farms (n=3), as well as conventional, rural farms (n=2), were compared to understand how farm scale, distance of the farm to the consumer, and management practices influence resource and material use. Yields varied between and within the organic farm categories, which had both the highest yields (>7 kg m^{-2} on the urban and one peri-urban farm) and the lowest yields (<2 kg>m^{-2} on other peri-urban farms). The rural, conventional farm category had the highest average yields (6 kg m^{-2}) after the urban farm. Differences in yields between organic farms appears to be linked to the amount of available labor and farmer experience. The conventional, rural farms had the lowest average energy, total Nitrogen, and plastic use per kg sellable crop, but the highest water use, packaging use, and average transport distances. The generally high resource and material use efficiency on conventional farms can be attributed to high production output and economies of scale achieved on these larger commercial farms. Some urban and peri-urban farms also showed high resource use efficiencies through the use of innovative waste cycling and material reuse strategies. It should be noted that higher resource and material use does not necessarily translate to higher environmental impacts, which will depend on the types of materials used. Thus, this study highlights an opportunity to promote the commercialization of peri-urban food production to shorten food supply chains, access labor from urban areas, and allow for waste cycling between farms and cities whilst embracing the efficiencies of larger scale production.

Keywords

urban agriculture, local agriculture, local food, organic, tomato, horticulture

Disciplines

Agriculture

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INTRODUCTION

Dwindling natural resources, such as freshwater supply, along with widespread agricultural soil degradation threaten the ability to provide a sufficient supply of food to a growing global population whilst also protecting the environment (Bai *et al.*, 2008; Rosegrant, Ringler and Zhu, 2009; FAO and ITPS, 2015; FAO, 2018). This is concurrent with a dramatic urbanization of the population, with the majority of people in the world now living in urban areas (UNDP, 2018). Bringing food from rural areas, either regionally or internationally, into cities has created complex and often inefficient supply chains which are potentially vulnerable to shocks.

The COVID-19 pandemic has proven exemplary in exposing the fragility of the global food system, with food system shocks and stresses expected to only increase with the economic fallout from the pandemic and from the environmental, political, and public health crises associated with climate change (Mbow *et al.*, 2019; Deaton and Deaton, 2020; Garnett, Doherty and Heron, 2020; Hickey and Unwin, 2020). During the pandemic, national food supply chains have been unable to cope with the vast increases in supermarket demand and the simultaneous loss of restaurant, school, and hotel markets, thus resulting in empty supermarket shelves and a massive waste of perishable foods such as milk, eggs, and produce (Church, 2020; Garnett, Doherty and Heron, 2020; Hobbs, 2020; Power *et al.*, 2020; Yaffe-Bellany and Corkery, 2020). On a global scale, perishable goods have been especially vulnerable to shipping delays from increased food safety and trade restrictions (Hobbs, 2020; Larue, 2020). The horticulture sector was significantly impacted due to its labor-intensive nature, as social distancing measures influenced the efficiency of certain operations such as harvesting, and new international travel and seasonal worker restrictions led to a loss in seasonal migrant labor as well as a rise in labor costs (Deaton and Deaton, 2020; Laborde *et al.*, 2020; Larue, 2020; Pelham, 2020; Wentworth, 2020). Consequently, there is a need to diversify trade channels and food suppliers to build food system resiliency, with many researchers and farmer-based organizations also advocating for increased regional food production and local food self-sufficiency as a way to ensure a consistent, accessible, and affordable food supply in the future (Fontan Sers and Mughal, 2020; Garnett, Doherty and Heron, 2020; Hickey and Unwin, 2020; Lal, 2020; Soil Association, 2020; Wentworth, 2020).

However, the sustainability of different types of local food production is still unclear. Traditional large-scale, conventional rural farms may achieve environmental benefits from economies of scale, but this can be negated through the use of environmentally harmful fertilizers and pesticides as well as the fact that food must travel farther distances to reach the majority of consumers in cities (Rothwell *et al.*, 2016; Kriewald *et al.*, 2019). Organic agriculture is usually seen as the option for more sustainable production, but the environmental benefits attained by using more ecologically conscious inputs can be reduced by the lower yields often seen in comparison to conventional farms (De Backer *et al.*, 2009; Cooper, Butler and Leifert, 2011; Foteinis and Chatzisymeon, 2016).

