CURRENT STATUS AND TRENDS IN URBAN AGRICULTURE

EDITED BY: Thomas Henry Whitlow, Yoshiki Harada, Zhongqi Cheng and Gaston Small

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CURRENT STATUS AND TRENDS IN URBAN AGRICULTURE

Topic Editors:
Thomas Henry Whitlow, Cornell University, United States
Yoshiki Harada, Cornell University, United States
Zhongqi Cheng, Brooklyn College (CUNY), United States
Gaston Small, University of St. Thomas, United States

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Table of Contents

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ORIGINAL RESEARCH
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Taylor Made Landscapes: Using Taylor's Law to Scale Between Metapopulations and Source-Sinks in Urban Garden Space

Theresa W. Ong[1], Kevin Li[2], Azucena Lucatero[3], Damie Pak[4], L'Oreal Hawkes[5], MaryCarol Hunter[6] and John Vandermeer[5]*

[1] Program in Environmental Studies, Dartmouth College, Hanover, NH, United States, [2] Department of Crop Sciences, Agroecology, University of Göttingen, Göttingen, Germany, [3] Department of Environmental Studies, University of California, Santa Cruz, Santa Cruz, CA, United States, [4] Department of Biology, Pennsylvania State University, University Park, PA, United States, [5] Department of Ecology and Evolutionary Biology, University of Michigan, Ann Arbor, MI, United States, [6] School for Environment and Sustainability, University of Michigan, Ann Arbor, MI, United States

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Gaston Small,
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United States

***Correspondence:**
Theresa W. Ong
theresa.w.ong@dartmouth.edu

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The structure of terrestrial landscapes is commonly viewed as a problem of statistical description defined by the number, size and distance between habitat patches. Yet, for organisms living in that landscape, structure may be perceived very differently depending on the dispersal capacity of the organism of concern—large animals may perceive a highly fragmented forest as a single patch if adjacent forest patches are sufficiently close, while small animals may be less likely to disperse across degraded habitat and therefore experience a much different patch structure. This is particularly relevant for fragmented landscapes like cities. Urban gardens are reputed to support a diversity of native and non-native urban species found in urban landscapes. Yet we know little about the long-term persistence of organisms associated with urban gardens. Here we utilize Taylor's law, a universal scaling law denoting a power law relationship between population size and variance to indicate the synchrony of arthropod populations sampled across time in a fragmented urban landscape. Our results indicate that the utility of urban gardens as habitat is strongly dependent on sampling month, spatial scale and taxon. Constrained dispersal across the landscape may limit the potential of urban gardens to conserve natural enemies including ladybird beetles and parasitoid wasps. In contrast, aphid pests are moving much more freely in the landscape as exhibited through synchrony in abundances sampled across local and landscape scales. We find that regardless of the fragmentation pattern existing in the landscape, short-ranged arthropods are isolated to small, independent garden habitat patches (metapopulation-like) with abundances that oscillate out of sync, while long-ranged species traverse greater distances, synchronizing abundances across large, shared spaces (source sink-like). These results suggest an inherent link between Taylor's temporal law and metapopulation theory, providing a potential mechanism to explain species-specific slopes of Taylor's law as arising from the ability of organisms to differentially experience fragmented space along the continuum between metapopulation and source-sink.

Keywords: metapopulations, dispersal, urban gardens, spatial ecology, Taylor's law

INTRODUCTION

With more than 54% of the human population residing in urban areas, urban agriculture is emerging as an alternative food movement that proposes to eliminate the rural-urban divide between food production and consumption, improve food security, build community and provide green space for people and biodiversity in urban areas (Brown and Jameton, 2000; Goddard et al., 2010; McClintock, 2010; Barthel et al., 2014; Lin et al., 2015; World Health Organization, 2016). Though many studies indicate that urban gardens can provide substantial resources to support a diversity of ecosystem service-providing organisms, the long-term viability of biodiversity in urban gardens is still in question (MacDougall et al., 2013; Beninde et al., 2015). Since urban agriculture is often small-scale, plots can be carefully managed to support a surprising amount of biodiversity in terms of crops, ornamentals and their associated wildlife (pollinators, natural enemies, birds, etc.) (Akinnifesi et al., 2009; Lin et al., 2015). These results suggest that urban gardens could represent high-quality habitat, akin to the source habitats of classic ecological theory. According to this theory, habitat patches differ in quality; source patches are capable of supporting positive population growth of a species, while sink patches incur population declines. Though gardens may be a clear improvement to cement in cities, when comparing urban gardens to rural sites on city outskirts, relative quality becomes unclear. Management for pest control, crop diversity, soil nutrition, and water conservation can significantly impact habitat quality of both urban and rural sites. In addition, metrics of habitat suitability are not necessarily universal across species. In a recent paper comparing ladybird beetles inhabiting urban gardens in Michigan and California, Egerer et al. found that beetles decreased in abundance and diversity with urbanization in Michigan but were positively associated with metrics of urbanization (% impervious surface) in California (Egerer et al., 2018). The authors suggest that drought conditions may serve to enhance the importance of source-like urban gardens in California, while the excess of wet and verdant habitat surrounding sites in Michigan make urban gardens more of a sink habitat. These results suggest that for some species and locations, urban gardens may represent higher quality habitat than rural sites, whereas for other locations or species, urban gardens may represent lower quality sink habitats with correspondingly lower conservation potential. However, there remains no simple way of assessing whether urban gardens are perceived of as sink or source habitat to different organisms.

The permeability of urban landscapes for dispersing organisms is another issue when considering the conservation potential of urban gardens. Many species of conservation concern are known to survive in small pockets of habitat in fragmented landscapes through a mechanism known as the rescue effect (Gotelli, 1991). According to this theory, if each urban garden represents a sink habitat that is at risk of extinction, random dispersal events between multiple sink patches can nonetheless allow for the collection of populations, known as the metapopulation, to persist long-term. However, lack of dispersal between isolated subpopulations can significantly increase extinction risks (Perfecto et al., 2009; Vandermeer, 2010). For example, fragmentation in landscapes may prevent species from dispersing and colonizing more appropriate habitats as climate change shifts species' ranges northward (Sæther et al., 2000). Thus, improving the matrix between habitat fragments is considered key for increasing the resilience of threatened populations to environmental perturbations (Goddard et al., 2010; McClintock, 2010; Gardiner et al., 2013; Lin et al., 2015).

In cities, impervious surface, heat island effects, human-wildlife conflict, and pollution present critical obstacles for the dispersal and maintenance of populations persisting in putative urban garden refuges (Goddard et al., 2010; Beninde et al., 2015). We can envision each garden as representing a habitat patch interspersed within a matrix of urban space. However, the degree to which organisms perceive urban gardens as quality habitat and the urban environment between gardens as an obstacle for dispersal is difficult to assess, especially for small organisms where mark and recapture techniques are largely unreliable (Nathan, 2001). This is particularly problematic since a large number of urban garden biodiversity studies focus on pest control and pollination service-providing arthropods (Goddard et al., 2010; Guitart et al., 2012; Lin et al., 2015). If urban gardens represent poor quality habitat for inhabiting organisms or if there is insufficient dispersal between garden patches, populations existing in urban gardens may not be viable in the long-term.

In this paper we use a universal scaling law known as Taylor's law to assess the permeability of an urban landscape to dispersing arthropods. The law has been described as one of the few unifying laws in ecology, with many case studies in support of its claims (Taylor, 1961; Kilpatrick and Ives, 2003; Eisler et al., 2008). It arises from the seemingly ubiquitous power law relationship between group sizes and their variances, a relationship that remains consistent across a great diversity of systems ranging from physics to economics (Eisler et al., 2008). There are two forms of the law, one spatial and one temporal. We focus on the temporal form of Taylor's law because it can measure synchrony of temporal oscillations in groups sampled across space (Ballantyne and Kerkhoff, 2005, 2007; Eisler et al., 2008). Since synchrony across subgroups is often induced by high dispersal rates in metapopulation models (Hanski and Woiwod, 1993; Ranta et al., 1995; Ruxton and Rohani, 1999), Taylor's law may provide a simple tool for assessing the permeability of urban landscapes to dispersing organisms.

The temporal form of the law states that the variance (V) of abundances over time will follow a power function relationship to the mean (M) of abundances over the same time frame, i.e., $V = aM^b$(Taylor, 1961). The exponent b, the slope of the linear regression on the log-scale, indicates whether temporal fluctuations are invariant to group size (slope = 2), or whether groups are more (slope > 2) or less (slope < 2) variable than expected by chance. Theoretical and empirical studies have demonstrated that the slope of Taylor's temporal law switches from 1 to 2 exactly at the point of synchrony where trees begin to exhibit masting behavior (Satake and Iwasa, 2000; Ballantyne and Kerkhoff, 2005, 2007; Eisler et al., 2008). This is because variance over time becomes independent of group identity when groups across a landscape grow and decline in complete synchrony

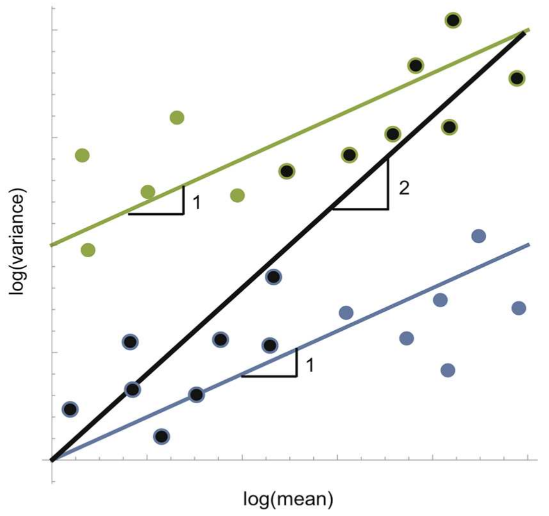

FIGURE 1 | Conceptual figure of how lower variance of large groups or higher variance of small groups can reduce Taylor's law slopes from the null of 2 to 1. Color of points match regression lines they belong to. Bicolor points belong to two regression lines.

(Eisler et al., 2008). Much of the literature on Taylor's Law is directed toward providing mechanisms that explain Taylor's Law slopes below 2 because they imply unusually high levels of stability (defined here as low variance) of large populations, an oft-sought goal for conservation (Anderson et al., 1982; Titmus, 1983; Kilpatrick and Ives, 2003). However, we note that slopes below 2 could just as easily imply that small populations are more variable than expected by chance (**Figure 1**). This observation links the temporal form of Taylor's law to metapopulation theory. When the permeability of a landscape is high, or the dispersal range of an organism is long, large amounts of habitat space in a landscape are shared, in other words, sampled populations are no longer independent. Since all samples in such a landscape are actually part of a single larger population, they are by default expected to grow and decline in synchrony, producing a Taylor's law slope near 2. However, when the dispersal range of an organism is short or the permeability of a landscape is constrained, sampled sites are actually isolated populations. Since individuals cannot move easily between isolated sites, rare and random dispersal events between sites should cause asynchrony across the metapopulation as a whole. This allows us to derive the potentially practical conclusion that populations closer to metapopulations will have slopes of Taylor's temporal law near 1, whereas populations in landscapes that are highly connected should have Taylor's law slopes near 2.

Few ecological studies have the resources or capability to directly assess landscape permeability with high-resolution tracking of organisms through space and time, though some recent advances have been made for larger organisms (Dell et al., 2014; Graving et al., 2019). Here we suggest that by leveraging the statistical relationship between group sizes and variances, we may be able to substitute time for space and reduce the temporal scale necessary to measure permeability across a given space. Since the time series used to calculate Taylor's temporal law are inevitably sampled from different spatial locations, Taylor's temporal law can be useful in short ecological studies where spatial samples are more easily obtained than temporal sequences. Rather than having to track the specific movements of organisms across large areas at many time points, we can assume that populations that are temporally synchronous across large spatial scales are moving relatively freely through that space, while those that are asynchronous are constrained. When organisms can move freely through space, high quality source patches are likely to be colonized first. These source patches then produce migrants that disperse to lower quality sink patches, defined as less suitable patches, in the landscape (Pulliam, 1988). Directed dispersal events in contiguous space can cause populations within that space to synchronize (Ruxton and Rohani, 1999). We can then use the slope of Taylor's law as a simple means for assessing how groups of organisms experience a fragmented urban landscape as a whole; is it split into many asynchronous metapopulations or does it function as a source-sink landscape where clear migratory pathways lead to synchrony?

We apply this theory to assess the permeability of an urban landscape to three specific groups of urban garden-inhabiting arthropods: aphids, ladybird beetles and parasitoid wasps. A variety of organisms inhabit urban gardens, but those of particular ease to study are also those of most concern to gardeners, agricultural pests. Aphids are important agricultural pests because of their propensity for spreading viral diseases combined with their incredibly fast rates of growth (Sylvester, 1980). Aphids are also long-distance dispersers known to be sensitive to broad scale changes in percentage of non-crop habitat within agricultural landscapes (Werling and Gratton, 2010). This makes them an ideal study organism to address questions regarding landscape permeability and habitat suitability. In addition, urban gardens are known to harbor an abundant and diverse suite of natural enemies that attack aphids and other agricultural pests (Goddard et al., 2010; Speak et al., 2015). Here we examine two of these groups, ladybird beetles and parasitoid wasps, excluding predator wasps, specifically those from the family Vespidae. Though Vespid wasps are important for controlling garden pests, we were more interested in parasitoid wasps due to their reliance on floral resources and potential to be natural enemies of aphids (Brodeur and Rosenheim, 2000; Donovan, 2003). Studies addressing how natural enemy communities respond to urbanization find that local level factors including garden management (% flowering plants, pesticide use) tend to be more important than landscape level factors such as the % impervious surface or agricultural land (Bennett and Gratton, 2012; Otoshi et al., 2015; Egerer et al., 2017; Philpott and Bichier, 2017). This sensitivity to local-scale conditions could potentially constrain the movement of natural enemies in urban landscapes. However, ladybird beetles are known to migrate long distances to wintering sites, and several invasive species have spread quickly throughout the globe (Bahlai et al., 2014). Less is known about the movement patterns of parasitoid wasps, which may depend and map onto specific parasitoid-host relationships. However, these three specific groups of winged arthropods are all commonly found in urban gardens and have the potential to disperse long-distances, making them ideal for assessing whether the quality of urban gardens as habitat or the permeability of a single urban landscape changes from taxon to taxon.

We expect differences in dispersal amongst organisms to change the perceived landscape structure of an urban landscape. If organisms are unable to easily move through the landscape, urban gardens are likely to represent very patchy, isolated sink habitats common of metapopulations. We expect this to increase the variation of small populations. However, if the urban landscape is highly permeable, gardens could form clusters and create source-sink dynamics in the landscape. We anticipate a heightened sensitivity to local conditions to constrain dispersal in wasps, translating to more asynchronous abundances and Taylor's law slopes nearer to 1. In contrast, we predict beetles and aphids to have more synchronous abundances with Taylor's law slopes nearer to 2 because of their capacity for long-distance dispersal.

MATERIALS AND METHODS

Arthropod Census

Glue-based, yellow sticky card traps were used to monitor aphid, ladybird beetle, and parasitoid wasp abundances in Ann Arbor, MI during the months of June, July and August 2013.

In order to determine how arthropods responded to gardens at different spatial scales, we placed sticky traps at mapped grid points spaced regularly across the landscape in one local and one landscape plot (**Figure 2**). The landscape plot corresponded to a regular grid over the total area of the city of Ann Arbor and the local plot covered just the area of downtown Ann Arbor and adjacent neighborhoods. The finer, local-level plot had 100 points spread an average of 128 m apart. The coarser, landscape-level plot had 28 points, spread an average of 1,470 m apart. We constructed these two plots in order to assess how spatial synchrony may change as a function of habitat overlap. If dispersal range is constrained at landscape scales but not at local scales, we would expect spatial synchrony to be higher in our local plot. Each sticky trap location represents an individual point in a regression of log mean abundances and variances taken over the three time points for each sampled site, the slope of which is the exponent of Taylor's law. At each site, a sticky trap was either taped to a metal street pole or stapled to a tree or wooden post at breast height. Every 5 weeks for 15 weeks (3-months), the sticky traps were collected and sampled for abundance of each arthropod group.

We used a 20–80 X magnification stereo microscope and characteristic morphological features to identify each aphid, ladybird beetle, and parasitoid wasp individual using field guides (Borror and White, 1970; Goulet et al., 1993). Aphids (superfamily Aphidoidea) were identified as soft bodied insects with sucking mouth parts and cornicles, a pair of tubes on the 5th abdominal segment that are present in most aphids (Borror and White, 1970). Ladybird beetles (family Coccinellidae) were identified as beetles with dome-shaped bodies, four wings including a pair of hard wings known as elytra and club shaped antennae (Borror and White, 1970). Parasitoid wasps (group

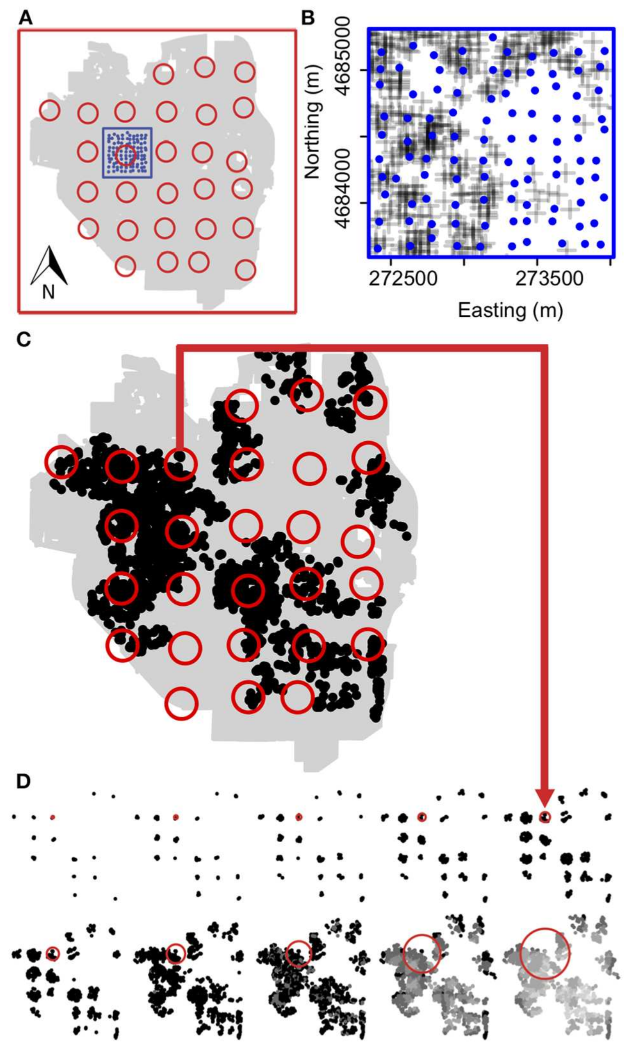

FIGURE 2 | Sampling scheme and scale-dependent landscape structure. **(A)** Sampling scheme of gardens in the area of Ann Arbor, MI (grey background). Sampling of arthropods was conducted regularly across the entire landscape in two plots (red box: landscape and blue box: local) and three time points (June, July, and August 2013). A total of 28 samples were collected at the landscape (open red circles), and 100 at the local plots (blue circles) per month. **(B)** Close-up of sampling locations (blue dots) and easement gardens (plus signs) in local plot. Landscape-plot samples are drawn in **(C)** at a radius of 400 m on top of actual distribution of urban gardens (closed black circles). Patch size was equal to number of gardens falling within the radius of a single sampling circle, visualized in **(D)** by plotting only the gardens (black/gray points) falling within radii of 100, 150, 200, 300, 400 m (top row), and 500, 750, 1,000, 1,500, 2,000 m (bottom row) for the 28 landscape-level sampling points only. One patch is highlighted for each radius (open red circles) to show scale, with a red arrow connecting this point to its location among all landscape-level sample points plotted at the same 400 m radius in **(C)**. At a radius of 1,000 m and beyond, neighboring landscape-level samples begin to overlap; degree of overlap is indicated by the darkness of garden points with lightest points having the greatest overlap. The same patch size analysis was done for local plot samples, but not visualized here.

of superfamilies) were identified as insects with 2 pairs of clear or smoky membranous wings, long antennae, a thin waist and the presence of an ovipositor. While we did not identify individuals into families or assign them into morpho-species (due to degraded sticky trap samples), we did exclude predatory wasps, specifically those from the family Vespidae using (Goulet et al., 1993) field guide (1993).