Urban agriculture (UA) and peri-urban agriculture (PUA) have long been espoused as ways to increase food self-sufficiency in cities, shorten food supply chains, and increase food access (Despommier, 2011; Ackerman, 2012; McClintock, Cooper and Khandeshi, 2013; Mok *et al.*, 2014), and have received even more attention recently in light of the COVID-19 pandemic (Lal, 2020; Pulighe and Lupia, 2020). However, urban soils can be variable and of poor quality due to compaction, degradation, and possible heavy metal contamination, which may influence yield variability and produce quality (Mitchell *et al.*, 2014; Beniston, Lal and Mercer, 2016; Lal, 2020). Urban farmers may also lack access to wholesale agricultural supplies and educational opportunities, such as relevant extension services. All together, these challenges may create higher resource use on urban and peri-urban farms (McDougall, Kristiansen and Rader, 2018), possibly negating the environmental benefits from lower transport distances. However, urban farms can create additional benefits within cities by contributing to waste cycling (e.g., from composting), as well as ecosystem service provisioning (Pearson, Pearson and Pearson, 2010; Lin, Philpott and Jha, 2015; Aerts, Dewaelheyns and Achten, 2016; Clinton *et al.*, 2018; Wilhelm and Smith, 2018; Lal, 2020).

Thus, questions remain on the best combination of metrics to evaluate the sustainability of food items, as the simple concept of 'food miles' (i.e., transport distances) does not provide sufficient detail to truly compare the sustainability of different food options (Weber and Matthews, 2008; Edwards-Jones, 2010). Environmental impacts from food items will depend greatly on the specific crops in question, the local climate and soil type, the production system used, and farmers' management practices and experience (Defra, 2008; Kulak, Graves and Chatterton, 2013; Webb *et al.*, 2013; Rothwell *et al.*, 2016). In order to compare different modes of local food production, it is thus necessary to evaluate the lifecycle of specific crops within a local context to understand the major sources of environmental impacts and options for sustainability improvements. Localised horticulture production in particular has been identified as the main opportunity for UA and PUA due to the high-value, labor-intensive, and perishable nature of produce (MacRae *et al.*, 2010; Grewal and Grewal, 2012; Eigenbrod and Gruda, 2015; Saha and Eckelman, 2017; Edmondson *et al.*, 2020; Kennard and Bamford, 2020).

This study aims to compare resource and material use throughout the lifecycle of tomato production for conventionally and organically managed urban, peri-urban, and rural farms in Georgia, USA. Tomatoes were chosen as the crop of interest as they were the highest produced vegetable by weight and the second highest by cultivated area in the U.S. in 2019 (USDA, 2020). This study provides insight to how differences in farm scale, distance of the farm to the consumer, and management practices influence resource and material use on farms in the southeast U.S. By considering trade-offs between production and resource use in a local context, strategies can be identified which build local food self-sufficiency whilst considering an area's own unique environmental challenges.

MATERIALS AND METHODS

Scope

This study compares the resources (energy, fuel, total Nitrogen, and water) and materials (plastic and packaging) used for tomato production during the nursery / germination, cultivation, and processing stages on organically managed urban, peri-urban, and rural farms, as well as conventionally managed rural farms, in Georgia, USA. The average transport distances that tomatoes travel from the farm to the final point of sale is also included.

Recruitment

Fruit and vegetable farmers were contacted directly for recruitment via email, phone call, or in person at conferences / meetings from September to December 2019. Contact information was obtained online through a variety of farmers' market listings, wholesale / direct sale market websites, farm directories, and farmer organizations, including: the Georgia Grown farmer directory (https://www.georgiagrown.com/), Georgia Fruit & Vegetable Growers Association (https://www.gfvga.org/), the Atlanta Farmers Coalition (https://www.youngfarmers.org/chapter/ga-atlanta-farmers-coalition/), Georgia Organics (https://www.georgiaorganics.org/), and Certified Naturally Grown (https://www.cngfarming.org/). The study was also advertised by various farmer associations, including county cooperative extension offices (https://extension.uga.edu/county-offices.html) and the Georgia Fruit and Vegetable Growers Association. Farms were screened based on the criteria of 1) being a for-profit, commercial farm and 2) selling produce into urbanized areas. During the recruitment period, over 350 fruit and vegetable farmers in Georgia were screened and contacted.

After an initial pool of interested farmers were recruited, preliminary interviews and site visits were conducted to learn more about the main crops produced on each farm, the farmer's management practices, and their markets for sale. Tomatoes were then selected as one of the commonly produced crops among interested farmers to be analysed for this research project.

Farm classification

After the initial screening and crop selection, nine tomato-producing farms in Georgia took part in the study (Figure 1). These farms were classified based on 1) geographical location in reference to urban areas and 2) management practices.

Farms were defined as 'urban', 'peri-urban', and 'rural' based on urban definitions provided by the U.S. Census Bureau. The 2010 U.S. Census defines urban areas based on census tracts or blocks which meet minimum population density requirements; these include urbanized areas, which contain 50,000 or more people, and urban clusters, which contain at least 2,500 people and less than 50,000 people (U.S. Census Bureau, 2010). Urbanized areas within this context include both 'urban' and 'peri-urban' classifications for this study, whilst any area not included within the urbanized areas or urban clusters was defined as rural as per the U.S. Census Bureau. 'Urban' and 'peri-urban' farms were further differentiated within urbanized areas based on the administrative boundaries of Atlanta, the capital city in the state of Georgia and the area with the highest population densities in the state. 'Urban' farms were classified as those within the Atlanta city administrative boundary, while 'peri-urban' farms were classified as those outside of the Atlanta administrative boundary but still within the urbanized area as defined by the 2010 U.S. Census. These peri-urban farms were all located within the 10-county Atlanta metropolitan area (Atlanta Regional Commission, 2020).

Farms were further classified as 'organic' and 'conventional.' Farms classified in this study as 'organic' included: farms which held organic certification from the U.S. Department of Agriculture (USDA, 2019), were certified naturally grown (Certified Naturally Grown, 2015), were Demeter certified biodynamic or organic (Demeter Association, 2019), and small farms which followed organic guidelines and self-identified as organic, but were not certified due to lack of funds. Farms were classified as 'conventional' if they did not meet U.S. organic guidelines and did not have any certifications included in the organic classification.

Based on these classifications, the following farms were included in this study: one organic, urban farm (U-1); three organic, peri-urban farms (PU-1 to PU-3); three rural, organic farms (RO-1 to RO-3); and two rural, conventional farms (RC-1 and RC-2). Summary averages presented in this paper are based on these farm classification categories.

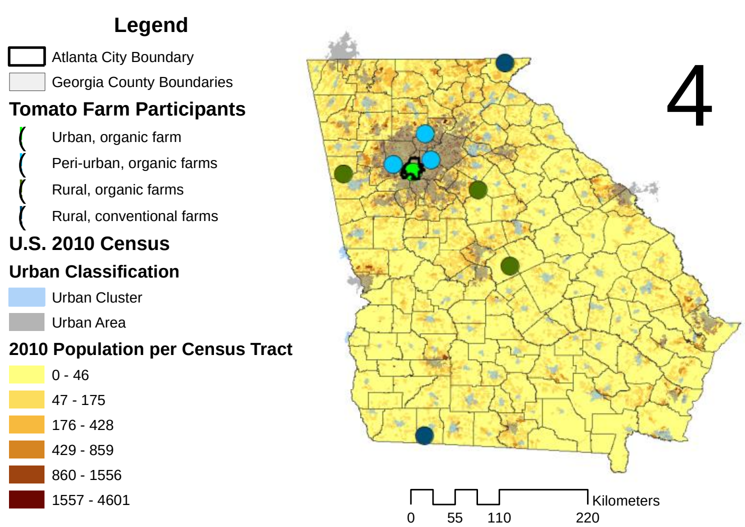

Figure 1. Map of participating tomato farms in Georgia, USA.

Farm interviews

Participating farmers were then provided questionnaires via email that asked about their tomato production in 2019. The questionnaires included detailed questions on yields and waste amounts, resource use, and energy use throughout various stages of the crop's lifecycle, including the nursery, cultivation, processing, and transport / distribution stages. Thus, resource and material use were tracked for tomatoes from when the seed was planted to when the crop arrived at the final sale location. Farmers provided information on specific amounts of the following materials and resources used: water, land, energy, fuel, germination materials (e.g., germination trays, potting media, seeds), infrastructure (e.g., polytunnels, greenhouses, sheds), cultivation equipment and materials (e.g., machinery, irrigation, trellising systems, plastic or natural mulches, harvesting equipment), fertilizers, pesticides, and packaging materials. In addition, farmers were asked to specify periods of use and lifetimes for each resource and material used where appropriate, and this information was then used for allocation purposes. After reviewing the returned questionnaires, site visits or phone calls were made to ask follow-up questions and measure any specific items on the farm. Various nurseries and agricultural suppliers used by the farms were also contacted to provide detailed information on specific practices and products.

Calculated metrics

Using information provided from the farmers' questionnaires, a summary of farm characteristics, production outputs, and resource / material use metrics were calculated. This information will ultimately be used to perform lifecycle assessments to identify environmental impacts over the crop lifecycles on each farm. However, this paper presents preliminary results related to average resource and material use across nine tomato farms in Georgia.

Yields presented in this paper include 1) harvest yield, the amount of crop harvested from the field per unit area and 2) sellable yield, the amount of sellable crop produced per unit area. The amount of harvested crop is calculated by the total amount of crop produced, minus the harvest waste (crops discarded during harvest). Sellable crop is the amount of crop harvested minus any processing waste (crops discarded during the processing phase). Harvest waste thus refers to the amount of crop wasted during the actual harvesting process, including crops removed during harvest due to appearance issues, such as from pest damage, as well as an estimation of crops not harvested and left in the field, possibly due to labor restrictions. Post-harvest waste includes crops sorted out during processing (processing waste) as well as any crops wasted because they could not be sold, either due to client specifications or lack of demand.