Urban Garden Census

In order to assess how sampled arthropods were using urban gardens as habitat, we mapped our spatio-temporal arthropod data onto an existing spatial dataset of urban gardens in the same area. Gardens were surveyed 1 year before the arthropod census. Though gardens were sampled 1 year prior to arthropods, we expect little change in home ownership and the spatial distribution of easement gardens within a 1 year span. Garden census data was taken from Hunter and Brown (2012), in which all private properties within the entire Ann Arbor, MI municipal region ($N > 20{,}000$) were surveyed in person, recording the location and presence of easement gardens (municipally owned green space that falls between the sidewalk and the road) (Lin et al., 2015). In Ann Arbor, homeowners are required to care and manage these city-owned parcels. The universal tranverse mercator (*UTM*) coordinates of any parcel showing signs of horticulture (other than mowed lawn) was recorded as an easement garden. Both primarily aesthetic and food-related gardens were recorded since both are important for insect communities. Urban gardens are very broadly defined in the literature and include any horticulture (both ornamental and edible) occurring in urban areas, including easement gardens (Mougeot, 1999; Lin et al., 2017). The majority of easement gardens in this study were dominated by flowering herbaceous perennials (91%), followed by shrubs (6%), ornamental grass (2%), and edible plants (1%). Further details on the specific easement gardens in this study are available from the original source (Hunter and Brown, 2012). Although the use of easement gardens in this study excludes other examples of urban gardens in Ann Arbor (public gardens, community gardens, backyard gardens, etc.), it is a consistent census tool that has been extensively ground-truthed in the study area. Results from the original mapping study showed that easement gardens are significantly clustered in space, which the authors argued is a result of a spatial-contagion effect (Hunter and Brown, 2012). Visual access to the nearest neighbor's easement garden increased the intensity of garden clustering so that homeowners were more than twice as likely to have an easement garden if one existed within 30 m. Due to this spatial-contagion effect, we expect areas with many easement gardens to contain other kinds of urban gardens in the region as well. To confirm this we calculated the bivariate Ripley's K clustering statistic known as the Cross K-function (Ripley, 1976; Juhász and Hochmair, 2017):

$$K_{ij}(r) = \lambda^{-1} E\left[f\left(r\right)\right] \tag{1}$$

K_{ij} *(r)* describes clustering of j type events within r distance of an i event with *f(r)* representing the number of j events and λ representing the density of j events within the circular area defined by r. We compared the spatial distribution of the easement gardens to the full set of Project Grow (PG) community gardens that were present within the city limits of Ann Arbor in 2012 and 2013. No PG gardens changed within this time frame. PG gardens is the largest and oldest community garden organization in Ann Arbor, first established in 1972 as part of the USA's victory garden wartime effort. The gardens are managed organically and split into allotments that are rented by community members who primarily grow annual edible crops but also perennial crops and ornamentals. We calculated the Cross K-function (1) for the observed distribution of PG and easement gardens as well as for $n = 999$ Monte-Carlo simulations where PG and easement garden labels were randomly assigned (Ripley, 1976; Juhász and Hochmair, 2017). We found that easement gardens were significantly more clustered to PG community gardens than expected by chance for radii from 300 to 2,500 m (**Figure 3**) suggesting a strong spatial relationship between easement gardens and PG community gardens in Ann Arbor. Thus, in this study we use easement gardens as a proxy for urban gardens, generally.

Urban Gardens as Habitat

To assess the habitat quality of urban gardens at each sampling point where arthropod data was taken, we calculated garden patch size by summing the number of gardens falling within a radius of 100, 150, 200, 300, 400, 500, 750, 1,000, 1,500, and 2,000 m from the sampling location. This range of radii was chosen so that sampled sites go from independent to overlapping as the sampling radius increases (**Figure 2**). Low quality sites had few gardens and high-quality sites had more gardens. We tracked how garden habitat size distributions changed with spatial scale by calculating skewness, kurtosis and Gini coefficients (a measure of inequality) for each sampling radius in both local and landscape plots (Gini, 1912). Though we acknowledge that other more specific indicators of habitat quality including local features like floral resources or landscape features including impervious surface could and should be used to assess quality in future studies, we feel that our patch size approach is universally applicable to all study organisms and the most useful metric considering our questions regarding habitat overlap and dispersal range.

In order to determine whether and at what spatial scale urban gardens were perceived as habitat by each taxon, we compared several linear models predicting the abundance of each group of arthropods as a function of patch size for the radii specified above. Sets of models at these radii were created to predict monthly abundances for each organism at each plot in the months of June, July and August 2013. The Akaike Information Criterion (*AIC*) for each radius was compared to a null model to determine whether and if so, at which radius, garden patch size best predicts organism abundance. If the null model was the best fit model, we concluded that gardens did not represent significant habitat. In cases where the null model was not the best fit, we concluded that gardens significantly influenced arthropod abundances. In these cases, we used the radius of the model with the lowest *AIC* to indicate the dispersal range of the taxon and from there, calculated the perceived distribution of garden patch size in the landscape. The magnitude of garden effects on abundances were quantified by calculating the estimate of the generalized linear model predicting arthropod abundance for the spatial scale and

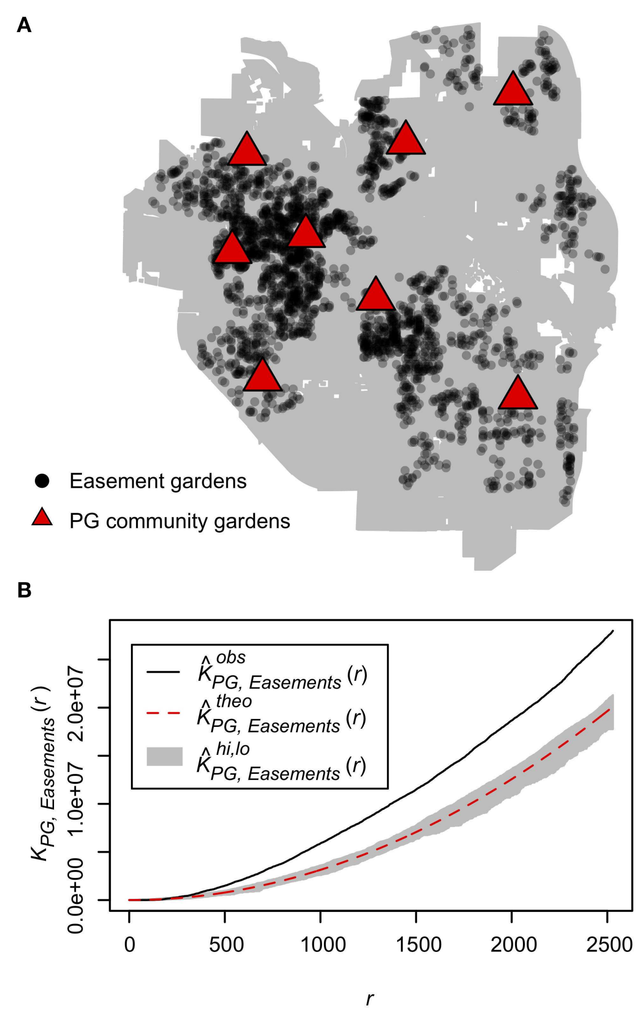

FIGURE 3 | Easement gardens cluster around community gardens. **(A)** Spatial distribution of easement gardens (black dots) and Project Grow (PG) community gardens in the city limits of Ann Arbor (gray polygon). **(B)** The observed Cross-K function (black line), which calculates the number of easement gardens within a radius *r* of every community garden compared to the mean (red dashed line) for $n = 999$ Monte Carlo simulations where easement and community garden labels are randomly assigned along with the upper and lower simulation envelope (gray band), which signifies a significance level of alpha = 0.002 for the Monte Carlo test.

month appropriate. We assumed Poisson error distributions for count data and tested for significant garden effects using Wald Z-tests (Bolker et al., 2009).

Landscape Permeability

We used synchrony in taxon abundances to measure the permeability of the urban landscape for each of our sampled arthropods. Synchrony of each arthropod group was measured directly using cross-correlation coefficients and indirectly using the slope of Taylor's law. Mean cross-correlations were calculated for each arthropod type by taking the mean of Pearson's correlation coefficient for all 3-pt time series in the lower half of the orthogonal N x N matrix in all unique taxon crosses, excluding the identity line for local ($N = 100$) and landscape ($N = 28$) plots. We averaged the absolute values for all cross-correlation coefficients and calculated the 95% quantiles for each arthropod group and sample plot to determine the average level of temporal synchrony (Hanski, 1987). The variance and means of arthropod group abundances over time were also calculated for each sampled site and regressed on a log scale. The slope of these regressions are the exponents of Taylor's temporal law (Eisler et al., 2008). The slope, R^2 and P-values (calculated using T-tests) of regressions were determined for each arthropod group and plot.

RESULTS

Habitat Patch Quality

We found that the distribution of urban garden habitat quality in our sampled arthropod groups depended strongly on the radius of influence of gardens from each sampled site. Patch quality, measured in terms of the number of gardens within a specified radius, moves from right, even, to left skewed distributions as sampling radius increases. This was indicated by decreases in skewness with sampling radius (**Figure 4**). Kurtosis, a measure of the tails of the distribution, also declines as sampling radius increases but is higher at smaller and larger radii where captured gardens in plots are more evenly distributed (all very small or large patches) (**Figure 4**). The gardens in each site become more similar as sampling radius increases and the Gini coefficient approaches 0. Note that the radius of influence determines whether sites represent independent or dependent samples. When sampling radius is small, most sampled locations represent low quality habitat patches with very few urban gardens. However, as sampling radius increases, quality becomes more even across samples as gardens in samples begin to overlap until eventually, all sample locations include the full set of gardens in the landscape (**Figure 4**). Thus, when sampling radius is large, most samples include the majority of urban gardens, with only a few isolated sites that capture few gardens. The rate at which the distribution changes, depends on how far apart sampled sites are from one another, as demonstrated by slower rates of change in the Gini coefficient for local vs. landscape plot samples (**Figure 4**).

Arthropod Responses to Gardens

We collected a total of 5,842 invertebrates with the aphids being the most abundant group. A total of 3,667 aphids were sampled between June and August. The highest numbers of aphids were collected in June (1,688 aphids) and July (1,850 aphids) and we surveyed far less aphids in August with only 129 aphids accounted for **Figure 5**. All aphids surveyed were winged alates. The second most abundant group was the parasitoid wasps with 1,686 wasps. The number of parasitoids surveyed was relatively constant for the 3 months with 549 wasps collected in June, 645 wasps collected in July and 492 collected in August (**Figure 5**). Finally, we collected a total of 492 ladybird beetles from June to August. Similar to the parasitoid wasps, the number of beetles collected from June to August remained relatively constant.

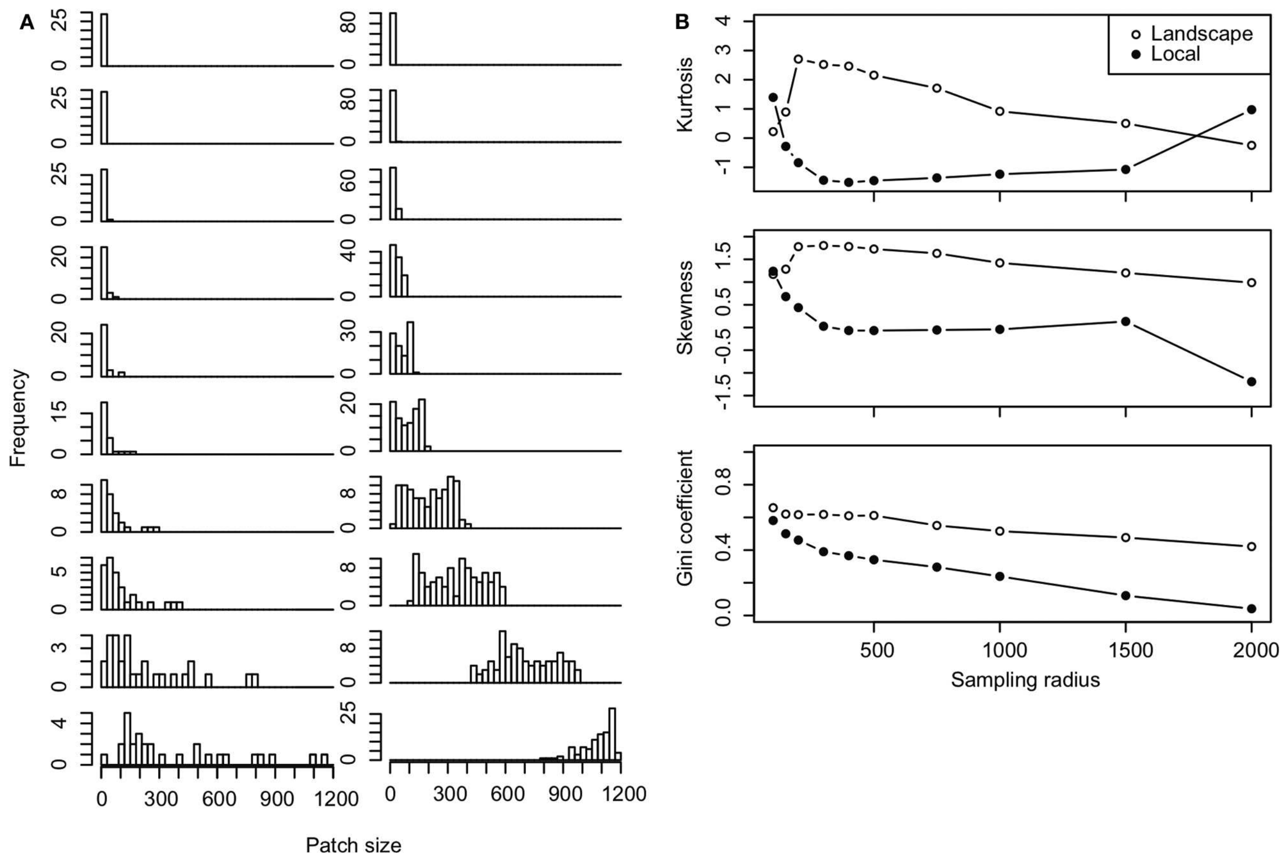

FIGURE 4 | Shifting patch size distributions. **(A)** Histograms of patch size at each sampling radius of 100, 150, 200, 300, 400, 500, 750, 1,000, 1,500, 2,000 m (from top to bottom rows) are plotted for local (left column) and landscape-plot samples (right column). **(B)** Kurtosis, skewness and Gini coefficients calculated for patch size distributions at each sampling radius in landscape (open circles) and local-plot samples (solid points).

A total of 119 ladybird beetles were collected in June, 254 in July and 119 in August (**Figure 5**).

The spatial scale in which abundances of arthropods best responded to urban gardens varied by arthropod group, sampling month and plot. Aphid abundances were positively driven by gardens at a scale of 100 m in June for the landscape plot, but this relationship did not hold for other months or in the local plot (**Figure 5**, **Table 1**). In August, more aphids were found where there were more gardens within a 300 m radius of local plot sites, but samples of aphids in the landscape plot were negatively associated with gardens at 3,000 m. Ladybird beetle abundances only responded to gardens when sampled at the local plot, moving from negative associations at 500 m in June to positive associations at 10 m in July and negative associations at 3,000 m in August (**Figure 5**, **Table 1**). Parasitoid wasp abundance responded positively to gardens at a 50 m radius for landscape and 500 m radius for local plots taken in June only. However, these relationships did not hold across the months of July and August (**Figure 5**, **Table 1**).

Spatial Synchrony

For aphids, the mean correlation was 0.71 (0.13–0.99, 95% quantiles) in the local plot and 0.91 (0.5–1.0, 95% quantiles) in the landscape plot. The slope of Taylor's law was 1.98 in the local plot ($R^2 = 0.88$, $P < 0.001$) and 2.15 in the landscape plot ($R^2 = 0.92$, $P < 0.001$) (**Figure 6**). Temporal synchrony for beetles and parasitoids was consistently lower; for beetles the mean correlation was 0.65 (0.00–1.00, 95% quantiles) in the local plot and 0.66 (0.18–1.00, 95% quantiles) in the landscape plot. Ladybird beetles had Taylor's law slopes of 1.42 for local ($R^2 = 0.68$, $P < 0.001$) and 1.40 for landscape plots ($R^2 = 0.65$, $P < 0.001$) (**Figure 6**). For parasitoids, the mean correlation was 0.63 (0.068–0.99, 95% quantiles) for the local plot and 0.61 (0.082–1.00, 95% quantiles) for the landscape plot. Parasitoid wasps had slopes equal to 1.46 for local ($R^2 = 0.45$, $P < 0.001$) and 0.92 for landscape plots ($R^2 = 0.20$, $P = 0.013$) (**Figure 6**). We found that declines in Taylor's law were driven by greater variance in smaller abundances of ladybird beetles and parasitoid wasps as compared to equivalently small abundances of aphids (**Figure 6**).

DISCUSSION

Our results link Taylor's temporal law slopes to perceptions of habitat quality on a continuum between metapopulation and source-sink. We find that aphids had a slope approaching 2

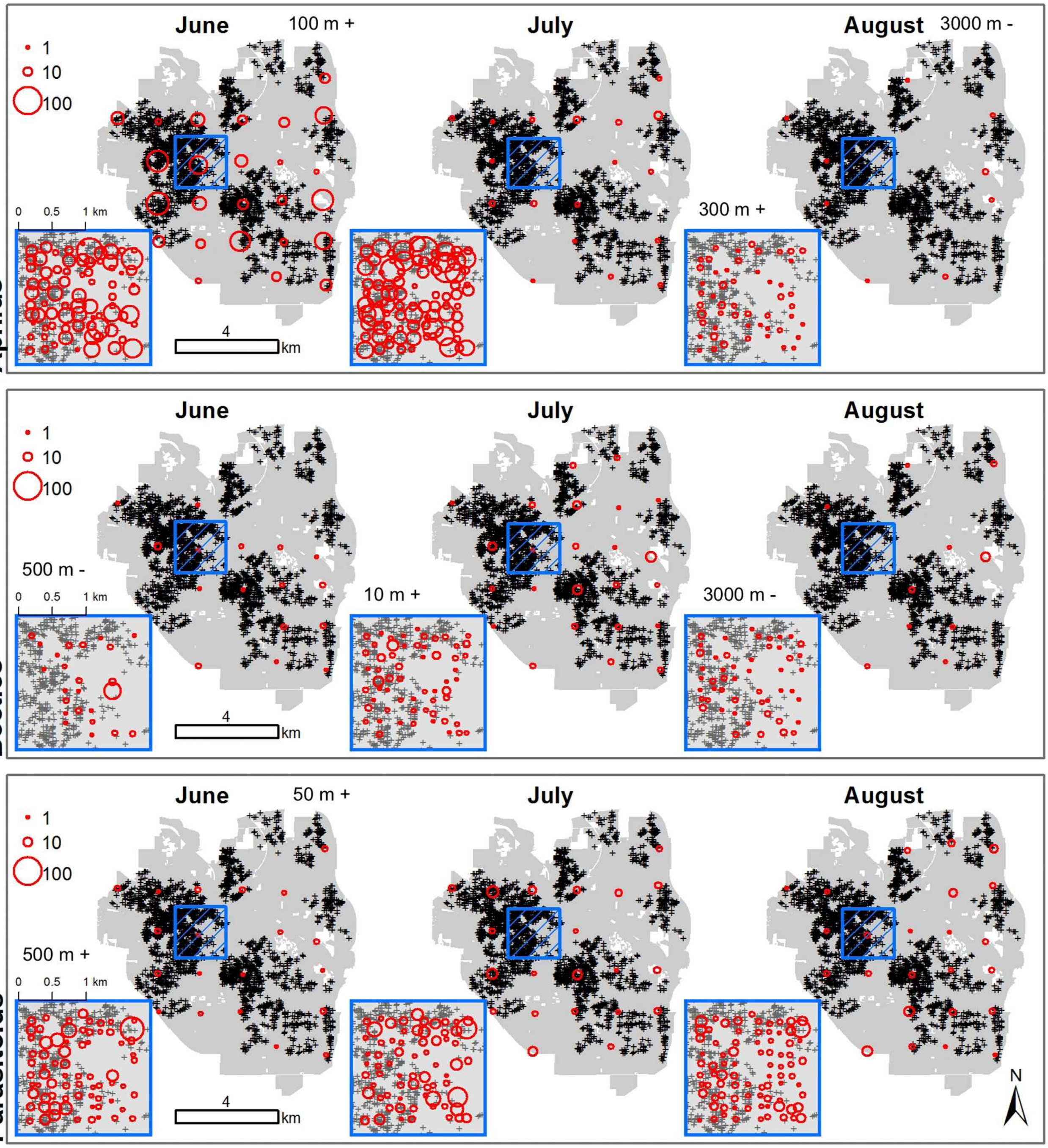

FIGURE 5 | Arthropods are sensitive to urban gardens at different spatio-temporal scales. The sizes of red, open circles indicate the abundance of aphids (top row), ladybird beetles (middle row), and parasitoid wasps (bottom row) in June (first column), July (second column) and August (third column) 2013. Small blue box indicates position of the local plot, which covers downtown Ann Arbor, MI and adjacent neighborhoods with 100 sampled points placed an average of 128 m apart. Larger blue box is an enlarged view of the local plot. The landscape plot covers the entire city landscape with 28 points placed an average of 1,470 m apart. Easement gardens are indicated by black and grey plus signs. Local and landscape plots in each month are labeled above plots with the spatial scale for which gardens had a significant positive (+) or negative (–) effect on abundances.

and larger mean cross-correlations, while ladybird beetles and parasitoid wasps had lower slopes and mean cross-correlations (**Figure 6**). These results are consistent with previous studies that link higher Taylor's law slopes with greater synchrony in temporal oscillations sampled across landscapes (Satake and Iwasa, 2000; Ballantyne and Kerkhoff, 2005, 2007; Eisler et al., 2008).

TABLE 1 | Summary of garden effects on arthropods.

Taxon	Plot	Month	Spatial scale	Estimate	Pr (>|z|)
Aphids	Local	June	NS		
		July	NS		
		August	300 m	1.80E-02	<0.001
	Landscape	June	100 m	2.00E-01	<0.001
		July	NS		
		August	3,000 m	−1.00E-03	0.05
Ladybird beetles	Local	June	500 m	−1.40E-02	<0.001
		July	10 m	1.80E+00	<0.001
		August	3,000 m	−3.90E-03	0.017
	Landscape	June	NS		
		July	NS		
		August	NS		
Parasitoid wasps	Local	June	500 m	4.70E-03	<0.001
		July	NS		
		August	NS		
	Landscape	June	50 m	5.40E-01	0.018
		July	NS		
		August	NS		

Estimates of best fit models for predicting arthropod abundances at different spatial scales, months, and plots.
P-values from Wald Z tests.

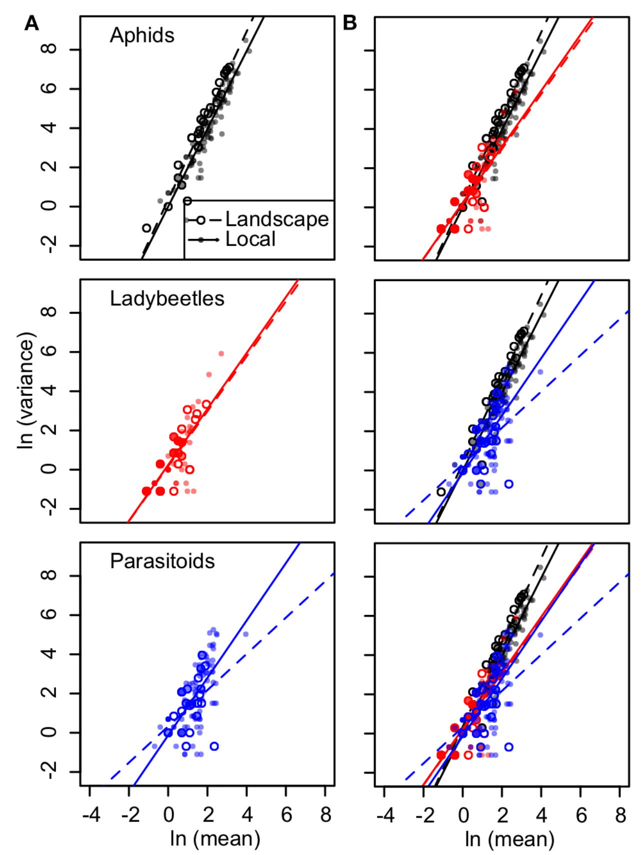

FIGURE 6 | (A) Linear regressions to calculate Taylor's temporal law for abundances of aphids (black), ladybird beetles (red), and parasitoid wasps (blue) at landscape (open circles) and local plots (solid points). For aphids, slopes = 2.14, 1.98, R^2 = 0.92, 0.88, $P < 0.001$ for both; ladybird beetles, slopes = 1.40, 1.42, R^2 = 0.65, 0.68, $P < 0.001$ for both; and parasitoid wasps, slopes = 0.92, 1.46, R^2 = 0.20, 0.45, $P = 0.13$ and $P < 0.001$ for landscape and local plot sample points, respectively. **(B)** Plots are repeated and overlaid in different combinations to visually compare arthropod groups.

We conclude that the permeability of Ann Arbor for aphids is relatively high, while dispersal for beetles and wasps may be more constrained. Constrained movement in the landscape not only increases the chance of random extinction events but also fundamentally changes the habitat distribution of sampled sites so that they consist of smaller, right skewed distributions of gardens patches (**Figure 4**). The greater variance of small ladybird beetle and parasitoid abundances in comparison to small aphid abundances supports the hypothesis that these natural enemies are more isolated and prone to random dispersal and extinction events like in the sink patches of a metapopulation (**Figures 1**, **6**).

The sensitivity of organism abundances to gardens at various spatial scales in local and landscape plots also support this conclusion, although there was significant variation in individual responses. As expected from the relatively high levels of synchrony observed across the landscape, aphid abundances responded to gardens primarily in the landscape plot (**Figure 5**). These observations support our predictions that permeability of the urban landscape is high for aphids. Since landscape plot samples were synchronized, dispersal must be sufficient to connect the visible clusters of urban garden habitats across the landscape (**Figures 2**, **5**). In a source-sink landscape, we would expect populations to have positive relationships with habitat quality at a larger scale, which we do find in our landscape plot aphid samples. However, aphids did also become sensitive to gardens in the local plot in August. During this last sampling month, gardens had a negative effect on aphid abundances at large spatial scales (3,000 m) in the landscape plot and a positive effect at smaller scales (300 m) in the local plot (**Figure 5**, **Table 1**). This may indicate a source-sink relationship between large source patches at the landscape scale early in the season to smaller sink patches at the local scale later in the season. At the end of the summer, aphids produce winged aphids that disperse for the purpose of sexual reproduction (Kring, 1972; Le Trionnaire et al., 2008). Because we placed sticky traps at breast height on telephone or other metal poles not necessarily in garden habitats, we only collected dispersing winged aphid alates. Dispersal across the landscape toward specific local nesting sites at the end of the growing season could explain the shift in spatial sensitivities for this final sampling month. We did observe a sharp decline in aphid abundances during August that we take to indicate that overwintering had already begun during this final sampling period and suggests that we were able to capture the seasonal dynamics in the system by accumulating abundances over 5 week periods across the season (**Figure 5**). Aphid dispersal can be passive through wind, though they move directionally when attracted to plants and in our case, yellow sticky cards (Kring, 1972). Our results indicate that winged aphid alates are moving through the landscape at large spatial scales and that they have a strong affinity to locations with more urban gardens (**Figures 5**, **6**, **Table 1**). This would suggest that their movement in Ann Arbor is more directed than passive. They do also appear in locations without gardens as indicated by sample sites where there are aphids and no gardens, however abundances at these sites are consistently lower (**Figure 5**). Aphids that are found in areas with few gardens are likely moving through that area passively by wind, but the presence of some individuals in these areas indicate that they do indeed move through them. Large clusters of urban gardens may encourage passively dispersing aphids to increase directed movement to traps in search of host plants.

In contrast, ladybird beetle abundances only responded to gardens in our local plot, which we take to indicate strong dispersal limitation and a metapopulation like landscape structure (**Figures 2**, **5**). Though beetles were consistently associated with local plot gardens, the specific effects were various. For example, garden effects on beetle abundance changed from negative to positive depending on the sampling month (**Figure 5**, **Table 1**). The tendency of many ladybird beetles to rely on urban resources including built infrastructure as nesting sites in the winter may explain these shifts (Evans and Dixon, 1986; Koch and Galvan, 2008; Bahlai et al., 2014). Researchers have reported divergent responses to urbanization by ladybird beetles (Egerer et al., 2017, 2018). We suggest that these varied responses may be driven by seasonal trends. The negative effects of gardens on beetle abundance occurred toward the beginning and end of the growing season, which could indicate beetles leaving and returning to urban nesting sites during these periods. Random dispersal between isolated patches could therefore explain the beetle's inconsistent spatial responses to gardens and asynchronous abundances, as indicated by low cross-correlation coefficients and slopes for Taylor's law. We note that since metapopulations are characterized by random migration between small sink patches, the inconsistency in our beetle abundance patterns generally supports the hypothesis that beetles are dispersal limited in Ann Arbor.

In contrast, parasitoid abundances appear much more sensitive to sampling month than spatial scale. These insects responded positively to gardens in both the local and landscape plots at various spatial scales but in June only. Gardens may be a particularly important habitat for parasitoid wasps early in the season when aphid hosts first emerge and establish clonal colonies (Kring, 1972). Aphids do also have a positive association with gardens in June but this relationship disapears in July and then reappears in August (**Table 1**). Though we cannot distinguish parasitoid species in this study or confirm whether their host species were predominantely aphids, if parasitoids were able to closely track aphid abundances, we would expect sensitivity to gardens to closely follow these aphid patterns, which we have no evidence for in August. We hypothesize that constrained dispersal may prevent parasitoids from tracking aphid hosts later in the season. However, since we did not classify parasitoid wasps by species, our results could also indicate a shift in wasp or host community compositions, which may not use urban gardens as habitat, during the later growing season months of July and August. Future research that can identify species compositions shifts along with abundance and distribution are needed to clarify such effects.

Despite these limitations, our empirical results do satisfy theoretical predictions and are biologically reasonable. Aphids are known to have long dispersal ranges and large, synchronized population booms and busts are typical for agricultural pests (Wallner, 1987; Hanski and Woiwod, 1993). We found evidence that aphid abundances are synchronized across the landscape, regardless of the fragmented distribution of urban gardens found in the landscape. In contrast, natural enemies like ladybird beetles and parasitoid wasps are known to be highly sensitive to local conditions, including flower density and diversity. Our results do indicate much more constrained movement of natural enemies. Navigating through highly disturbed urban landscapes is known to be difficult for some arthropod predators and parasitoids (Langellotto and Denno, 2004; O'Rourke et al., 2011; Bennett and Gratton, 2012; Jha and Kremen, 2013). Since Ann Arbor is not particularly urban, the asynchrony of the natural enemies observed in this study suggests that even suburban landscapes can pose significant barriers to dispersal.

Our study focused on group rather than species-level abundance patterns across time and space and their relationship to Taylor's law. Taylor's law is applied to many non-species-specific groups from traffic on Internet routers to transactions on the Stock Exchange (Eisler et al., 2008). The theory similarly applies to the three arthropod groups in this study. Though we did not identify arthropods to species and are not be able to interpret whether specific natural enemy species were responding to trends in their host or prey species, understanding how these groups of arthropods collectively respond to fragmentation patterns is still of interest and are of applied interest to urban garden practitioners who are concerned with overarching pest and natural enemy dynamics. Large-scale synchrony and dependence on urban gardens in aphid abundances suggest that species within the larger aphid group are responding similarly or are driven primarily by a dominant species we could not identify. Regardless of whether the results are general or species-specific, recent work indicates that trophic position may strongly influence how dispersal effects the persistence of metacommunities. In a study of tropical terrestrial leaf litter communities, higher rates of dispersal in non-predators caused higher rates of extinction for predator species (Hajian-Forooshani et al., 2019). Our study could indicate that such a pattern exists since aphid prey were observed to have much greater levels of dispersal than natural enemies. Examining levels of synchrony across trophic levels in other ecological communities where we can separate species from community-level effects may help determine whether greater rates of dispersal are generally more common amongst lower trophic levels and are somehow subject to multi-level selection pressures (Nowak et al., 2010).

We expected synchrony in abundances to decrease when moving from local to landscape plots if dispersal across the landscape is constrained. Taylor's law slopes were very consistent across plots for ladybird beetles and aphids (**Figure 6**). However, we did find that parasitoid wasps had much lower Taylor's law slopes in our landscape plot, confirming our prediction that synchrony of arthropod groups sampled far from one another should decrease. The greatest differences in cross-correlations across plots was in aphids, with lower cross-correlation coefficients in local samples (0.71) than landscape samples (0.91) but the large 95% quantile confidence intervals of this and other cross-correlation coefficients suggest that these values may not be very useful metrics of synchrony. In our study, Taylor's law may provide a more accurate measure of spatial synchrony since our time series were short, 3 time point samples (**Figure 6**). We had only one plot of each type in a single fragmented landscape, limiting our ability to generalize the results of our work too broadly. Future work comparing the same arthropod groups distributed across many landscapes that vary in degrees of fragmentation may better elucidate how fragmentation can differentially influence spatial synchrony and Taylor's law generally.

In this paper we focused on investigating how Taylor's law maps onto spatial synchrony and the permeability of fragmented landscapes for three different arthropod groups. Our study is unique in having an expansive survey of urban gardens in the entire city of Ann Arbor to test the relationship between gardens and arthropod abundances. However, if other studies did not have the underlying information on the habitat distribution or if the habitat was unknown, a simple calculation of Taylor's law may still be sufficient to assess how a group of organisms is filtering a fragmented space like the peri-urban city of Ann Arbor, MI. We predict that future work utilizing Taylor's law in other cities or fragmented landscapes like agriculture may reveal divergent trends in the slope of Taylor's law, even for the same species in different landscapes. This would suggest that this slope depends not only on species identity as previously suggested (Taylor, 1961), but also on the permeability of a given landscape to that species. As such, we believe that Taylor's law will be a particularly useful tool for studying how the role of urban gardens to urban biodiversity changes across cities.

Here we show that different organisms can perceive the same fragmented landscape very differently depending on their dispersal capacities and the slope of Taylor's temporal law may be intricately linked to these perceptions and the fundamental structure of communities. Not only may organisms respond to landscapes forming a continuum from metapopulation to source-sink, but a single landscape may fall anywhere along this continuum simultaneously and differentially for each organism that exists within it.

In the context of trophic interactions, other questions arise. Is biological control best achieved when organisms experience the landscape similarly, or does a disjunction between perceptions keep the system in a state of persistence that may be impossible to maintain otherwise? Is there a way of maximizing long-distance dispersal events in organisms of conservation concern while maintaining asynchrony of their populations across the landscape? The answers to such questions require further study, but the results of this work imply that we may no longer be able to simplify landscapes to their obvious physical features such as size and distance between habitat patches. Here we demonstrate one example where aphid pests are less constrained than their natural enemies in a fragmented, sub-urban landscape. Future studies testing the effects of fragmentation patterns on Taylor's temporal law across multiple landscapes and organisms may help untangle the complex relationship between population, community and landscape structures. Practical applications including the design of urban garden landscapes that can maximize natural enemy persistence, while reducing synchronous dynamics in long-range pest species is just one example.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

AUTHOR CONTRIBUTIONS

TO and JV conceived and developed the study. TO, LH, and AL jointly designed and carried out the field surveys. DP and LH identified the field specimens. TO, KL, DP, and AL analyzed the field data. MH provided the original garden data. TO and JV drafted the manuscript. All authors contributed the revisions.

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College-Age Millennials' Preferences for Food Supplied by Urban Agriculture

Iryna Printezis[1]* *and Carola Grebitus*[2]

[1] *Department of Supply Chain Management, W. P. Carey School of Business, Arizona State University, Tempe, AZ, United States,* [2] *Morrison School of Agribusiness, W. P. Carey School of Business, Arizona State University, Tempe, AZ, United States*

Millennials are the largest generation, yet. As a result, their preferences are critical when it comes to evaluating success of urban agriculture. Using two online choice experiments, this paper investigates the preferences and willingness to pay of college student millennials for unprocessed (fresh) or processed (typically come in a container) food products sold at urban farms. We also examine whether competing points of sale and other attributes, such as organic, affect preferences, and willingness to pay for urban farm food. We find that, on average, college-age millennials are willing to pay a premium for local food. However, they are not willing to pay premiums for local food that is sold at farmers markets, and discount it when it is purchased directly from an urban farm. Our findings suggest that, if the goal is to increase the sales of urban farm food, targeted promotions are needed. Urban farms have to show the value from purchasing products through their channels to college-age millennials or seek the means to supply their food through grocery stores.

Keywords: farmers market, food systems, local, organic, tomatoes, tomato pasta sauce, sustainability, urban farm

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Gaston Small,
University of St. Thomas,
United States

Reviewed by:
David Conner,
University of Vermont, United States
Lijun Chen,
University of Florida, United States

***Correspondence:**
Iryna Printezis
iiermole@asu.edu

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INTRODUCTION

Consumers' interest in direct-to-consumer marketing channels such as farmers markets, and urban farms is increasing (Zepeda, 2009; Landis et al., 2010; Tropp, 2013). These venues attract consumers because they offer the opportunity to purchase food directly from the grower (AMS, 2016). This in turn, allows customers to connect and develop a personal relationship with the seller (Onianwa et al., 2006). It also enhances their trust in food production because they appreciate knowing where their food comes from Zepeda and Leviten-Reid (2004) and McGarry-Wolf et al. (2005). Moreover, consumers believe that direct-to-consumer channels have a positive effect on the environment, local economy, and farmers' profits (Zepeda, 2009; Landis et al., 2010), while offering access to natural, fresh, and organic food with perceived health benefits (Kolodinsky and Pelch, 1997; Armstrong, 2000; Landis et al., 2010; Sumner et al., 2010). In order to cater to this trend, municipalities started to work on re-purposing vacant lots within cities to provide more opportunity for urban agriculture (Goldstein et al., 2011; Dieleman, 2017)[1]. However, overall direct sales are still rather low (Low et al., 2015).