Reported energy, fuel (including diesel, petrol, and propane), water, and total Nitrogen use refers to the direct use of these resources on the farm (e.g., polytunnel electricity use, tractor fuel, irrigation water, etc.) and does not include embedded resources for products used on the farm (i.e., energy used to manufacture fertilizers). Energy use describes the total energy used during the germination, cultivation, and processing / storage stages, and does not differentiate between non-renewable and renewable sources, with only one farm utilizing renewable energy. Upon analysis, the trends for total energy use and non-renewable energy use were consistent, so only total energy use is reported.

Plastic use refers to the plastic used on the farm for growing (e.g., plastic mulch) or packaging purposes, but does not include packaging for agricultural supplies (e.g., bags for fertilizer);

similarly, packaging use refers solely to the packaging used for the tomato crop, not for other purchased agricultural supplies.

These resource and material use metrics are presented for each farm classification category as averages, normalized by dividing the total amount of the resource or material used on each farm by the amount of sellable crop (kg) produced on that farm. The use of various resources and materials have been allocated to the specific crop and year in question, based on an item's time of use out of the year for tomatoes and the item's overall lifetime; for example, this applies to items which may be used for many different crops over many years, such as irrigation and polytunnel equipment (ISO, 2006). Therefore, reusing materials will ultimately lower the material amount allocated to tomatoes.

Transport distances are presented as the average one-way distance the tomato crop would travel to the final point of sale from the farm. This was calculated for each farm using a weighted average of the transport distances to each sale point, based on the amounts sold at each location. These transport distances were then averaged for each farm classification category when possible.

RESULTS AND DISCUSSION

Farm characteristics, yields and waste

Participating farms differed greatly in scale and sale markets used, especially between organic and conventional farms (Table 1). The urban and peri-urban farms were all managed organically and were small in scale, at 0.40 ha or less in total cultivated area. These four farms were situated either in vacant lots within urban and suburban areas or in home yard spaces. The main sale markets for the organic farms included on-farm stands, community supported agriculture (CSA) schemes, farmers' markets, and direct sales to restaurants. Peri-urban farms concentrated on just one or two specific sale markets, while all other organic farms utilized three different sale markets. Rural organic farms also sold produce to small-scale wholesale firms in Atlanta that supply to restaurants. The rural conventional farms, located much farther from Atlanta (Figure 1), each had 202 total ha in cultivation for horticulture production and sold produce mainly through vendors which supply major supermarket chains across the East coast of the U.S. Tomatoes were seen as a popular crop and an important source of revenue for the organic farmers (12-14% of total crop revenue on average), who grew a wide variety of produce because of the consumer demand in their sale markets. Only one conventional farm (RC-2) reported revenue generated from tomatoes, but again this constituted a large proportion (40%) of their total revenue from horticulture production.

Average harvest yields for all farm categories were consistent or higher than the average harvest yield reported for the top tomato-producing states in the Southeast, which was 3.47 kg m^{-2} in 2018 (Table 1); however, all the participating farms' yields were lower than the national average tomato yield of 9.68 kg m^{-2}, which is largely driven by the high yields obtained in California (USDA, 2020).

The peri-urban, organic farms had the lowest average yield compared to other farm categories, although these showed high variability; indeed, this average yield was driven down by one extremely low yield (0.39 kg m^{-2} harvest yield from PU-2), which was due to lack of irrigation, the use of solely field production on poor quality urban soil, and inconsistent management / lack of labor. The highest harvest yields were achieved by U-1 (7.03 kg m^{-2}) and PU-3 (7.28 kg m^{-2}), which was largely driven by intensive management and more farmer experience compared to other peri-urban farms. Indeed, the urban farm could easily access volunteer labor due to its location in the city, and this farm also employs three full-time workers; at the same time, the peri-urban farms have limited access to volunteers and, on similarly sized farms, have mainly one to two workers. Rural, organic farmers also mentioned the difficulty of recruiting full-time farm workers to remote locations and the need for more consistent labor sources.

Prior studies have also shown that vegetable yields in urban agriculture and on other small-scale farms can be higher than standard commercial production due to the higher resource use efficiency and more intensive use of space, as well as the more concentrated management associated with smaller-scale farms (Woodhouse, 2010; McDougall, Kristiansen and Rader, 2018). For example, Gittleman et al. (2012) found that community gardeners in New York City averaged approximately 8.98 kg m^{-2} in tomato yield over 2011, compared to their reported commercial average of 2.93 kg m^{-2} in 2011. McDougall et al. (2018) reported average total vegetable, herb, and fruit production on organic urban farms and gardens in Sydney at 5.94 kg m^{-2}, nearly twice the average yields of commercial vegetable farms in the region.