The low direct-to-consumer sales are rather surprising, as previous research suggests that consumers consider "local" to be the highest value-added claim (Loureiro and Hine, 2002; James et al., 2009; Onozaka and Thilmany-McFadden, 2011). In fact, an abundance of research examines the trends in consumer demand and support of locally grown food, uncovering strong preference and higher willingness to pay (WTP) for it (Hu et al., 2009, 2012; Onken et al., 2011; Carroll et al., 2013; Willis et al., 2013; Meas et al., 2015; Printezis and Grebitus, 2018). For instance, using a national Web-based survey, Onozaka and Thilmany-McFadden (2011) provided evidence that "locally grown" is the most valued claim for Gala apples and red round tomatoes compared to other types of food certifications (e.g., organically grown and fair trade). Also, interviewing Colorado residents in supermarkets, Loureiro and Hine (2002) show that consumers are willing to pay more for local, Colorado grown, fresh potatoes compared to organic and GMO-Free potatoes. Similarly, surveying consumers in 65 counties of Pennsylvania, James et al. (2009) find that consumers have a higher WTP for local applesauce compared to applesauce labeled as USDA organic, low fat, or no sugar added. Apart from local, consumers are also willing to pay more for "organic" (Loureiro and Hine, 2002; Costanigro et al., 2011; Hu et al., 2012; Meas et al., 2015), and in some instances, food labeled as being both local and organic. For example, conducting a study among the shoppers in Colorado chain store, Costanigro et al. (2011) found that consumers are willing to pay more for both organic and local attributes of fresh Gala apples. However, the WTP of $1.18 for local attribute is comparatively higher than the WTP for organic, which is $0.20. This attests further to the fact that local is a more important attribute than other value-added characteristics. Nevertheless, the interaction effects between food labeled as local and organic needs to be investigated because previous studies suggest that there could be a sub-additive or super-additive relationship[2] among these competing attributes (Gracia et al., 2014; Meas et al., 2015).

In addition to food attributes, the literature on WTP for local has shed light on a number of different product types. It becomes evident that consumers' preference for locally produced food persists for fresh, unprocessed locally grown produce (Willis et al., 2013) as well as for processed items, such as local blackberry jam (Hu et al., 2012), and local strawberry preserves (Onken et al., 2011). Moreover, studies show that consumers are willing to pay more for a wide variety of processed local food. For example, conducting an in-store survey among Kentucky residents, Hu et al. (2009) find that consumers have a higher WTP for pure blueberry jam, blueberry-lime jam, blueberry yogurt, blueberry dry muffin mix, and blueberry raisinettes. Furthermore, research suggests that again local ranks higher than other attributes for processed food, as demonstrated by local blackberry jam compared to organic blackberry jam (de-Magistris and Gracia, 2016), and local applesauce compared to one labeled as USDA organic, low fat, or no sugar added (James et al., 2009). Given the profound evidence on preferences for local food, the question arises as to why direct sales are still low (Low et al., 2015). Therefore, it is of interest to examine consumer preferences and WTP for fresh and processed food sold at urban farms, since venues like this seem to offer the "most local" food.

To conduct our study, we focus on the largest adult generation in the U.S. – millennials. With over 80 million people in the U.S. alone, millennials, born between 1982 and 2000, are a particularly influential group of food consumers (Wey Smola and Sutton, 2002; Heaney, 2007; US Census Bureau, 2015; Futurum Research, 2016). They have a tremendous spending power that is predicted to reach one trillion dollars in 2020 (Futurum Research, 2016). It is also valuable to focus on this generation because in 2020 one in three Americans will be a millennial (Futurum Research, 2016). Given the low number of overall direct sales and the large share of millennials, it is of interest to investigate the demand of this consumer segment for direct-to-consumer channels. In fact, analyzing millennials' purchase behavior is not only relevant because of their current spending power, but also because their impact on the food system will continually increase over time. Therefore, we examine whether millennials prefer direct-to-consumer channels, and more specifically, whether they are willing to pay a premium for food from urban farms.

Millennials represent a large share of the U.S. population, and they are a corner stone when it comes to purchase power in food markets. Given the size of this cohort, their impact may grow even further. To the authors' knowledge, research that examines millennials and their preferences for urban farm food is sparse. Past research involving millennials shows that they have a positive attitude toward organic food (Kamenidou et al., 2019) and a higher WTP for it (Organic Trade Association, 2016; Molinillo et al., 2019). In fact, they are very knowledgeable about organic products and possess a high level of trust in its labeling, resulting in them being the largest organic food buyer segment in the U.S. (Organic Trade Association, 2016). College-aged millennials, interested in buying organic produce to prepare their meals, shop at farmers markets (Detre et al., 2010). Also, millennials with higher involvement in food are more attentive to food labels and country of origin labeling (Küster et al., 2019). Finally, millennials who are more knowledgeable with regards to food are more accepting of technologies, where such technologies can improve sustainability (Cavaliere and Ventura, 2018). This implies that millennials may be willing to pay a premium for organic food supplied directly through urban agriculture. In addition, they might prefer local food since they are taking origin labeling into account.

This research contributes to the literature by examining millennials' preferences and WTP for food sold by urban farms, farmers markets, and grocery stores, as reference point. Specifically, we focus on millennials' WTP for processed and

[1]Urban agriculture includes farming in vacant lots and parks in urban areas (USDA Urban Agriculture, 2016), CSAs in urban locations, as well as, farms in the greenbelts of metropolitan areas (Urban Agriculture, 2016; Bailkey and Nasr, 1999).

[2]Two attributes are considered to have a sub-additive (super-additive) relationship when there exists (does not exist) an overlap between their values in the WTP that results in a discounted (higher) total premium compared to the sum of individual WTP for the attributes. This overlap can be determined by examining the sign of the interaction effects between these attributes.

unprocessed food, while accounting for possible interactions between local and organic labeling. We also account for possible interactions between the point of sale, and local and organic labeling. We do so because Grebitus et al. (2017) found that consumers perceive food from urban farms as organically produced, while Ellison et al. (2016) showed that tomatoes from direct-to-consumer outlets were believed to be organic. We aim to answer the following questions. (1) Do millennials prefer to shop for (local and organic) food from urban farms? (2) Are millennials willing to pay more when purchasing (local and organic) food from an urban farmer? (3) Does WTP for urban farm food differ based on whether it is processed or unprocessed? We address our research questions using two online choice experiments surveying millennials – specifically college students, who are the youngest members of the millennial generation and are responsible for purchasing the food they consume—in the Phoenix Metropolitan Area. Previous research shed some light on consumption behavior of college-age millennials in different retail outlets, including farmers markets (Noble and Noble, 2000; Morton and Linda, 2002; Noble et al., 2009; Detre et al., 2010). However, to our knowledge, no study has explored their preference for food from urban farms.

The remainder of the paper is as follows. In the next section we describe the choice experiments, then we explain the econometric model before we present the empirical results. We finish with some concluding remarks.

METHODS

We conducted two online choice experiments with millennials, i.e., Generation Y college students, to simulate food purchase decision making. We used hypothetical choice experiments including cheap talk to estimate marginal WTP (Carlsson and Martinsson, 2001; Lusk and Schroeder, 2004). To account for differences in processed and unprocessed food products we carried out two studies with: (1) a fresh produce item, one pound of fresh tomatoes, and (2) a processed food item, 24-ounce jar of tomato pasta sauce, which is a standard size jar for this type of product. We chose these products because they are common and familiar food items that consumers can buy at all three shopping locations included in the study. Also, tomatoes are the second most consumed fresh vegetable[3] in the US, with 28.7 pounds of tomatoes available for consumption per person in 2017 (USDA, 2017a,b). Tomato pasta sauce, on the other hand, is the most consumed processed tomato product (USDA Tomatoes, 2016). This ensures that participants are familiar with the products they are choosing. Furthermore, in the study location Arizona local tomatoes can be grown year-round (Arizona Harvest Schedule, 2016). Thus, tomatoes and tomato pasta sauce are not season specific items and are readily available to consumers throughout the year.

[3]Even though botanically tomato is a fruit, in 1893 the U.S. Supreme Court ruled it to be considered a vegetable (NIX v. HEDDEN, 1893).

TABLE 1 | Choice experiment attributes and levels.

Attributes	Levels		
Price			
Tomatoes (1 lb)	$0.99	$2.99	$4.99
Tomato pasta sauce (24-ounce jar)	$1.99	$3.99	$5.99
Travel time	Travel time one-way 5 min	Travel time one-way 15 min	Travel time one-way 25 min
Point of Sale	Grocery store	Farmers market	Urban farm
Certified organic	USDA organic	No label	
Local production	Locally grown	No label	

Choice Experiment Attributes

Our two choice experiments include five attributes—point of sale, organic, local, travel time, and price—displayed in **Table 1**. The price has three levels with a price range reflecting low-end, average, and high-end prices of the products in the marketplace. The attribute regarding local production was displayed as a "Locally grown" label, which was either present or absent. Similarly, the certified organic attribute was displayed as the "USDA Organic" label that was either present or absent.

The focus of this study is on the distribution location, which is deemed an important food shopping attribute (Craig et al., 1984). We include urban farm, farmers market, and, for comparison, grocery store. We provide a definition of urban farm before the experiments in case participants are unfamiliar with it. In addition, we do not only include location itself but also travel time because consumers will always try to minimize distance to the outlet (Handy, 1992). Hence, convenience is a significant driver of store choice (Briesch et al., 2009). Urban farms might be at a disadvantage due to not only a limited assortment but also a more remote location (Kezis et al., 1984; McGarry-Wolf et al., 2005; Gumirakiza et al., 2014). We include 5, 15, and 25 min for a one-way trip to the point of sale as our measure of travel time as choice experiment attribute.

The extent of processing may confound the identification of the distribution channel, as direct channels are often associated with fresh foods only, and also with local labeling. Previous studies on local food examine preferences and WTP for fresh produce (Darby et al., 2008; Costanigro et al., 2011; Onozaka and Thilmany-McFadden, 2011) and processed food items (James et al., 2009; Hu et al., 2012). The question of how processing affects the "local premium" and how this is related to urban farming is important as it represents a substantial investment in value-added by often small and potentially urban farmers. A review from 2000 to 2014 supports this notion (Feldmann and Hamm, 2015). Therefore, we compare the WTP for an unprocessed, fresh produce item (tomatoes) and a processed food item (tomato pasta sauce) sold at different points of sale, including urban farms, farmers markets and grocery stores.

Design of Experiment

The choice experiment design consists of four blocks with nine choice sets each, for a total of 36 choice sets. To minimize fatigue

A	B	C	D	E
$0.99 Urban Farm Locally grown Travel time one way 15 min.	$2.99 Farmers Market Travel time one way 25 min.	$4.99 Urban Farm USDA Organic Locally grown Travel time one way 25 min.	$4.99 Grocery store Travel time one way 15 min.	None of these

FIGURE 1 | Sample choice set for 1 lb of tomatoes.

or learning effects each participant is only presented with one block (Lusk and Norwood, 2005). The order of the choice sets in each block is randomized, and each respondent is randomly assigned to one of the four blocks. Each choice set consists of four choice options plus an opt-out option ("None of these").

The design was created following Scarpa et al. (2012). First, an orthogonal design was generated. This design was used in a pre-test with $n = 21$ participants. The pre-test data was analyzed, and the estimated coefficients were used as priors to create a Bayesian efficient design. The design included price, organic, local, point of sale, and travel time as attributes. Furthermore, interaction effects were included to account for relationships between farmers market and urban farm, and local, and organic. As a result, we are able to specify whether organic or local food from urban farms leads to higher or lower WTP. In addition, this allows us to investigate, whether products labeled as local *and* organic increases or decreases WTP.

TABLE 2 | Sample characteristics.

Characteristics	Tomatoes (% unless stated)	Tomato pasta sauce (% unless stated)
Number of observations	172	270
Age in years (mean)	21.66	22.84
Household size (mean)	3.27	3.04
Children under the age of 12 in the household	5.81	7.04
Household income (mean in $)	48,386.63	45,028.41
Gender (female) (%)	45.35	34.44
Educational level (%)		
High school diploma	16.30	13.58
Some college	71.51	64.15
Bachelor's degree	12.21	22.26

Data

The online choice experiments were conducted using a between-subject design with $n = 173$ participants in the "tomato" experiment and $n = 270$ participants in the "tomato pasta sauce" experiment. Data for the experiments can be found in **Supplementary Tables 1** (tomato pasta sauce) and **2** (tomatoes). The respondents recruited were third- and fourth-year students—who are the youngest members of the millennial generation—at Arizona State University students that received class credit for their participation.

The experiment was programmed in Qualtrics. To begin, each participant read a cheap talk script to lower hypothetical bias (Cummings and Taylor, 1999). Cheap talk explained that it is important to make each decision as if one was actually facing it in real-life. Afterwards, respondents were asked to make their choices. A sample choice set is displayed in **Figure 1**.

In addition to the choice experiment, participants answered demographic questions, specifying, among others, their age, gender, and household size. The survey produced an eligible sample of 442 participants, one participant had to be excluded as (s)he did not complete the survey. Summary statistics for the basic socio-demographic characteristics of the sample are presented in **Table 2**. Less than half of participants are female. Participants are on average 22 years old, living in a 3-member household. Using this sample, we are able to estimate the WTP with an econometric model appropriate for discrete-choices among local food products.

Model

To analyze our data we used mixed logit models to allow for variations in consumer preferences that may arise from correlation in unobserved factors over sequential treatments, unrestricted substitution across product attributes, and random taste differences (Train, 2009).

In choice modeling it is assumed consumer i maximizes his or her utility by choosing a product among j alternatives with attributes that provide the highest level of utility at choice occasion t. The utility consists of a deterministic component

V_{ijt}, which includes the specified attributes of the product, and a random component e_{ijt}, which is unobservable to the researcher:

$$U_{ijt} = V_{ijt} + e_{ijt} \tag{1}$$

Under the assumption of a linear utility functional form, the deterministic component can be written as $\beta'_i x_{ijt}$ so the indirect utility function is written:

$$U_{ijt} = \beta'_i x_{ijt} + e_{ijt} \tag{2}$$

where β_i is a vector of structural parameters that are specific to consumer i and x_{ijt} is a vector of the observed variables of the alternative j faced by consumer i at the choice occasion t.

In our choice experiments respondents were asked to make nine choices each for tomatoes and tomato pasta sauce. The choices are analyzed as follows:

$$\begin{aligned} U_{ijt} = {} & \alpha_i Price_{jt} + \beta_{1i} UrbanFarm_{jt} + \beta_{2i} FarmersMarket_{jt} \\ & + \beta_{3i} OrganicLabel_{jt} + \beta_{4i} LocalLabel_{jt} + \beta_{5i} TravelTime_{jt} \\ & + \beta_{6i} UrbanFarm_{jt} OrganicLabel_{jt} \\ & + \beta_{7i} UrbanFarm_{jt} LocalLabel_{jt} \\ & + \beta_{8i} FarmersMarket_{jt} OrganicLabel_{jt} \\ & + \beta_{9i} FarmersMarket_{jt} LocalLabel_{jt} \\ & + \beta_{10i} OrganicLabel_{jt} LocalLabel_{jt} + e_{ijt} \end{aligned} \tag{3}$$

where α_i is the price parameter, and β_{ki} are attribute parameters varying over consumers *i*. $Price_{jt}$ is one of the three price levels of option j in choice set t. *TravelTime* is one of the three travel times of option j in choice set t. *UrbanFarm* and *FarmersMarket* are binary variables equal to 1 if tomatoes (tomato pasta sauces) are sold at either the urban farm or farmers market, and zero if they are sold at the grocery store. *OrganicLabel* and *LocalLabel* are binary variables equal to 1 if the products are certified organic or produced locally, and zero otherwise. *UrbanFarm** *OrganicLabel* is an interaction term representing the products sold at the urban farm *and* labeled as certified organic, and zero otherwise. *UrbanFarm** *LocalLabel* is an interaction effect indicating that tomatoes (tomato pasta sauces) sold at the urban farm are locally produced, zero otherwise. *FarmersMarket** *Organic* is an interaction effect representing those products that are sold at the farmers market *and* labeled organic zero otherwise. Similarly, *FarmersMarket** *LocalLabel* is an interaction effect representing those products that are sold at the farmers market *and* produced locally, zero otherwise. *LocalLabel** *OrganicLabel* is an interaction effect representing those products that are both, organic and local, zero otherwise, and e_{ijt} is the error term. The mixed logit models are estimated with 500 Halton draws (Revelt and Train, 1998).

Once preferences are determined we calculate WTP by dividing the attribute coefficients by the negative of the price coefficient (Greene, 2016):

$$WTP_n = \left(\sum_{i=1}^{k}\left(-\frac{\beta_{ni}}{\beta_{pricei}}\right)\right)/k \tag{4}$$

We determine the significance of the WTP estimates following Daly et al. (2012):

$$\left(\frac{\beta_n}{\beta_0}\right)^2 \left(\frac{\omega_{nn}}{\beta_n^2} + \frac{\omega_{00}}{\beta_0^2} - 2\frac{\omega_{n0}}{\beta_n \beta_0}\right) \tag{5}$$

where β_0 is the price parameter, β_n are attribute parameters, and ω is the variance and covariance for the parameter estimates.

EMPIRICAL RESULTS

Preferences

The results of the mixed logit models for tomatoes and tomato pasta sauce are presented in **Tables 3**, **4**, respectively. In each table the first column shows the model without interaction effects, the next two columns introduce interaction effects stepwise, and the last column shows the results of the full model including all interaction effects. The models are highly significant as shown by McFadden's Pseudo R^2. Based on the log-likelihood functions the full model is significantly improving in model fit for both, tomatoes and pasta sauce, when tested against the limited models.

The full models include five interaction effects. This means that the interpretation of the main effects depends on the interaction effect interpretation. We follow Meas et al. (2015) and include interaction effects as dummy variables (values one or zero) in the equations.

In both models the *price* coefficient is significant and negative as expected, indicating that a higher price of an alternative lowers the probability to be chosen. Compared to shopping for the products at the *grocery store*, college-age millennials do not have a significant preference for shopping at the *farmers market* (main effect). The main variable of interest, *urban farm*, is significant and negative for the main effect indicating that college-age millennials would rather shop for tomatoes and tomato pasta sauce at the grocery store. Both products are preferred when carrying labels for being locally and organically produced (main effects). *Travel time*, not surprisingly, is preferred to be shorter rather than longer for both products.

Looking at the interaction effects, we find differences between the products. The coefficient for the interaction effect for tomatoes labeled as being *local* and *organic* is significant and negative—this is not significant for tomato pasta sauce. The interaction effect indicating that food labeled as *local* are sold at a *farmers market* is significant and negative for both, tomatoes and tomato pasta sauce. The interaction effects for *urban farms* are not significant. This means that it is not relevant for college-age millennials whether urban farms' products are labeled as organic or local. However, there is some heterogeneity in preferences, as displayed by significant standard deviation parameters.

For both products, the main standard deviation coefficient for *urban farm* tomatoes and tomato pasta sauce is significant. This means that there are college-age millennials that do prefer urban farm tomatoes and tomato pasta sauce. Also, for tomato pasta sauce the standard deviation for the interaction effect for *local* tomato pasta sauce sold at *urban farms* is significant. Other significant standard deviations coefficients are *organic* and *travel time* for both tomatoes and pasta sauce, indicating heterogeneity

TABLE 3 | Mixed logit model estimation results for tomatoes.