In this study, rural organic farms also produced yields above the commercial average for the southeast U.S., thus showing the viability of these farm models and management practices. Indeed, the fact that three organic farms (U-1, PU-3, and RO-3) were able to attain higher yields than the conventional farm average shows that organic agriculture can be a viable and prolific production method, provided that these farms are intensively managed.

The highest average levels of harvest waste were from the urban organic and rural conventional farm categories, with the highest levels of post-harvest waste from the urban and rural organic farms (**Error! Reference source not found.**). Insufficient labor influenced the amounts of harvest waste present on farms; for example, PU-2 and PU-3 listed time restrictions and poor harvest management as reasons for their harvest waste. RC-2 also mentioned potential harvest waste due to the inability to meticulously harvest all tomatoes over such a large area (78.63 ha). The rest of farms reported appearance issues from cracking, pest, and weather damage as the reasons for harvest waste. Post-harvest waste was mainly from appearance issues and produce that could not be sold due to insufficient demand.

The average harvest season across all participating farms was 4.65 months in 2019, with the standard commercial harvest season being 4 months, based on the large-scale conventional farms participating in this study (**Error! Reference source not found.**). However, several organic farms aimed to increase the growing season through the use of polytunnels, with two rural organic farms extending the season by an additional 2.0-4.5 months. These two farms showed the highest annual yields in their farm category, thus highlighting the importance of season extension.

Table 1. Farm characteristics, yields, and waste. Displayed as amount ± standard error.

Farm	Total Farm Size (ha)	Tomato Cultivation Area (ha)	Tomato % of total crop sales	Harvest yield (kg m^{-2})	Sellable yield (kg m^{-2})	Harvest Waste (% wasted of crop produced)	Post-harvest Waste (% wasted of crop harvested)	Cultivation Type	Harvest Season (no. months)	Markets for Sale
U-1 (organic)	0.40	0.025	13%	7.03	5.98	25%	15%	Polytunnels + Field	4.0	Farm Stand, CSA, Restaurants
PU-1	0.19	0.010	7%	1.88	1.52	10%	19%	Polytunnels	5.0	Farmers' Markets, CSA
PU-2	0.40	0.046	10%	0.39	0.39	7.1%	0	Field	5.0	Farm Stand
PU-3	0.04	0.013	18%	7.28	7.28	8.7%	0	Polytunnels + Field	3.0	CSA
Peri-urban organic, AVERAGE	0.21 ± 0.11	0.023 ± 0.012	12% ± 3.3%	3.18 ± 2.09	3.06 ± 2.14	8.6% ± 0.8%	6.3% ± 6.3%		4.3 ± 0.7	
RO-1	1.11	0.017	3.5%	2.52	2.11	13%	17%	Polytunnels	2	Farm Stand, Farmers' Markets, Restaurants
RO-2	2.83	0.084	Not reported	3.81	3.54	0.5%	7.1%	Polytunnels	8.5	Farmers' Markets, CSA, Wholesale
RO-3	3.24	0.016	25%	6.87	5.50	20%	32%	Polytunnels + Greenhouses + Fields	6.0	Farmers' Markets, Restaurants, Wholesale
Rural organic, AVERAGE	2.40 ± 0.65	0.039 ± 0.023	14%	4.40 ± 1.29	3.71 ± 0.98	11% ± 5.7%	18% ± 5.2%		5.4 ± 1.3	
RC-1	202	24.28	Not reported	4.54	4.54	30%	0	Field	4.0	Wholesale Supermarket Distributor
RC-2	202	78.63	40%	6.83	5.97	4%	13%	Field	4.0	Farm Stand, Wholesale Supermarket Distributor

Rural conventional, AVERAGE	202	51.46	40%	5.68	5.26	17%	6.3%	4.0

Resource use

Overall, rural organic farms showed the highest energy, fuel, and total Nitrogen use per kg sellable crop out of all farm categories, as depicted in Figure 2. The conventional farms had the lowest energy use of 0.02 kWh per kg sellable crop compared to 1.41 kWh per kg sellable crop for rural organic farms. The main contributors to higher energy use on the organic farms were the use of fans and heating in polytunnels (mainly for germination) and irrigation pumps during the cultivation phase. While the conventional farms also had these same uses of energy, the larger scale of production (approximately 50 ha compared to <1 ha on the organic farms) allowed for more efficient energy use per amount of crop produced. The peri-urban and rural organic farms also had an additional energy use associated with storing tomatoes: either in refrigerators, cool rooms, or in sheds with fans. The conventional farms largely packed straight into delivery trucks, so there was minimal storage.

The main contributors to fuel use was the use of propane by peri-urban and rural organic farms. This was from the heating of greenhouses and polytunnels, mainly during germination, as well as the use of flame weeding by one peri-urban farm. RO-3 used heated greenhouses to harvest tomatoes into November, producing a harvest yield consistent with the conventional farms (6.87 kg m^{-2} compared to 5.68 kg m^{-2}, respectively). The trade-offs of using season extension to obtain higher annual yields and higher energy and fuel use should thus be analyzed, along with associated environmental impacts and the scope for use of renewable energy. RO-3 produced 48% of on-farm energy from solar, although still had the highest non-renewable energy use per kg crop produced. Petrol was used by the peri-urban and rural farms to run small two-wheel tractors, while the conventional farms had the highest diesel use due to the more prevalent use of tractors, which were used minimally on the organic farms.

The organic farms had the highest levels of total N applied per kg sellable crop compared to the conventional farms. However, this is expected as organic farms cannot use urea, ammonium nitrate, or other chemical-based fertilizers, which have much higher levels of plant available N than organic sources; thus, organic farmers must apply higher amounts of slow-releasing organic fertilizers (Hue and Silva, 2000). Therefore, this does not necessarily translate to higher amounts of N being available to the crop or higher amounts of N leaching, due to the differences in available N between organic and synthetic fertilizers. Higher total N use by the organic farmers also does not translate to higher environmental impacts; indeed, the embedded energy in synthetic N fertilizers, manufactured using the energy-intensive Haber Bosch process, is often considered to be one of the highest contributors to environmental impacts on farms (Goucher *et al.*, 2017). This is in comparison to the organic fertilizers used in this study, which were mainly produced from waste materials (e.g., compost, manures, feathermeal, etc.). Even with these high levels of total N use, the organic farmers may still have not been applying enough organic fertilizer to reach the necessary plant available N requirements for tomatoes, a common issue seen on organic farms, such as by Bulluck et al. (2002) in Virginia, thus possibly contributing to the lower average yields seen on the rural organic farms compared to the conventional farms.

For water use, there is a trend of increasing water use from urban to rural farms, with the conventional rural farms having the highest amounts of water use per kg sellable crop. This may be due to the careful management of water resources by the urban and peri-urban farms, which rely on higher-cost municipal water supplies, compared to the use of wells and ponds by the rural farms.

Overall, for all categories except water use, rural organic farms had the highest levels of direct resource use, while the rural conventional farms had relatively low levels of resource use per sellable crop produced. This showcases the efficiency of large-scale production achieved by these conventional farms, thus contradicting the notion that small-scale, hyperlocal and organic production is always more resource-efficient or sustainable. However, it should be noted that higher resource use does not necessarily translate to higher environmental impacts, as the embedded impacts of other agricultural resources and materials need to be evaluated via lifecycle assessment in order to provide a true comparison of the environmental sustainability of these farms (Kulak, Graves and Chatterton, 2013; Rothwell *et al.*, 2016). Additionally, resources used by organic farms, such as organic fertilizers like compost and manures, may indeed provide additional environmental benefits by allowing for waste cycling and increased carbon sequestration in soils (Yan and Gong, 2010; Ortas, Akpinar and Lal, 2013).