	Coefficient		SE	z-value	Coefficient		SE	z-value	Coefficient		SE	z-value	Coefficient		SE	z-value
Price (M)	−0.696	***	0.034	−20.470	−0.692	***	0.035	−19.790	−0.682	***	0.034	−19.870	−0.692	***	0.035	−19.730
Farmers market (M)	−0.150		0.111	−1.350	−0.072		0.176	−0.410	0.069		0.153	0.450	0.131		0.195	0.670
Urban farm (M)	−0.683	***	0.118	−5.790	−0.829	***	0.172	−4.820	−0.660	***	0.169	−3.910	−0.815	***	0.216	−3.760
Organic (M)	0.712	***	0.116	6.130	0.916	***	0.197	4.660	0.860	***	0.137	6.260	0.904	***	0.199	4.550
Local (M)	0.186	*	0.098	1.890	0.440	***	0.141	3.120	0.606	***	0.178	3.400	0.665	***	0.181	3.670
Travel time (M)	−0.161	***	0.011	−14.460	−0.164	***	0.011	−14.740	−0.165	***	0.011	−14.560	−0.167	***	0.012	−14.460
Local*organic (M)					−0.443	**	0.193	−2.300	−0.357	*	0.190	−1.870	−0.420	**	0.194	−2.170
Farmers market* organic (M)					−0.177		0.220	−0.800					−0.146		0.227	−0.640
Farmers market* local (M)									−0.619	***	0.230	−2.690	−0.600	***	0.230	−2.600
Urban farm* organic (M)					0.169		0.232	0.730					0.224		0.231	0.970
Urban farm* local (M)									−0.127		0.213	−0.600	−0.089		0.216	−0.410
None (M)	−3.938	***	0.251	−15.710	−3.835	***	0.278	−13.810	−3.714	***	0.267	−13.890	−3.821	***	0.280	−13.670
Farmers market (SD)	0.289		0.264	1.100	0.337		0.247	1.360	0.412	**	0.207	1.990	0.132		0.467	0.280
Urban farm (SD)	0.521	***	0.191	2.720	0.476	**	0.210	2.260	0.509	**	0.205	2.490	0.564	***	0.216	2.610
Organic (SD)	0.938	***	0.139	6.770	0.789	***	0.167	4.730	0.801	***	0.157	5.110	0.764	***	0.164	4.670
Local (SD)	0.289		0.205	1.410	0.012		0.270	0.050	0.010		0.254	0.040	0.076		0.281	0.270
Travel time (SD)	0.095	***	0.011	8.460	0.092	***	0.010	9.280	0.093	***	0.010	9.300	0.095	***	0.010	9.790
Local*organic (SD)					0.837	**	0.220	3.810	0.814	***	0.211	3.860	0.715	***	0.265	2.700
Farmers market* organic (SD)					0.271		0.344	0.790					0.594	***	0.223	2.670
Farmers market* local (SD)									0.116		0.427	0.270	0.252		0.379	0.660
Urban farm* organic (SD)					0.223		0.466	0.480					0.053		0.558	0.090
Urban farm* local (SD)									0.189		0.333	0.570	0.224		0.347	0.640
None (SD)	1.840	***	0.206	8.950	2.027	***	0.222	9.120	2.031	***	0.222	9.160	1.901	***	0.203	9.350
Log–likelihood		−1602.504				−1595.434				−1592.586				−1590.021		
McFadden pseudo R–squared		0.357				0.360				0.361				0.362		

****, **, and * denote statistically significant differences at 1%, 5% and 10%, respectively.*
SE, Standard Error.

TABLE 4 | Mixed logit model estimation results for tomato pasta sauce.

	Coefficient		SE	z–value	Coefficient		SE	z–value	Coefficient		SE	z–value	Coefficient		SE	z–value
Price (M)	−0.469	***	0.022	−21.370	−0.464	***	0.022	−20.650	−0.468	***	0.023	−20.670	−0.469	***	0.023	−20.440
Farmers market (M)	−0.029		0.088	−0.330	0.031		0.132	0.240	0.137		0.120	1.130	0.168		0.152	1.100
Urban farm (M)	−0.313	***	0.083	−3.750	−0.247	**	0.120	−2.060	−0.359	***	0.126	−2.850	−0.280	*	0.156	−1.800
Organic (M)	0.494	***	0.081	6.110	0.692	***	0.141	4.920	0.621	***	0.100	6.240	0.672	***	0.142	4.730
Local (M)	0.453	***	0.075	6.080	0.541	***	0.101	5.340	0.696	***	0.131	5.330	0.687	***	0.134	5.150
Travel time (M)	−0.112	***	0.007	−15.840	−0.114	***	0.007	−15.660	−0.114	***	0.007	−15.610	−0.113	***	0.007	−15.490
Local*organic (M)					−0.241	*	0.140	−1.720	−0.265	*	0.142	−1.870	−0.236		0.144	−1.640
Farmers market* organic (M)					−0.097		0.159	−0.610					−0.060		0.161	−0.370
Farmers market* local (M)									−0.481	***	0.170	−2.840	−0.498	***	0.171	−2.900
Urban farm* organic (M)					−0.172		0.161	−1.070					−0.155		0.163	−0.960
Urban farm* local (M)									−0.004		0.162	−0.030	−0.004		0.161	−0.030
None (M)	−2.965		0.180	−16.480	−2.863	***	0.203	−14.120	−2.964	***	0.196	−14.580	−2.903	***	0.210	−13.810
Farmers market (SD)	0.600	***	0.128	4.680	0.592	***	0.126	4.700	0.620	***	0.133	4.680	0.637	***	0.132	4.810
Urban farm (SD)	0.488	***	0.148	3.290	0.458	***	0.148	3.110	0.403	**	0.177	2.280	0.449	***	0.155	2.900
Organic (SD)	0.800	***	0.098	8.160	0.641	***	0.115	5.590	0.634	***	0.122	5.190	0.631	***	0.123	5.150
Local (SD)	0.471	***	0.144	3.270	0.202		0.320	0.630	0.087		0.536	0.160	0.134		0.232	0.570
Travel time (SD)	0.074	***	0.007	11.150	0.078	***	0.008	10.220	0.077	***	0.007	10.870	0.077	***	0.007	10.760
Local*organic (SD)					0.858	***	0.154	5.580	0.927	***	0.143	6.500	0.870	***	0.138	6.320
Farmers market* organic (SD)					0.0526		0.234	0.230					0.298		0.254	1.170
Farmers market* local (SD)									0.372		0.332	1.120	0.359		0.360	1.000
Urban farm* organic (SD)					0.009		0.200	0.050					0.042		0.205	0.210
Urban farm* local (SD)									0.479	**	0.227	2.110	0.460	**	0.218	2.110
None (SD)	1.768	***	0.159	11.120	1.793	***	0.161	11.160	1.794	***	0.172	10.400	1.813	***	0.157	11.540
Log–likelihood	−2986.976				−2977.597				−2971.526				−2964.087			
McFadden pseudo R-squared	0.236				0.239				0.240				0.242			

****, **, and * denote statistically significant differences at 1%, 5% and 10%, respectively.*
SE, Standard Error.

TABLE 5 | Mean willingness to pay estimates.

	Tomatoes $/lb		Tomato pasta sauce $/24-ounce jar	
Farmers market	0.19		0.37	
Urban farm	−1.19	***	−0.58	*
Organic	1.31	***	1.43	***
Local	0.96	***	1.46	***
Travel time	−0.24	***	−0.24	***
Local*organic	−0.62	**	−0.50	***
Farmers market* organic	−0.20	***	−0.11	***
Farmers market* local	−0.87		−1.05	***
Urban farm* organic	0.32	*	−0.33	**
Urban farm* local	−0.13		−0.02	***

****, **, and * denote statistically significant differences at 1%, 5%, and 10%, respectively.*

in preferences. Furthermore, there is preference heterogeneity for the interaction effect of *organic* and local for both products, as well as for *farmers market* for pasta sauce, and organic tomatoes sold at *farmers markets*.

Willingness-to-Pay

Next, **Table 5** shows the WTP per pound of tomatoes and 24oz jar of tomato pasta sauce. Most of the WTP estimates for both products are similar in sign and significance, however, we do find a difference in magnitude between tomatoes and tomato pasta sauce. While WTP is not significant for *farmers market,* it is significantly negative for *urban farm,* indicating that college-age millennials would only consider purchasing fresh tomatoes and tomato pasta sauce at an urban farm if prices were lower than at the grocery store (grocery store serves as point of sale reference category).

Findings for *local* and *organic* labeling show a significant and positive WTP, all else constant, suggesting that college-age millennials would pay more for local or organic tomatoes and tomato pasta sauce. This is in line with previous studies (Hu et al., 2009; Yue and Tong, 2009; Costanigro et al., 2011; Onozaka and Thilmany-McFadden, 2011; Carroll et al., 2013). For *Travel Time* we find a significant and negative WTP indicating that longer distances to the point of sale decreases college-age millennials' WTP. This matches previous research that showed the value for convenient shopping locations (Bell and Lattin, 1998; Leszczyc et al., 2000).

As for the interaction effects, results for *organic* tomatoes and pasta sauce sold at the *farmers market* show a lower WTP indicating that college-age millennials discount the products. The same is found for *organic* pasta sauce sold at *urban farms*. That said, the WTP for *organic* tomatoes sold at an *urban farm* is positive. This means that urban farms could realize a premium when selling organic tomatoes in the amount of $0.44 (-$1.19 + $1.31 + $0.32). Compared to the significant and negative WTP (–$1.19) when tomatoes are sold at the *Urban Farm* this is quite large (this is in comparison to the baseline, which is the grocery store). Also, we find a significant and negative interaction effect for tomato sauce labeled as *locally* produced and sold at either the *farmers market* or the *urban farm*. This might stem from the fact that college-age millennials do not necessarily expect processed products to be sold at these outlets and might be unsure of the value. Uncertainty has been associated with lower WTP.

When products were labeled as *locally* and *organically* produced WTP significantly decreased, which means that college-age millennials would pay less for tomatoes and tomato pasta sauce that is certified as being local and organic.

CONCLUSION

In this research we investigate if college-age millennials are willing to pay a premium for processed and unprocessed food sold at competing points of sale, including urban farms. In addition, we examine if this premium is affected by the convenience of the shopping venue, as well as, by being labeled as locally and organically grown.

Results from two online choice experiments show that college-age millennials are willing to pay a premium for local food. However, the positive WTP for local food is not attached to the point of sale. While one could assume that urban farms have an advantage selling the ultimate local food, we do not find positive WTP for food sold directly at urban farms. In other words, millennials in our study do not prefer direct channels over grocery stores to buy local food, instead WTP declines for processed food labeled as local sold at farmers markets and urban farms. Reasons for this could be the attitude that these venues cater to price conscious consumers, or that less financial input is required when growing, processing, and selling is done in one place. Moreover, the negative WTP for local tomato pasta sauce at farmers market or urban farm could be explained with the expectation that processed local food at farmers markets and urban farms should be more affordable (McGarry-Wolf et al., 2005; McCormack et al., 2010).

Similarly, the discount for organic tomatoes and pasta sauce sold at the farmers market and for tomato pasta sauce sold at urban farms might suggest that consumers believe that products sold at farmers markets are of inferior quality, e.g., they do not carry the premium brands available at grocery stores. On the other hand, the millennials we studied have a positive WTP for organically produced items at urban farms. Hence, selling organic products might be economically beneficial for urban farms. Those producing organically might benefit from adding a label that indicates local production given the positive WTP we find. Therefore, while urban farms may not be able to charge higher prices, focusing on these labels could be valuable when advertising their products.

Our results can be used by fresh produce growers, processed food manufacturers, retailers and legislators who seek to influence urban farm sales. We find that college-age millennials do not have a strong preference for urban farms, as distributors compared to grocery stores, and are not willing to pay a premium. On the contrary, they are willing to pay less at urban farms. Also, we provide evidence that college-age millennials have lower preferences and WTP for local products sold at farmers markets, while their preferences and WTP for products at urban farms do not depend on the fact that the food sold there is local. However, longer travel distances could become an obstacle for urban farms that try to sell their products on or near their premises, if they have a remote location. Bringing their products closer to customers or offering additional shopping experience, e.g., light shows during the holidays, corn labyrinth, could help urban farms to offset the travel distance.

There are some limitations to our research. First, we focus on college-age millennials with a convenience sample of college students being on average 22 years old. This means they are among the youngest millennials, whereas the oldest millennials are 40 years old. Also, we focus exclusively on college students not taking into account millennials without a college education. Future studies could expand the sample by focusing on older millennials and on those without a college degree. That said, we believe that college-age millennials are a valuable target group as their food preferences are important to understand in order to prepare our food systems for the future demand of this consumer segment. We consider this group to be highly influential in terms of future food consumption, especially since they soon will move on to higher paying jobs.

Second, this research studies participants in a certain region. Expanding to other research locations might be valuable. In addition, we only tested preferences for tomatoes and tomato pasta sauce. Future research could expand the variety of processed and unprocessed food products. For instance, we only investigated plant products, animal products or more processed products with a lot of ingredients, e.g., pizza could lead to more detailed findings.

Third, we did not introduce consumer characteristics, such as attitudes, knowledge and perception, into our choice models. Since we already included interaction effects between the choice attributes, introducing additional controls would lead to triple interaction effects. Future research could abstain from interactions between the attributes and research underlying effects of preferences for urban farm food. It is possible that college-age millennials are not used to visit urban farms when shopping for food given their budget is more constrained. As a result, they might be less experienced with these outlets, which could explain the discount effect for food sold at direct marketing channels.

Finally, future research could investigate the fact that college-age millennials have a positive WTP for organic food from urban farms. It might be valuable to conduct a cost benefit analysis regarding costs of organic certification needed by those urban farms. However, consumers may not have the knowledge to differentiate between local and organic production, since they often believe local food is organically produced. Thus, more education might be necessary to capitalize on the organic production.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/**Supplementary Material**.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Internal Review Board of Arizona State University. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

IP contributed to conception and design of the study, organized the database, performed the analysis, and wrote the first draft of the manuscript. CG served as secondary writer of the manuscript and contributed to conception and study design. All authors contributed to manuscript revision, read and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2020.00048/full#supplementary-material

Supplementary Table 1 | Data set for tomato pasta sauce.

Supplementary Table 2 | Data set for tomatoes.

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Urban Rooftop Agriculture: Challenges to Science and Practice

*Yoshiki Harada** *and Thomas H. Whitlow*

Urban Horticulture Institute, Horticulture Section, School of Integrative Plant Science, Cornell University, Ithaca, NY, United States

Urban green infrastructure includes both natural inputs and artificial supplements, including irrigation, synthetic substrates, and drainage layers. Green infrastructure aims to make cities more resilient and less dependent on outside resource inputs through more efficient use. Over the past 2 decades, these constructed ecosystems have expanded to include green roofs, elevated urban parks, and rooftop vegetable farms. This paper outlines opportunities and challenges for advancing the science of these constructed ecosystems with particular emphasis on rooftop agriculture. Although in concept rooftop agriculture could contribute to urban food security, water management, and biodiversity, research comparing design and management strategies across climate zones and regional economies is necessary to fully integrate ecological understanding into urban planning policy.

Keywords: green infrastructure (GI), urban biogeochemistry, urban ecology, green roof, rooftop agriculture, ecosystem services (ES), urban agriculture (ua)

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Panagiotis Nektarios, Hellenic Mediterranean University, Greece

***Correspondence:**
Yoshiki Harada
yh535@cornell.edu

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INTRODUCTION

Cities are recognized as having environmental footprints extending far beyond their political borders, consuming resources and producing wastes in ways that can globally impact nature and human well-being (Vitousek et al., 1997; Alberti et al., 2003; Grimm et al., 2008). Beginning in the 1990s, this recognition has led to studies of urban biogeochemical cycles, while practices of urban planning and design have applied this knowledge, and explored diverse options for restoring ecological functionality to the built environment (Palmer et al., 2004; Kennedy et al., 2011; Pataki et al., 2011; Pickett et al., 2011). For example, horticultural technologies support the establishment and maintenance of soil-plant systems, such as green roofs, bio-retention basins, and other green spaces constructed on built surfaces, including roofs, pavements, and street-level portions of underground structures (Dunnett and Hitchmough, 2004; Dunnett and Clayden, 2007; Oberndorfer et al., 2007; Driscoll et al., 2015; Lundholm, 2015).

Major strides have been made in the practice of growing drought-tolerant succulents, grasses, and shrubs by using synthetic substrates on top of built surfaces with little or no supplemental irrigation and nutrients (**Figure 1A**) (Dunnett and Hitchmough, 2004; Dunnett and Kingsbury, 2008; Dunnett et al., 2008; Dvorak and Volder, 2010; MacIvor and Lundholm, 2011; Kotsiris et al., 2012; Nektarios et al., 2012, 2014, 2015; Ntoulas et al., 2013b; Van Mechelen et al., 2015). Design approaches have even expanded to include large-scale (e.g., > 2 ha) elevated urban parks (**Figure 1B**) and rooftop agriculture (**Figure 1C**) (Harada et al., 2017; Houston and Zuñiga, 2019). Since the late 1990's, these constructed ecosystems have become integral components of urban "green infrastructure" projects (Lundholm, 2015). The diverse goals of these green infrastructure projects include stormwater management, energy savings, biodiversity restoration, air pollution abatement, crop production, and recycling food waste through composting (Oberndorfer et al., 2007; Berndtsson, 2010; Rowe, 2011; Ahern et al., 2014). There are growing bodies of research relevant to performance measurements and improvements of constructed ecosystems in the fields of plant and soil science, hydrology, and biogeochemistry, while further research is needed for developing best management practices that directly inform urban planning and policy (Pataki et al., 2011; Driscoll et al., 2015; Pataki, 2015).

Novel Ecosystems

An overarching framework of ecological communities represented in green infrastructure is useful for delineating and understanding constructed urban ecosystems. In terms of the intensity of ecosystem modification, urban green infrastructure projects range from remnant natural ecosystems to entirely constructed ecosystems (**Figure 2**). Urban ecosystems are often described as "novel ecosystems" which have no analog in the non-urban environments traditionally studied in the field of ecology (Hobbs et al., 2006; Kowarik, 2011; Perring et al., 2013). For example, remnant natural ecosystems in the urban environment can have distinct species composition and dynamics as the result of unintentional human influence such as the legacy of industrial activities (Kowarik, 2005, 2011). Although the difference between novel and constructed ecosystems is still debated, the concept of novel ecosystem has been used to describe constructed ecosystems as the direct outcome of urban planning and design (Lundholm, 2015; Ahern, 2016; Higgs, 2017). For example, biogeochemical properties of constructed ecosystems are engineered using artificial components such as synthetic substrates, drainage layers, and water-proofing membranes, which alter ecological processes such as movements of water and nutrients across spatiotemporal scales (Berndtsson, 2010; Pataki et al., 2011; Rowe et al., 2014; Fassman-Beck et al., 2015; Harada et al., 2018a,b). These artificial components are studied from various points of view in the disciplines of horticulture, controlled-environment agriculture, and civil and environmental engineering, all of which need to be included in collaborative research if the goal is increased understanding and improved performance of constructed ecosystems (Ampim et al., 2010; Sloan et al., 2012; Harada et al., 2017).

Advancing Urban Ecology Through Constructed Ecosystems

Planning and design of constructed ecosystems could offer opportunities for advancing the "ecology of cities" which is the science of coupled human-natural systems in the urban environment (Grimm et al., 2000; Pickett et al., 2001; McPhearson et al., 2016). In green infrastructure projects, design strategies intended to assure specific ecological processes and environmental goals often lack evidence. For example, green roofs and rooftop agriculture intended to reduce the nutrient load in runoff may in fact increase the load due to fertilizer application, because the present state of knowledge and technology are insufficient to allow precision nutrient management (Driscoll et al., 2015; Harada et al., 2018a). Socio-ecological assumptions are often implicit in constructed ecosystems, which could drive interdisciplinary studies of feedback loops between society, science, and transformation of the urban environments (Tanner et al., 2014; McPhearson et al., 2016). "Adaptive experiments" or "designed experiments" are among the approaches of embedding experiments and applying science to urban ecosystems by involving ecologists in design and management practices from the onset (Cook et al., 2004; Felson and Pickett, 2005; Kotsiris et al., 2013; Ntoulas et al., 2013a; Ahern et al., 2014). Constructed ecosystems are ideal for collaborative ecological research because components of constructed ecosystems such as plant selection, substrate properties, and drainage systems can be experimentally manipulated and replicated through design and management practices (Felson and Pickett, 2005; Felson et al., 2013). Design constraints could also be an advantage for experiments. For example, engineers are often constrained by abrupt hydrologic boundaries, shallow substrates, and centralized drainage systems because of budget limitations, regulations, professional guidelines, and load bearing capacity of buildings and underground structures. In such simple and discreet hydrological systems, inputs and drainage losses of water and nutrients can be studied most completely as in the forested catchments in the Hubbard Brook Long-Term Ecological Research (Likens, 2013). This approach would serve as a foundation for pursuing precise water and nutrient management in constructed ecosystems, which reduces the drainage loss of water and nutrients, while maintaining satisfactory crop yield and quality (Harada et al., 2017). Water and nutrient management is important for the practices of rooftop farming.