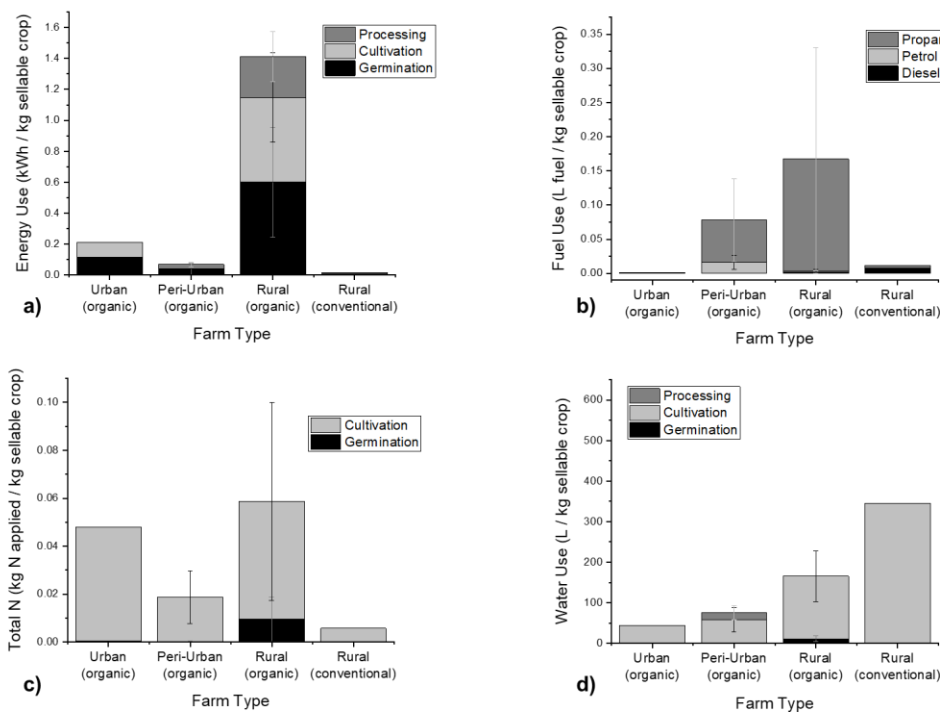

Figure 2. Average resource use across urban (n=1), peri-urban (n=3), and rural organic farms (n=3) and conventional, rural farms (n=2). Graphs display the total amounts of a) energy, b) fuel, c) total Nitrogen, and d) water use across farms per amount sellable crop produced on each farm, averaged for each farm category. Error bars show standard error.

Material use

The organic farms had higher plastic use per kg sellable crop than the conventional farms, as seen in Figure 3. Most plastic use across the farms was utilized in the cultivation stages. The main plastic use by the organic farms was for polytunnels; six out of the seven organic farms utilized polytunnels for at least some of their tomato production, while the conventional farms utilized solely outside field production (Table 1). The use of polytunnels by the organic farms was mainly for season extension as well as for protection from pests and weather damage. Although season extension did not always mean higher yields for organic farms vs. conventional farms, it is still an important practice for organic farmers who sell directly to consumers, as tomatoes are a popular crop that draw in business and contribute significantly to overall profits (Table 1). The use of polytunnels also allows for targeted biological pest control (e.g., releasing ladybugs), thus showing an environmental trade-off between plastic use and pesticide use. The main plastic use by the conventional farms was for plastic mulch, which is standard for staked tomato field production in the southeast U.S. (UGA Extension, 2017). The urban farm and two rural, organic farms also utilized plastic mulch, although the peri-urban farms used natural mulches (e.g., leaf litter and hay). Other uses of plastic during cultivation included items in the irrigation and trellising systems.

Packaging used for tomatoes was mainly paper based, with only two organic farms utilizing some plastic bags at farmers' markets. The rural, conventional farms had the highest packaging use, at an average of 239 g of paper packaging per kg sellable crop (Figure 3). The packaging use by the organic farms was collectively much lower, at an overall average of 19.7 g packaging per kg sellable crop. This is mainly due to the reuse of packaging on organic farms. Since the majority of these farms sell through farmers' markets, CSAs, and on-farm stands, they encourage customers to bring their own reusable bags and therefore simply reuse the paperboard containers that showcase the produce at each market. The conventional farms sell mainly to supermarket suppliers, and thus must use new cardboard packaging for each shipment.

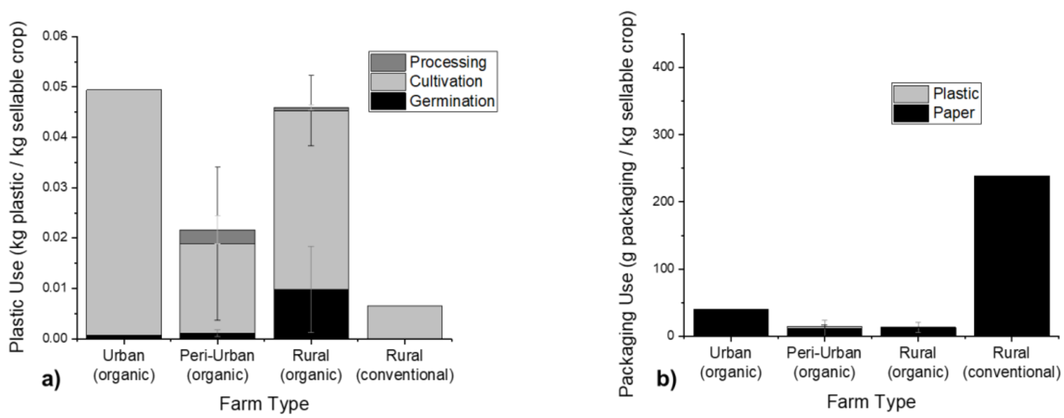

Figure 3. Average material use across urban (n=1), peri-urban (n=3), and rural organic farms (n=3) and conventional, rural farms (n=2). Graphs display the total amounts of a) plastic and b) packaging use across farms per amount sellable crop produced on each farm, averaged for each farm category. Error bars show standard error.

Transport

The average one-way transport distance (km) that a tomato travels from each farm follows an expected trend, as seen in Figure 4. The average transport distance generally increases from urban to rural farms as crops produced on the rural farms must travel farther to reach consumers in Atlanta. The urban and peri-urban farms transport their tomatoes similarly small distances (average of 8.1 km for the urban farm and 5.5 km for the peri-urban farms). The low transport distance for the peri-urban farm category is due to the fact that two of these farms sell all their produce on site (0 km transport distance). Additionally, it should be noted that all the organic farms in this study sell their produce only within Georgia. In contrast, the rural, conventional farms sell to wholesale vendors in Atlanta, who then transport their tomatoes to supermarkets across the East Coast of the U.S. Thus, the average distance a tomato would travel from these conventional farms is much higher than for the organic farms.