INTEGRATION OF ROOFTOP INTENSIVE AGRICULTURE IN URBAN ECOSYSTEMS

Rooftop Farming

Urban agriculture is a growing movement which aims to address the diverse goals of urban sustainability, including food security, food equity, efficient food supply chains, stormwater management, mitigation of urban heat island effects, and waste management using compostable waste (Brown and Jameton, 2000; Brown and Bailkey, 2002; Mougeot, 2006; Lovell, 2010; Lovell and Taylor, 2013; Ackerman et al., 2014; Russo et al., 2017). In economically developed countries, urban planning practices treated agriculture as a temporary activity for vacant lots before conversion to more profitable residential, commercial, and industrial land uses (Alonso, 1964; Van Veenhuizen and Danso, 2007). However, urban agriculture is becoming a long-term enterprise by increasing and stabilizing profits through (1) intensive production of fresh and perishable vegetables that have high long distance transportation costs from rural farms; (2) unique marketing strategies such as organic cultivation and production of heirloom and exotic varieties; (3) diversifying crop selection, and/or (4) incorporating non-cropping services such as tourism, environmental education, green job training, culinary events, nature therapy, and creation of lively neighborhood (van der Schans and Wiskerke, 2012; Plakias, 2016; Pölling et al., 2016, 2017).

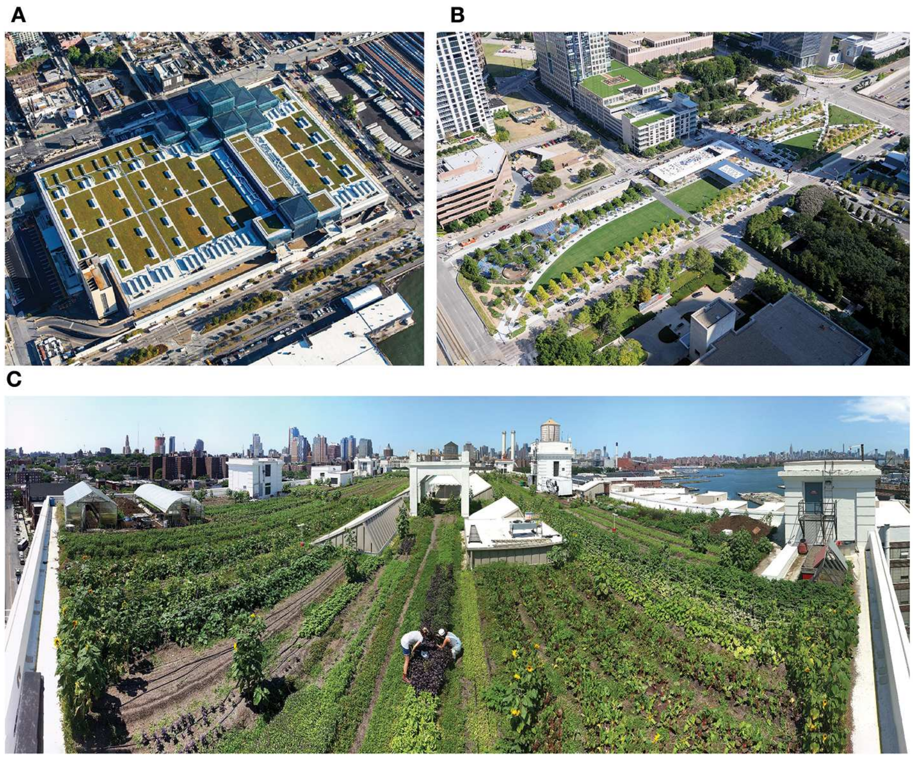

FIGURE 1 | Examples of constructed ecosystems on built surfaces. **(A)** A 2.7-hectare green roof growing drought-tolerant sedum species on the Javits Center in New York City, New York (Image © Javits Center). **(B)** Klyde Warren Park: a 2.1-hectar public park, growing trees, shrubs, lawns, and ornamental herbs on the capping structure over Woodall Rodgers Freeway in Dallas, Texas (Image © OJB Landscape Architecture). **(C)** The Brooklyn Grange: a 0.6-hectar rooftop farm growing vegetables on top of an 11-story building in the former Brooklyn Navy Yard in New York City, New York.

Limited space and competitive real-estate markets are impediments for in-ground agriculture, while farms retrofitted to roofs occupy otherwise underutilized space in the built environment (Specht et al., 2014; Thomaier et al., 2015; Whittinghill and Starry, 2016). New York City alone has 15,482 ha of rooftop surface, equal to 445 times the size of existing community gardens (Ackerman et al., 2013). Converting even a small portion of this space to agriculture presents important opportunities for advancing urban agriculture.

In addition to private investments, rooftop farming can combine policy supports and public funding from green building and green infrastructure initiatives. Since 2011, for example, Community-Based Green Infrastructure Program of NYC Department of Environmental Protection provides grants for construction of green infrastructure projects including rooftop farms as a part of 20-year green infrastructure masterplan (NYC DEP, 2010, 2011), while since 2013, NYC's new zoning code, "Zone Green," allows modification of buildings for enhancing urban sustainability, including the construction of rooftop farms (NYC DCP, 2012). One of the outcomes is the Brooklyn Grange, a 0.6 ha intensive vegetable production farm atop an 11-story building in the former Brooklyn Navy Yard, NYC (**Figure 1C**). The Brooklyn Grange yields 11,000-13,000 metric tons year^{-1} of organic vegetables, while expanding relationships with local residents, schools, restaurant owners, and non-profit organizations through vegetable sales, green job training, environmental education, and waste collection for composting (Plakias, 2016; Harada et al., 2018a).

Rooftop farming could enjoy further opportunities through the NYC's new green building policy known as "Climate Mobilization Act," which takes effect in 2024, mandating improvements in building energy performance including vegetated roofs (New York City Council, 2019). However, the scientific community has little hard data on the environmental and economic performance of rooftop farming. Empirical studies of water and nutrient budgets for operational rooftop farms could serve as a starting point for understanding and improving the performance of rooftop farming.

Hypothetical City-Scale Effects

Among the studies of rooftop farming using experimental systems, city-scale production capacity of rooftop farming was estimated only once (Orsini et al., 2014). They report that outdoor hydroponic systems (57% of site area) and planters using synthetic substrates (43% of site area) could maximize the yield of lettuce (*Lactuca sativa* L.), black cabbage (*Brassica oleracea* Acephala Group), chicory (*Cichorium intybus* L.), tomato (*Solanum lycopersicum* L.), eggplant (*Solanum melongena* L.), chili pepper (*Capsicum annum* L.), cantaloupe (*Cucumis melo* L.), and watermelon (*Citrullus lanatus* Thumb.) in the flat

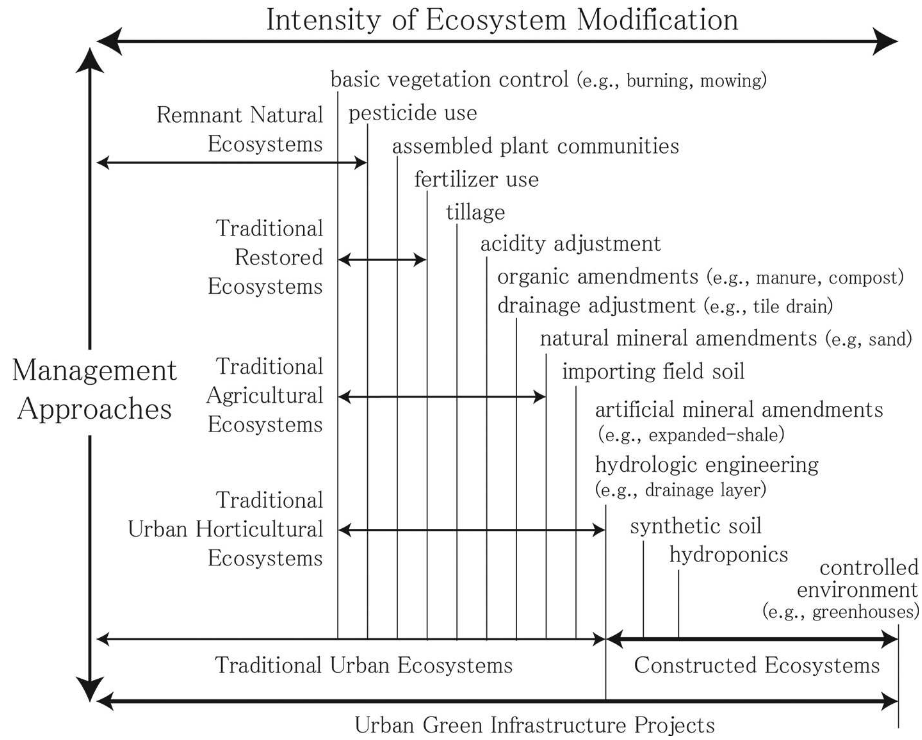

FIGURE 2 | Types of Urban Ecosystems and Intensity of Ecosystem Modification. (adapted from Figure 2 in Sloan et al., 2012).

roof areas (82 ha) of Bologna, Italy, thereby providing 77% of the city's fresh vegetable demand (16,169 metric tons year^{-1}). The study did not estimate city-scale environmental impacts, such as potable water consumption for irrigation, fertilizer input, and drainage loss of water and nutrients (Orsini et al., 2014). Although measurements from experimental systems provide useful insights for understanding the performance of rooftop farming, it is important to study operational rooftop farms because efficiency of water and nutrient management is often higher in small-scale well-managed experimental plots than that in operational farms (see Cassman et al., 2002).

Among the studies of operational rooftop farms, only Harada et al. (2018a,b) report the budget of water and nitrogen of the Brooklyn Grange Navy Yard Farm in NYC, which can be used for estimating the city-scale effect of rooftop farming as summarized in **Supplementary Table S1, S2**. If all suitable rooftops in NYC (1,246 ha) were occupied by rooftop farms like the Brooklyn Grange, the city-scale potable water consumption and nitrogen discharge from wastewater treatment plants to surface water could increase by 0.3 and 0.6%, respectively, while producing 27,344 metric tons year^{-1} of fresh vegetables, equivalent to fresh vegetable consumption of 3.8×10^5 people, or 4% of the estimated city-scale vegetable consumption (**Supplementary Table S1, S2**). Leafy vegetables are one of the most important fresh vegetables grown in urban agriculture including rooftop farming (Ackerman et al., 2013; Baudoin et al., 2017; Harada et al., 2018a), and city-scale demand of greens mix (leafy lettuce and mustard greens) is largest among leafy vegetables grown at the Brooklyn Grange (**Supplementary Table S2**). If all cropped area were dedicated to mixed greens, then the city-scale rooftop farming could produce 38% of the NYC's demand (**Supplementary Table S2**).

Although the NYC's city-scale suitable rooftop area was 15 times of that in Orsini et al. (2014), fresh vegetable production was only 1.1 times of that in Orsini et al. (2014) due to the relatively low yield at the Brooklyn Grange. Average yield per unit are of the entire roof (including both cropped and uncropped areas) at the Brooklyn Grange is only 14% of that reported by Orsini et al. (2014) (15.2 kg m^{-2} year^{-1}), in part, because the growing season was longer (year-around) in Bologna than at the Brooklyn Grange (226 days). Also, the percentage of cropped area in the entire roof is smaller at the Brooklyn Grange (47%) than that reported by Orsini et al. (2014) (65%), while even when the uncropped area is excluded, the average yield at the Brooklyn Grange is only 20% of that reported by Orsini et al. (2014). Other factors for relatively low yield at the Brooklyn Grange include crop selection, design of the production system, and the less intensive management in larger operational farms than that in small experimental plots.

Biodiversity Conservation

Within the context of city-scale ecosystems, isolated patches of urban green space, including urban agriculture and green roofs, can be hotspots for biodiversity (Cook-Patton and Bauerle, 2012; Forman, 2014; Williams et al., 2014; Borysiak et al., 2017; Lepczyk et al., 2017). Declining wildlife populations in farmland and rural areas due to pesticide use increased the importance of cities as wildlife refuge, while organic cultivation in rooftop farming can increase plant, insect, and bird habitat in densely built environments and contribute to urban corridor networks (Gilbert, 1989; Chamberlain et al., 2000; Orsini et al., 2014; Bretzel et al., 2017; Dang, 2017; Hall et al., 2017). Insect pollinators are important indicators of biodiversity across land uses including urban environments, while beekeeping contributes directly to food production (Tommasi et al., 2004; Broadway, 2009; Plakias, 2016; Bretzel et al., 2017; Hall et al., 2017). Studies of green roofs report that management, plant selection, and substrate properties have strong influence on species composition and abundance for wild flora, birds, invertebrates, and the substrate microbial community, emphasizing the need of empirical studies specific to rooftop farming (Dunnett et al., 2008; Dvorak and Volder, 2010; Fernández Cañero and González Redondo, 2010; McGuire et al., 2013, 2015; Williams et al., 2014; MacIvor and Ksiazek, 2015; Bretzel et al., 2017; Ksiazek et al., 2018; Aloisio et al., 2019).

Stormwater Management

Estimated city-scale evapotranspiration (ET) summarized in **Supplementary Table S1** indicates that the potential of stormwater retention by rooftop farming, equals 2.3 X that of the urban forest in NYC. The Brooklyn Grange uses a synthetic substrate for growing vegetables, while the base material of the substrate is heat-expanded shale, which can increase drainage by lowering water-holding capacity of the substrate (Rowe et al., 2014; Ntoulas et al., 2015; Harada et al., 2018b). Although the Brooklyn Grange retained little stormwater during the growing seasons, it should be noted that precipitation exceeded ET at the Brooklyn Grange, which means that stormwater discharge and irrigation demands could be eliminated while maintaining satisfactory yield through enhanced water-holding capacity of the substrate and recirculating drainage (Harada et al., 2018b). Outdoor hydroponic systems can also be used for rooftop farming, which could eliminate drainage discharge by using closed-circuit systems for nutrient solution, and incorporating stormwater recycle systems (Orsini et al., 2014; Sanyé-Mengual et al., 2015b; Rodríguez-Delfín et al., 2017; Tsirogiannis et al., 2017). However, water management using electric pumps requires further research because pumps' electricity consumption can be the largest environmental cost of rooftop farming (Sanyé-Mengual et al., 2015b).

Rooftop Greenhouses

Another option for rooftop intensive agriculture is rooftop greenhouses which could achieve higher levels of yield, water use efficiency, and stormwater retention than those of rooftop farming. For example, Sanjuan-Delmás et al. (2018) report the tomato yield of 19.6 kg m^{-2} $year^{-1}$ in rooftop greenhouse in the city near Barcelona, Spain, which exceeds yields of rooftop farms (5.1–14.3 kg m^{-2} $year^{-1}$) (Orsini et al., 2014; Grard et al., 2015; Harada et al., 2018a; Boneta et al., 2019). Rainwater was collected from roofs of the greenhouse and adjacent building, contributing to 80–90% of total water supply. While nutrient discharge exceeded that of a conventional greenhouse, this could be reduced by using a closed-circuit hydroponic system (Sanjuan-Delmás et al., 2018).

However, construction costs for rooftop greenhouse (299–764 USD m^{-2}) can be higher than those for commercial rooftop farming (54–150 USD m^{-2}) (calculated as 1 Euro = 1.12 USD) (Mandel, 2013; Sanyé-Mengual et al., 2015a; Proksch, 2016). Furthermore, it could be a challenge for rooftop greenhouses to compete with conventional greenhouses in terms of economic and environmental returns. For example, Sanyé-Mengual et al. (2015a) estimated that life-cycle production cost of rooftop greenhouses for tomato is 2.8 times that of conventional greenhouse (a steel-framed high tunnel with vertical sidewalls), requiring yield of 55 kg m^{-2} $year^{-1}$ for rooftop greenhouses to achieve higher economic and environmental returns than those of conventional greenhouse in Barcelona, Spain.

In terms of life-cycle costs of vegetable production, greenhouse cropping systems could be superior to outdoor agriculture in arid and cold regions that have high irrigation demands and short growing seasons, while life-cycle costs specific to rooftop greenhouses highly depend on regional economy, design, microclimate, and distance to major agricultural areas, which require further research (Cuéllar and Webber, 2010; Barbosa et al., 2015; Sanyé-Mengual et al., 2015a; Van Ginkel et al., 2017). While providing opportunities for sustainable food production, rooftop greenhouses do not contribute to habitat creation and environmental education relevant to wildlife biodiversity.

CONCLUSIONS

Constructed urban ecosystems can be different from traditional subjects of ecology in terms of environmental and economic performance, but they are direct outcomes of urban planning and design intentions, which are important and testable subjects for understanding and improving coupled human-natural systems. Among those constructed ecosystems are rooftop intensive vegetable production systems aiming to achieve diverse goals of sustainability within the practices of urban green infrastructure projects, while the scientific community has little information for instructing and navigating urban planning and design. Future research could be motivated by the following questions:

(1) What are the optimal levels of yield, water and nutrient use efficiency, and stormwater management for balancing environmental and economic costs of rooftop intensive agriculture?
(2) How do economic and environmental returns of rooftop intensive agriculture differ in specific system design, climate zone, regional economy, and distance to major agricultural areas?
(3) What are the specific contributions of rooftop farming to enhancing urban biodiversity?
(4) What are the best ways of involving scientists and designing experiments in rooftop intensive agriculture for understanding and improving social ecological systems?
(5) How could urban planning and design integrate different options of rooftop intensive agriculture

and other green spaces for achieving diverse goals of urban sustainability?

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/**Supplementary Material**.

AUTHOR CONTRIBUTIONS

YH: experimental design, sample collection, sample analyses, data analyses, and manuscript preparation. TW: experimental design and manuscript preparation.

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SUPPLEMENTARY MATERIAL

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Consumers' Perception of Urban Farming—An Exploratory Study

Carola Grebitus[1]*, *Lauren Chenarides*[1], *Rebecca Muenich*[2] *and Alex Mahalov*[3]

[1] Morrison School of Agribusiness, W. P. Carey School of Business, Arizona State University, Tempe, AZ, United States, [2] School of Sustainable Engineering and the Built Environment, Ira A. Fulton Schools of Engineering, Arizona State University, Tempe, AZ, United States, [3] School of Mathematical and Statistical Sciences, College of Liberal Arts and Sciences, Arizona State University, Tempe, AZ, United States

Urban agriculture offers the opportunity to provide fresh, local food to urban communities. However, urban agriculture can only be successfully embedded in urban areas if consumers perceive urban farming positively and accept urban farms in their community. Success of urban agriculture is rooted in positive perception of those living close by, and the perception strongly affects acceptance of farming within individuals' direct proximity. This research investigates perception and acceptance of urban agriculture through a qualitative, exploratory field study with $N = 19$ residents from a major metropolitan area in the southwest U.S. Specifically, in this exploratory research we implement the method of concept mapping testing its use in the field of Agroecology and Ecosystem Services. In the concept mapping procedure, respondents are free to write down all the associations that come to mind when presented with a stimulus, such as, "urban farming." When applying concept mapping, participants are asked to recall associations and then directly link them to each other displaying their knowledge structure, i.e., perception. Data were analyzed using content analysis and semantic network analysis. Consumers' perception of urban farming is related to the following categories: environment, society, economy, and food and attributes. The number of positive associations is much higher than the number of negative associations signaling that consumers would be likely to accept farming close to where they live. Furthermore, our findings show that individuals' perceptions can differ greatly in terms of what they associate with urban farming and how they evaluate it. While some only think of a few things, others have well-developed knowledge structures. Overall, investigating consumers' perception helps designing strategies for the successful adoption of urban farming.

Keywords: cognitive structures, concept mapping, exploratory, semantic network, urban agriculture

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Indira Devi Puthussery,
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Yong Liu,
Hunan Academy of Agricultural Sciences (CAAS), China

***Correspondence:**
Carola Grebitus
carola.grebitus@asu.edu

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INTRODUCTION

At present, the number of people living in urban areas worldwide is over three billion, or 55% of the world population, and it is projected that 68% of the world's population will be living in urban areas by 2050 (United Nations, 2018). In the United States alone, 82% of the population currently lives in urban areas (World Bank, 2016). The continued expansion of cities nationwide places a heavy toll on the demand for resources, such as sustainable infrastructure and affordable food retail options, to meet the basic needs of households living within city limits. Within the food sector, the accelerating rate of migration into cities coupled with a growing population imposes the challenge of producing sufficient quantities of food (Satterthwaite et al., 2010). This challenge needs to be addressed to ensure everyone has access to high-quality, nutrient-dense food. Simultaneously, it raises the question of how to provide satisfactory nourishment while consumers are increasingly asking for fresh and local foods (Grebitus et al., 2017).

With urbanization on the rise, one solution to this challenge is the development and expansion of urban agriculture[1]. **Figure 1** below shows the replacement of agricultural areas (yellow) by urban areas (red) in the Phoenix Metropolitan Area. Urban agriculture is a growing sector within the farming industry that aims to increase overall food production in urban and peri-urban areas through the conversion of available land into agricultural farms. As reported in Smith et al. (2017), there are 67,032 vacant parcels (19,592 hectares) potentially suitable for urban agriculture in the Phoenix Metropolitan Area.

Cities across the United States have already begun to integrate food production, such as commercial urban farms and private or community gardens, into communities (Hughes and Boys, 2015; Printezis and Grebitus, 2018). To predict whether urban farming will be successful and to influence its longevity, it is important to understand consumer perception (Grebitus and Bruhn, 2008). Hence, the objective of this research is to investigate how consumers perceive urban farming and to evaluate whether they would accept this form of commercial agriculture close to their residence.

Food produced in urban and peri-urban communities has various implications. For example, for small- to mid-size farmers, the profitability of urban farmers can be dependent on producing local foods that can be (exclusively) sold through direct channels, such as farmers markets. Urban agriculture also has an effect on societal health. Direct access to local produce through direct-to-consumer marketing channels affects the dietary quality and diversity of food choices of urban consumers. Unlike large agricultural production facilities that occupy 75% of the land in the U.S. and predominantly grow commodity crops used for animal feed, biofuels, and industrial inputs (DeHaan, 2015), outputs from urban agricultural production are largely specialty crops, which require comparatively minimal processing before consumption. Specialty crops, which include most fruits, vegetables, and tree nuts, are rich in nutrients, vitamins, and minerals and are constituents of an optimal diet (WHO, 2018). In this way, both the increased consumption of fruits and vegetables along with the diversity of produce consumed is closely linked with positive human health outcomes and serves as a measure of societal health. Finally, urban agriculture affects environmental quality through changes in urban-vegetation-atmosphere interactions, e.g., the reduction in food miles and the mitigation effects of urban heat islands, as a result of urban agriculture practices. Overall, urban agriculture has the potential to provide a number of benefits, for instance, improving sustainability, and local ecology (Wakefield et al., 2007), assisting with food security (Dimitri et al., 2016; Freedman et al., 2016; Sadler, 2016), and contributing to healthy dietary patterns (Zezza and Tasciotti, 2010; Warren et al., 2015).

Alternatively, urban agriculture may produce negative externalities (Brown and Jameton, 2000; Wortman and Lovell, 2013). For example, a farmer growing food in a city might encounter pushback by the people living next to the farm who might be bothered by dirt and noise from machinery, odors from organic fertilizers, or they might be afraid that pesticides and fertilizers are polluting the air they breathe and the water they drink. A recent study by Wielemaker et al. (2019) showed urban farmers apply fertilizers in excess of crop needs by 450–600%, potentially leading to negative public perceptions. At the same time, urban farms might be preferred due to access to fresh, local, nutrient-dense food which enhance positive perceptions. This suggests that consumers' perception and acceptance of urban farms is vital to ensure that urban agriculture can be successful (Grebitus et al., 2017).

Previous empirical research on urban agriculture has focused on investigating the relationship between urban agriculture and nutrition (variety, food security, and nutrition status), with a particular emphasis on its role in developing countries [see Warren et al. (2015) for a broad review of previous studies]. Mougeot (2005) compiles case studies of development strategies used by developing countries and pays specific attention to the potential that urban agriculture has in meeting development goals (e.g., increased food availability, decreased poverty, increased health status) in each respective country. Studies focused on developed countries highlight the social context of urban agriculture. They assess how community gardens affect communities (Armstrong, 2000; Wakefield et al., 2007; Firth et al., 2011), analyze what urban farmers need when only limited resources are available (Surls et al., 2015), and examine success factors of urban agriculture, such as positive consumer attitudes and increased knowledge regarding local food production (Grebitus et al., 2017).

Recently, Grebitus et al. (2017) found in a quantitative online consumer survey that consumers perceive urban agriculture positively based on food quality characteristics, such as food safety and health. More generally, related to perception, they find the three sustainability pillars (economy, society, and environment) are important with regards to consumer perception. Nevertheless, the authors state that consumers' perception is sometimes conflicting. For example, some consumers perceive produce from urban farms as less expensive while others perceive it as more expensive. Our research builds on the study by Grebitus et al. (2017) by investigating the in-depth perception of urban farming using qualitative, exploratory methods in a face-to-face study. While Grebitus et al. (2017) used a word association test, we employ the method of concept mapping. Concept maps can uncover cognitive structures related to urban farming and show differences between individuals regarding their knowledge structures.

The implications of our findings will offer several insights to those charged with designing and implementing food and

[1]The FAO defines urban agriculture as "a dynamic concept that comprises a variety of livelihood systems ranging from subsistence production and processing at the household level to more commercialized agriculture. It takes place in different locations and under varying socioeconomic conditions and political regimes" (FAO, 2007, p. 5).

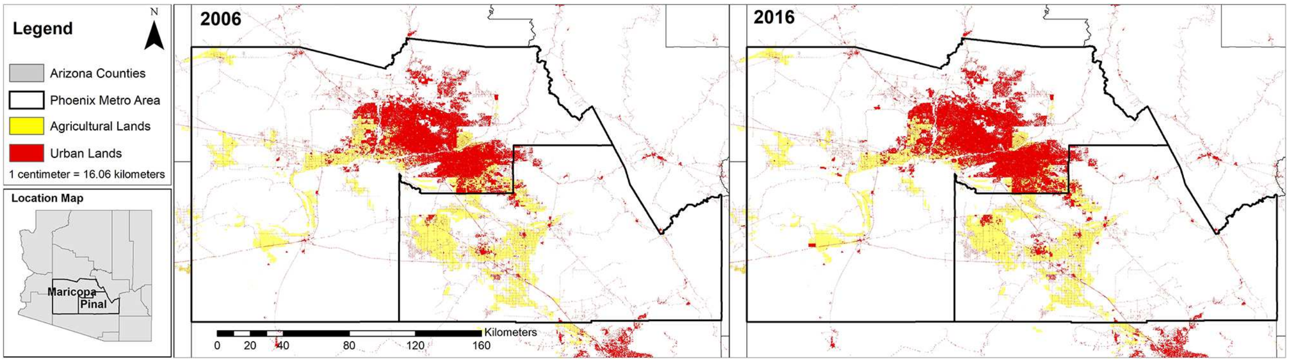

FIGURE 1 | Land use map showing the replacement of agricultural areas (yellow) by urban areas (red). Data from the 2006 and 2016 USGS National Land Cover Dataset.

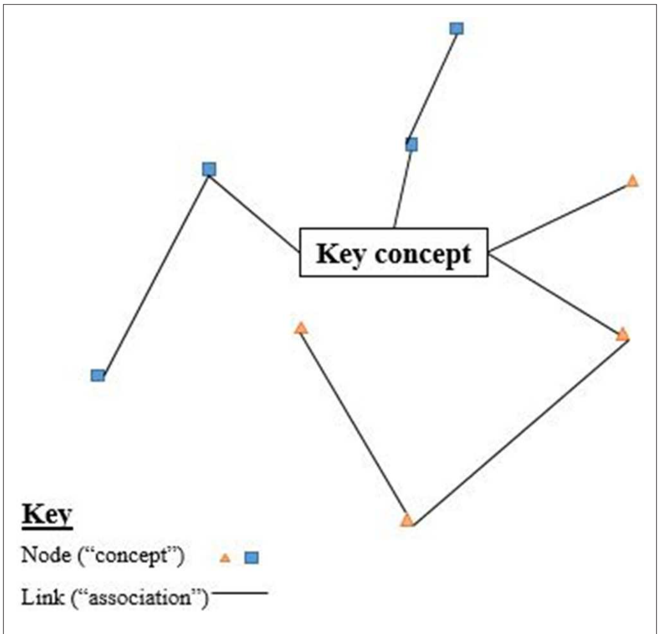

FIGURE 2 | Illustrative figure of a semantic network.

TABLE 1 | Descriptive statistics for the associated concepts.

Number of concepts	Mean	SD	Min.	Max.
Total sample (n = 19)				
333	17.5	13.5	8	68
First location sample (n = 14)				
258	18.4	15.5	8	68
Second location sample (n = 5)				
75	15.0	5.1	10	23

agricultural policy. Such policies have the potential to affect new and emerging trends in urban communities, stimulate the growth of direct-to-consumer marketing channels where small-to mid-size farmers sell their products and address the effects of urban agriculture on the environment. Our results will provide insight into how urban farming is perceived by individuals to ensure that incorporating farms in urban areas is accepted by those living there. For example, if our analysis shows that consumers are apprehensive and afraid, e.g., of pesticides or fertilizer run-off, targeted communication can be used to alleviate such tensions.

In the following section, the methodological background is described covering concept mapping, counting, and content analysis. Section three presents the results and section four concludes.

MATERIALS AND METHODS

Concept Mapping

In consumer behavior research, perception is defined as subjective and selective information processing (Kroeber-Riel et al., 2009). Whether something is positively or negatively perceived by consumers is determined by cognitive structures, i.e., semantic networks, which capture a part of the knowledge (associations/concepts) in memory (Martin, 1985; Joiner, 1998). A semantic network is composed of nodes, which represent concepts and units of information, and links, connecting the concepts, which represent the type and the strength of the association between the concepts (Cowley and Mitchell, 2003). To investigate perception toward urban farming we aim to provide insight into consumers' individual cognitive structures, i.e., semantic networks (Kanwar et al., 1981; Jonassen et al., 1993).

Associative elicitation techniques are appropriate to analyze semantic networks (Bonato, 1990). By presenting stimuli, spontaneous reactions and unconscious thoughts are evoked and enable us to analyze individual cognitive structures (Grebitus and Bruhn, 2008). A great variety of associative elicitation techniques exists, ranging from the most qualitative techniques like word association technique (Roininen et al., 2006; Ares et al., 2008) to more structured techniques such as repertory grid (Sampson, 1972; Russell and Cox, 2004) or laddering (Grunert and Bech-Larsen, 2005).

For this study, the qualitative graphing procedure concept mapping was chosen. Concept mapping is a method that produces a schematic representation of the relationships of stored units of information, which are activated by the stimulus (Zsambok, 1993). The interviewees are asked to recall freely their associations concerning a certain stimulus (Olson and Muderrisoglu, 1979). Additionally, they are asked to directly link the associations to each other, which allows the visualization of the semantic networks (Bonato, 1990). The open setting of tasks optimizes the variety of associations of the interviewees (Joiner, 1998). Concept map diagrams are two-dimensional and show relationships between units of information concerning a certain theme. The concepts are understood as terms, i.e., associations, which come to mind regarding the stimulus (Jonassen et al., 1993).

Concept mapping is supported by semantic network theory and can be explained using the spreading activation network model (Rye and Rubba, 1998). Retrieving stored knowledge can be explained by the spreading activation (Collins and Loftus, 1975; Anderson, 1983a,b). When consumers perceive/associate something with a stimulus, information-processing takes place and cognitive structures are activated for interpretation, assessment, and decision-making. The stored knowledge is retrieved by spreading activation from associations (Anderson, 1983b). In this context, existing networks are active cognitive units that can, once activated, influence behavior directly (Olson, 1978). How much and what information is integrated into the information-processing depends on the construction of the semantic network (Cowley and Mitchell, 2003).

The spread of activation constantly expands through the links to all connected nodes (associations) in the network, starting with the first activated concept. At first, it expands to all the nodes directly linked to the first node, and then to all the nodes linked

TABLE 2 | Content categories.

Category	Count	% of total
Environment	119	36
Food & Attributes	84	25
Society	66	20
Economy	37	11
Other	27	8
Total	333	100

TABLE 3 | Results of concept mapping and content analysis.

Food & attributes (N = 84)	Count	% category	% total	Environment (N = 119)	Count	% category	% total	Society (N = 66)	Count	% category	% total
Health	12	14.3	3.6	Production	39	32.8	11.7	Community	26	39.4	7.8
Fresh	9	10.7	2.7	Conservation	17	14.3	5.1	Education	18	27.3	5.4
Convenience	8	9.5	2.4	Agriculture	9	7.6	2.7	Family	6	9.1	1.8
Food security	8	9.5	2.4	Waste	9	7.6	2.7	Municipality	5	7.6	1.5
Local	7	8.3	2.1	Sustainability	8	6.7	2.4	Advocacy	4	6.1	1.2
Plant	6	7.1	1.8	Environment	6	5.0	1.8	Research	3	4.5	0.9
Produce	6	7.1	1.8	Beautification	5	4.2	1.5	Migration Trends	2	3.0	0.6
Location	5	6.0	1.5	Pollution	5	4.2	1.5	Youth	2	3.0	0.6
Organic	5	6.0	1.5	Resources	5	4.2	1.5				
Marketing	4	4.8	1.2	Elements	4	3.4	1.2				
Food	3	3.6	0.9	Energy	4	3.4	1.2				
Food safety	3	3.6	0.9	Recycling	4	3.4	1.2				
Quality	3	3.6	0.9	Seasonal	2	1.7	0.6				
Variety	3	3.6	0.9	Return to real food	2	1.7	0.6				
Diet	2	2.4	0.6								

Economy (N = 37)	Count	% category	% total	Other (N = 27)	Count	% category	% total
Cost	13	35.1	3.9	Miscellaneous	10	37.0	3.0
Labor	6	16.2	1.8	Positive feelings	6	22.2	1.8
Economics	5	13.5	1.5	Space	4	14.8	1.2
Externalities	5	13.5	1.5	Farmer's market	3	11.1	0.9
Policy	4	10.8	1.2	Gratitude	2	7.4	0.6
Benefits	2	5.4	0.6	Transportation	2	7.4	0.6
Vocation	2	5.4	0.6				

to each of those nodes. This way, the activation is spreading through all nodes of the network, even through those nodes that are only indirectly associated with the "stimulus node" (Collins and Loftus, 1975). The stronger the link between two nodes, the easier and faster the activation passes to the connected nodes (Cowley and Mitchell, 2003). How far the activation spreads also depends on the distance from the stimulus node. Concepts that are closely related and directly linked will be activated faster and with higher intensity (Henderson et al., 1998). See **Figure 2** for an illustration of nodes and links in a semantic network.

The concept mapping technique elicits respondents to recall knowledge from long-term memory and to write down what they know, which stimulates the spread of activation in memory (Rye and Rubba, 1998). The more linkages a semantic network contains, the higher is the dimensionality and complexity of cognitive structures. The higher the dimensionality of the cognitive structures, the larger the number of concepts that can be activated and the more differentiated and complex the networks (Kanwar et al., 1981). Depending on personal relevance and involvement, consumers' semantic networks are more or less extensively structured (Peter and Olson, 2008).

Concept Mapping Application to Urban Agriculture

To conduct the concept mapping procedure, we adapted the instructions used by Grebitus (2008). Respondents received an instructions page. At the top of the page, the respondents read the following passage:

Researchers believe that our knowledge is stored in memory. The knowledge we have can be described through central concepts and the relationship between them. These concepts depict our belief of different knowledge domains such as food or vacation. These beliefs can also be related to each other. For example, when you think of a car, you may spontaneously think of "tires", "white", or "traffic". If you then think further, "gas" and "expensive" may come to mind. These can also be related to each other and thus are indirectly related with a car. People have a lot of such associations. To find out yours is one objective of this study.

Respondents were then given a blank piece of paper and started by writing the term "Urban Farming" in the center of the paper. They were then instructed to start thinking of anything that comes to mind, related to the key concept and write it down. After writing down the concepts, the interviewees had to construct the concept map by connecting all the words that they believe, in their minds, are related to each other and belong to each other (i.e., drawing links). Then, they had to add a plus or minus to associations they thought to be positive or negative.

To investigate how many associations and what kind of information is stored in memory concerning urban farming, the items were counted and aggregated (Kanwar et al., 1981; Martin, 1985; Grebitus, 2008). Next, the individual associations were evaluated using qualitative content analysis following Mayring (2002). This allowed us to make assumptions, and investigate intent and motivation regarding the topic in a formal way (Stempel, 1981; Hsia, 1988). Content analysis is an objective and systematic way to apply quantitative measures to qualitative data (Stempel, 1981; Wimmer and Dominick, 1983; Hsia, 1988, p. 320).

The aim of this study is to provide meaning to the participants' associations. Hence, we classified the content according to categories. This offers a framework to assess the perception of urban farming. The associations written down by the respondents in the concept maps regarding the key stimulus, urban farming, were organized and categorized, then they were added up into frequencies (Bonato, 1990; Lamnek, 1995). The categories are the core of the perception analysis. They are used to investigate the topic further (Wimmer and Dominick, 1983). Therefore, the categories should be closely related to the research topic. They have to be practical, reliable, comprehensive (each word fits into one of the categories) and mutually exclusive (each word fits only one category) (Stempel, 1981; Wimmer and Dominick, 1983). In this research, we used the categories provided by Grebitus et al. (2017) who used a word association test for the key concept: urban agriculture, a close proxy for the one used in our study "urban farming." Accordingly, we used the three sustainability pillars Economy, Society, and Environment, as well as, Food and Attributes, and Others as categories to group the data for urban farming in a meaningful way.

TABLE 4 | Evaluation of Urban farming.