However, the environmental implications of this food transport will depend upon the mode of transport and the amount able to be transported during each trip (Weber and Matthews, 2008; Kulak, Graves and Chatterton, 2013). The conventional farms in this study are transporting larger amounts of food at one time using semi-trucks, whereas the organic farmers are transporting their crops in cars or vans. Previous studies have also shown that 'food miles' may not actually be as important of a sustainability indicator compared to other environmental impacts on a farm, especially for large-scale production (Weber and Matthews, 2008; Edwards-Jones, 2010).

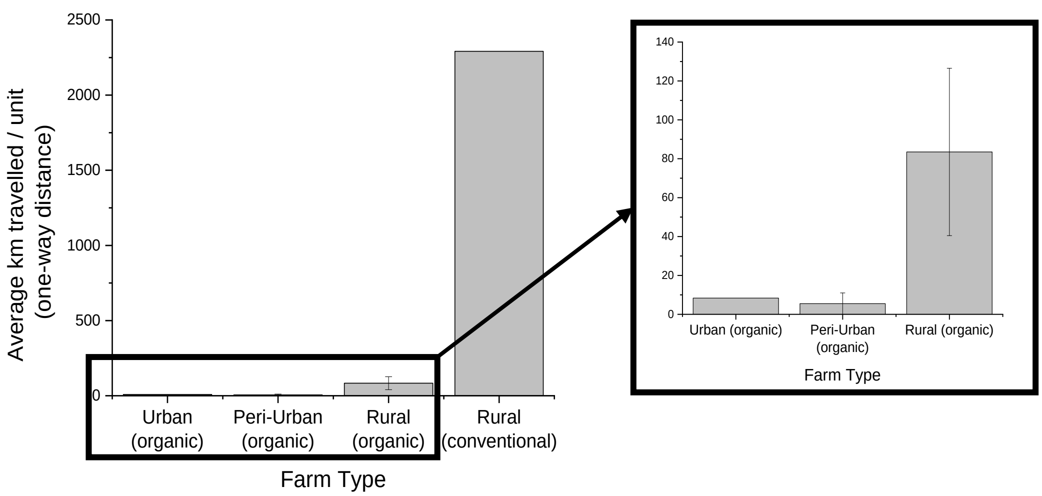

Figure 4. Average one-way transport distance (km) that a tomato travels from each farm, averaged across urban (n=1), peri-urban (n=3), and rural organic farms (n=3), as well as rural conventional farms (n=2). Error bars show standard error.

CONCLUSION

This study describes resource use, material use, and transport distances for tomato production on organically managed urban, peri-urban, and rural farms, and conventionally managed rural farms. Yields were variable among the organic farms, with one urban, one peri-urban, and one rural organic farm achieving yields higher than the conventional farms (>6.83 kg m^{-2}); however, two peri-urban farms also had extremely low yields (<2.00 kg m^{-2}), with the Southeast U.S. average tomato yield being 3.47 kg m^{-2}. The production capacity of the farms greatly influenced resource and material use efficiencies. The much larger, conventional rural farms achieved, for most categories, the overall lowest levels of resource and material use per kg sellable crop. This shows the efficiency of large-scale production through the achievement of economies of scale and begs for further analysis into the resource efficiency and sustainability of small-scale, hyperlocal production and organic production.

Still, some urban and peri-urban farms (namely U-1 and PU-3) were able to achieve high resource use efficiency due to their high yields and intensive management. This shows that there are practices to be learned from small-scale farms and highlights an opportunity to couple the efficiencies achieved by large-scale production with the innovative waste reduction strategies and closed-loop material cycling utilised on small-scale, organic farms.

An optimal solution could be to commercialize production on the fringes of urban areas (peri-urban areas), where there is more available land. This could allow for the embracing of economies of scale whilst reducing the transport distances that food must travel and the logistical inefficiencies that come with this. Additionally, by strategically locating farms near urban centres, there are more opportunities for consistent laborers and volunteers.

It should also be noted that the higher resource and material use seen on small-scale organic farms does not necessarily translate to higher environmental impacts; this will depend on the types of materials and resources used, and indeed, organic inputs may need to be added in larger volumes but may result in much lower environmental impacts. Therefore, the trade-offs between production and environmental impacts still need to be explored.

This study thus provides a platform and robust dataset for cradle-to-gate lifecycle modelling, which will be used in future research to elucidate differences in the environmental impacts of various inputs and to explore how the different local agriculture approaches and practices could feed into an optimised system.

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