ID	Positive	Negative	Positive or negative	Total associations	Location
1	0	0	0	11	1
2	18	11	0	29	1
3	15	1	2	18	1
4	12	0	0	12	1
5	4	0	0	8	1
6	9	4	0	13	1
7	2	8	0	10	1
8	10	1	0	11	1
9	12	2	0	14	1
10	14	4	0	18	1
11	5	3	0	8	1
12	42	10	2	68	1
13	13	0	0	13	1
14	21	3	0	25	1
15	16	0	0	16	2
16	11	0	0	11	2
17	17	0	0	23	2
18	13	2	0	15	2
19	8	1	1	10	2
Total	242	50	5	333	
Percent	72.7	15.0	1.5	100	

EMPIRICAL RESULTS

Design of the Study and Sample Characteristics

To investigate consumer perception of urban farming, exploratory, face-to-face interviews were conducted. The

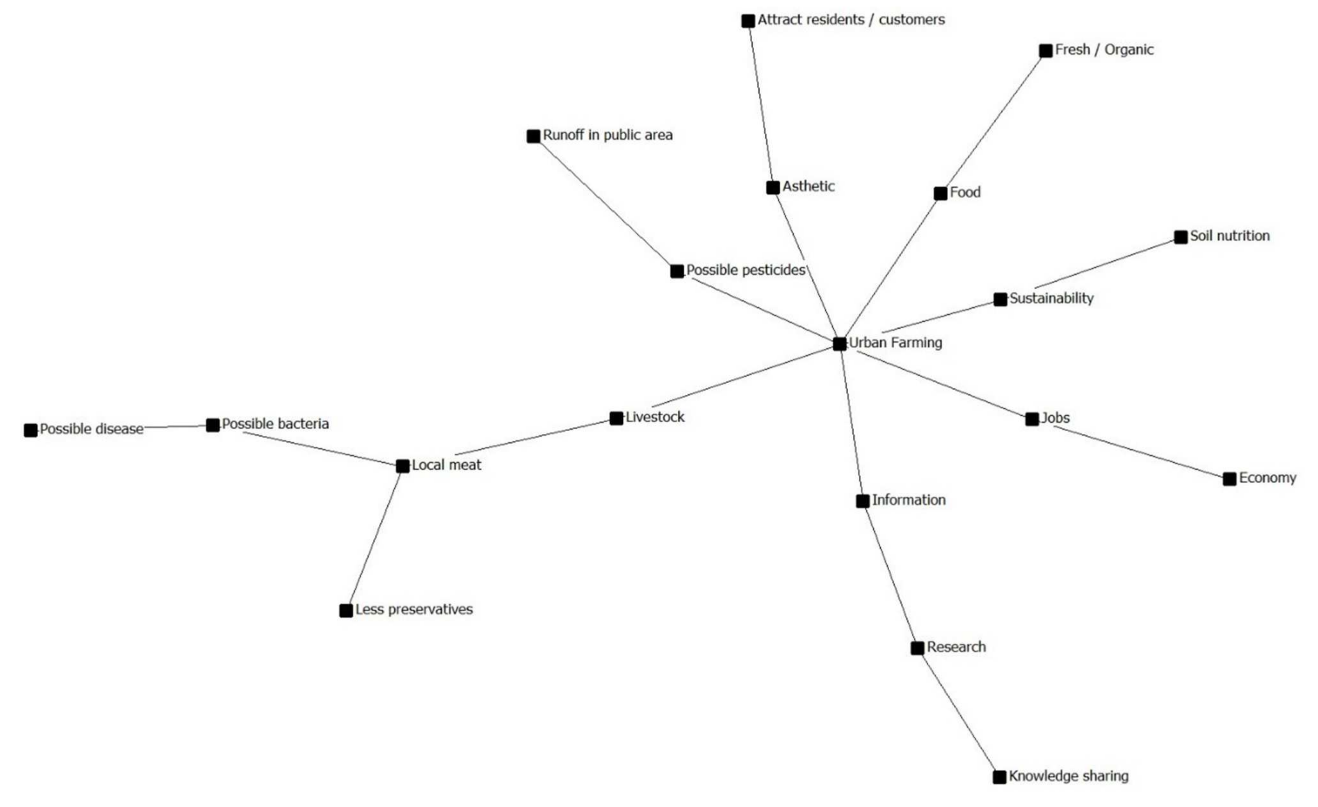

FIGURE 3 | Example of an individual network 1 (location 1, ID 10).

qualitative graphing procedure concept mapping was used to reveal consumers' associations regarding urban farming. In addition to concept mapping, participants filled out a survey to collect socio-demographic information. For detailed information on the data collected, refer to **Table S1** in the Supplementary Material.

We collected data in Phoenix, AZ. We chose this location because the Phoenix metropolitan area is ideal for a case study as it is home to a large and growing urban population. Phoenix provides context that has many similar natural and social complexities and barriers (e.g., climate challenges, a lack of food access, rapidly growing, diverse, multi-cultural population), with a large variance in educational and economic levels of residents compared to other urban areas in the U.S. The Phoenix metropolitan area (i.e., Maricopa and Pinal Counties) is the eleventh largest metro area in the U.S. with Maricopa County identified as the fastest-growing county in the U.S. (U.S. Census Bureau, 2019). This rapid population growth demonstrates an important need for sustainable urban farming practices, given the benefits of food security, economic stability, and environmental conservation. Phoenix has a climate where food can be grown all year round, with multiple growing seasons. The extended growing season allows harvest year-round and may affect consumer purchasing patterns and related dietary quality differently than when food is grown only during certain seasons. Meanwhile, Phoenix experiences unique climatic extremes: from being an urban heat island, experiencing short and long-term drought, while simultaneously dealing with seasonal monsoons that can bring rapid and devastating flooding. Hence, urban farming might have different environmental impacts compared to cities where this is not the case. Also, within urban planning and development, Phoenix has begun to recognize urban agriculture as an attractive fixture in revitalizing communities, especially since urban expansion has replaced nearby agriculture at a large rate (Shrestha et al., 2012). Also, Phoenix has vacant land available that can potentially be used for urban farming (Aragon et al., 2019).

We interviewed a total of 19 participants in the summer of 2019 at two locations. A total of 14 participants were interviewed at a large public farmers' market. Another five participants were interviewed at a second location near an open green space[2]. All interviews were carried out by one interviewer. The sample is a

[2]Note the relatively small sample size in this study. While this would be a drawback for a quantitative study targeting to be representative, our objective is to provide an exploratory study on the perception of urban farming. The aim is not to uncover the perception of the whole population. In that case, a method such as concept mapping would not be well-suited, rather one would use free elicitation technique. That said, free elicitation technique does not allow for a depiction of cognitive structures. This could be tackled by future research. In this research, we set out to conduct qualitative research. The sample size for qualitative studies often ranges from 5 to 50 participants, as pointed out by Dworkin (2012): "An extremely large number of articles, book chapters, and books recommend guidance and suggest anywhere from 5 to 50 participants as adequate." Participant numbers are similarly small, for example in studies by Sonneville et al. (2009), Lachal et al. (2012), Bennett et al. (2013), Van Gilder and Abdi (2014), Takahashi et al. (2016), Hunold et al. (2017), and Mitter et al. (2019) ranging from 12 to 21.

convenience sample. Participants were reimbursed for their time with $10 each.

In terms of sample characteristics, 47% of the sample were female, the average age was 38 years old. Household size was on average three persons in the household, with 26% having children in the household. 21% were graduate students and 21% were undergraduate students. In terms of the level of education, 26% had some college education, 32% a Bachelor's degree, and 42% a graduate degree.

Perception of Urban Farming: Results From Content Analysis

This paper aims to analyze consumers' perception of urban farming. This objective is based on the notion that for urban farming to be more fully and successfully integrated into urban and peri-urban communities, consumers need to perceive it positively.

Table 1 depicts the descriptive findings for the counting of the concepts of the two groups and the total over both samples. The results show a total of 333 associations were written down when considering all participants. The mean is 17.5 concepts with a standard deviation of 13.5. The lowest number of concepts associated with urban farming is eight, the highest 68. The farmers' market sample had a higher mean (18.4) than the second location ($M = 15$). The standard deviation, however, was considerably smaller at the second location ($SD = 5.1$) compared to the farmers' market sample ($SD = 15.5$).

Among the 333 concepts were single terms (e.g., community, convenience, microclimate) and whole phrases [e.g., "Creates 'villages' (people work together)"]. Following Grebitus et al. (2017), the concepts were grouped into five categories: Economy, Society, Environment, Food and Attributes, and Other shown in **Table 2**. Note, Grebitus et al. (2017) had a sixth category, Point of Sale, but this did not apply to our data. Findings show that participants primarily think of environment-related associations (36%) followed by specific foods and attributes associated with urban farming (25%), and society (20%). The category economy ranks fourth with 11%.

Table 3 shows the associations that were organized in the categories. To reduce the large number of associations, concepts were merged based on similarity using content analysis. For example, "community," "community centered," and "community experience" were aggregated up to "community" (see the complete list of associations in **Appendix A** included in the Supplementary Material). The strongest category, "environment" is dominated by associations related to production (33% of category associations) and conservation (14% of category associations), as well as agriculture (8% of category associations)

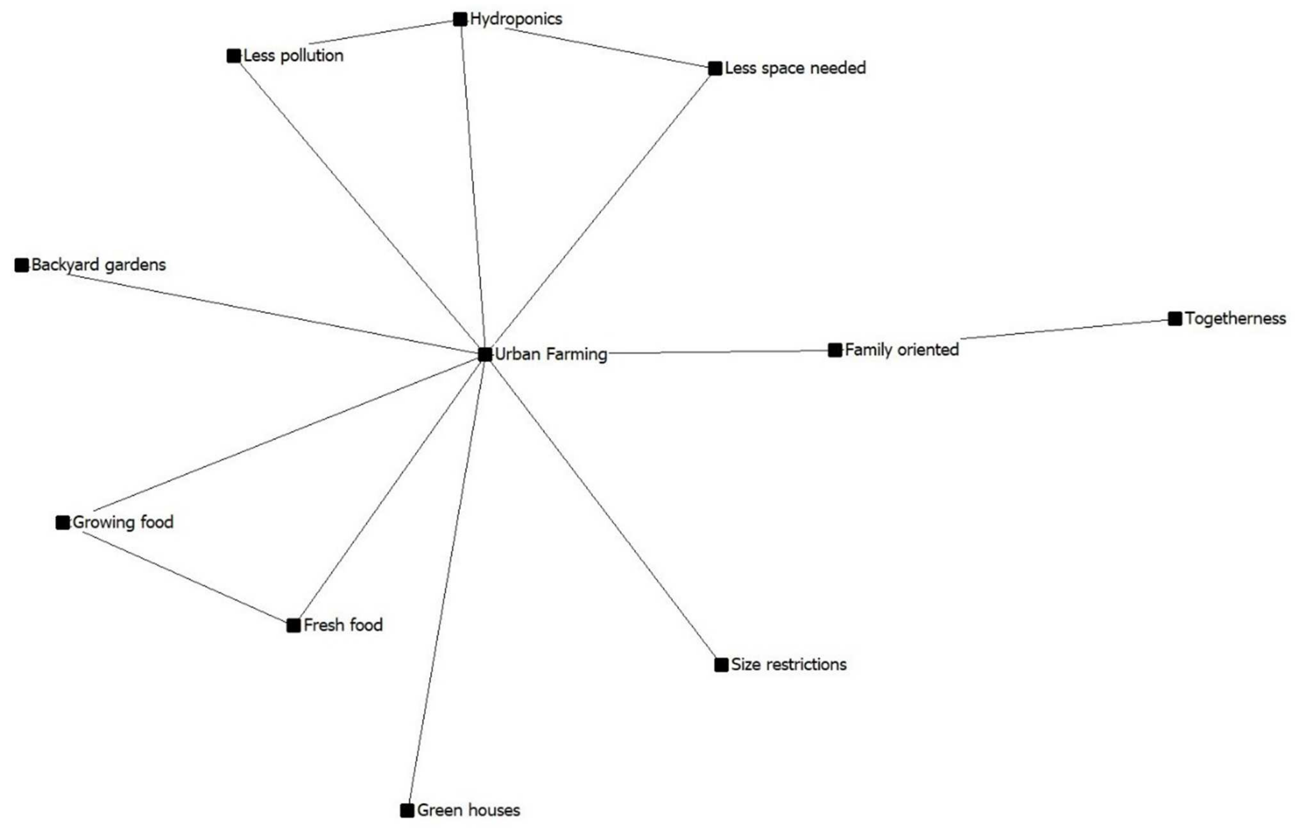

FIGURE 4 | Example of an individual network 2 (location 2, ID 19).

and waste (8% of category associations). "Sustainability," "environment," "beautification," and "pollution" are also included in this category. The category "food and attributes," is dominated by associations related to health (14% of category associations) and fresh (11% of category associations), as well as convenience (10% of category associations) and food security (10% of category associations). "Local," "plant," and "produce" are also mentioned, as well as, "location" and "organic." The category "society" is dominated by associations related to community building (39% of category associations), education (27% of category associations), family (9% of category associations) and municipality (8%). "Advocacy," "research," "migration trends," and "youth" also fit this category. The category "economy" is dominated by associations related to cost (35% of category associations) and labor (16% of category associations), as well as economics (14% of category associations) and externalities (14% of category associations). "Policy," "benefits," and "vocation" are the remaining associations in this category. The category "other" entails associations, such as "positive feelings" and "gratitude," that did not fit in the other established categories. Out of all associations, community and sustainability are among those associated most with urban farms. The result that these two concepts are the most prevalent among our responses suggests the importance of environmentally sustainable farms in urban communities.

Overall, findings show that consumers mainly associate production and environmentally related concepts with urban farming. Many food attribute associations can be considered as generally positive, such as "fresh," "healthy," "convenient," "organic," and "local." Participants also associate sustainability and conservation with urban farming. They think of social aspects, such as "flourishing neighborhood," "friend development," and "meet other gardeners," when asked about urban farming. Furthermore, urban farming evokes thoughts of "the economy," "saving money," "reducing grocery cost," and "cost effectiveness." In this regard, we find some differing opinions with some participants believing that they can save money while others consider urban farming is expensive. This is an indicator that urban farming most likely will not be perceived positively by everyone. Some citizens will be in favor of urban farming and others not. This could be resolved using educational measures given that previous studies have shown that individuals do not feel very knowledgeable with regards to urban agriculture (Grebitus et al., 2017).

To get a better understanding of consumer acceptance of urban farming and whether they perceive urban farming as predominantly positive or negative, they were asked to indicate with a plus (+) those associations they think are positive, and with a minus (–) those they consider to be negative. **Table 4** summarizes the number of positive and negative evaluations that were given. **Appendix A** provides a complete

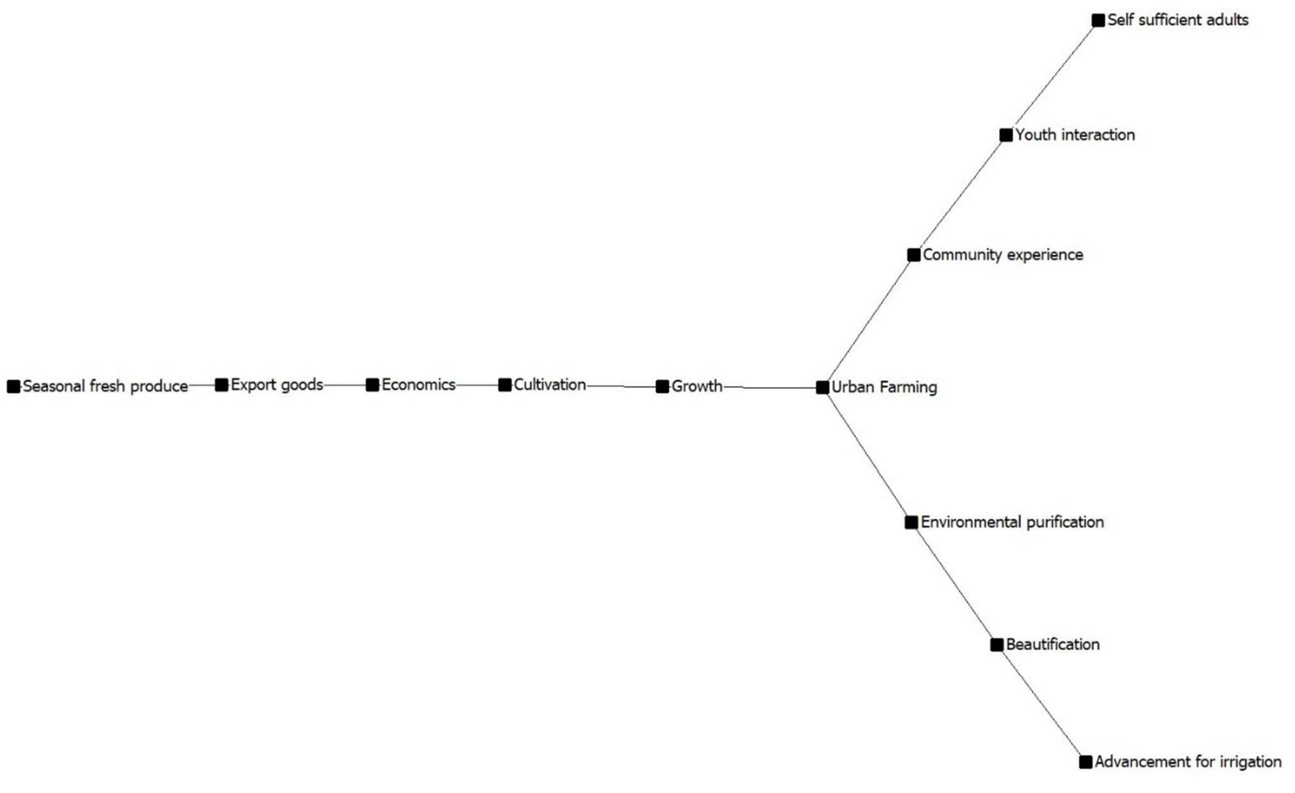

FIGURE 5 | Example of an individual network 3 (location 2, ID 16).

list of all associations including the evaluations. As shown in **Table 4**, urban farming is mainly perceived as positive. Seventy-three percent (73%) of all associations are evaluated positively while only 15% are evaluated as negative. Less than two percent (1.5%) of the associations fall in the category where individuals felt it could go either way. Except for ID 7, all participants that evaluated their associations have a larger share of positively perceived characteristics. ID 7 has 20% positive and 80% negative associations. Only a small share of associations was left unevaluated. Examples of positive associations are "community," "environment," "fresh," "local," "green," "farmer's market," "healthy," "organic," and "sustainability." Meanwhile, "cost," "expensive," "pollution," "smell," "possible bacteria," "disease," and "pesticides" are examples of negative associations.

Perception of Urban Farming: Results From Semantic Network Analysis

After considering what associations are stored in memory regarding urban farming, this section aims to give insight into how the information is stored and what relationships exist between the stated concepts described in the section Perception of urban farming: Results from content analysis. In this regard, figures 3 through 7 show five different concept maps as examples of semantic networks from five different participants, illustrated by the use of the software UCInet (Borgatti et al., 2002). The concept maps differ in shape and complexity.

Figure 3 is a star-shaped semantic network (Wasserman and Faust, 1994). Based on the spreading activation network theory, this pattern means that when "urban farming" is activated, i.e., the individual thinks about it all related associations will be activated and included in thoughts, evaluations and decision making. In this case, sustainability, jobs, information, livestock, possible pesticides, aesthetic and food. These associations can then lead to further associations if the activation is strong enough. For example, possible pesticides can lead to thoughts about runoff in public areas.

Figure 4 depicts a graph that contains three cycles but is also mainly in a star-shaped composition (Wasserman and Faust, 1994). Here, urban farming is seen as family-oriented, providing fresh food with less pollution and less space, e.g., when using hydroponics.

Figure 5 depicts a graph in a tree-shaped composition (Wasserman and Faust, 1994). In this case, more activation is needed to reach associations that are further away from the key stimulus. For example, self-sufficient adults might not be activated, and hence not be included in decisions unless the activation is strong. That said this individual has a semantic network that is more developed in terms of linking associations further. For example, the individual thinks that urban farming is a community experience that can lead to youth interaction, which then should ultimately lead to self-sufficient adults.

Figure 6 displays a more complex semantic network as displayed by the larger number of associations that are more connected to each other. This individual thinks urban farming

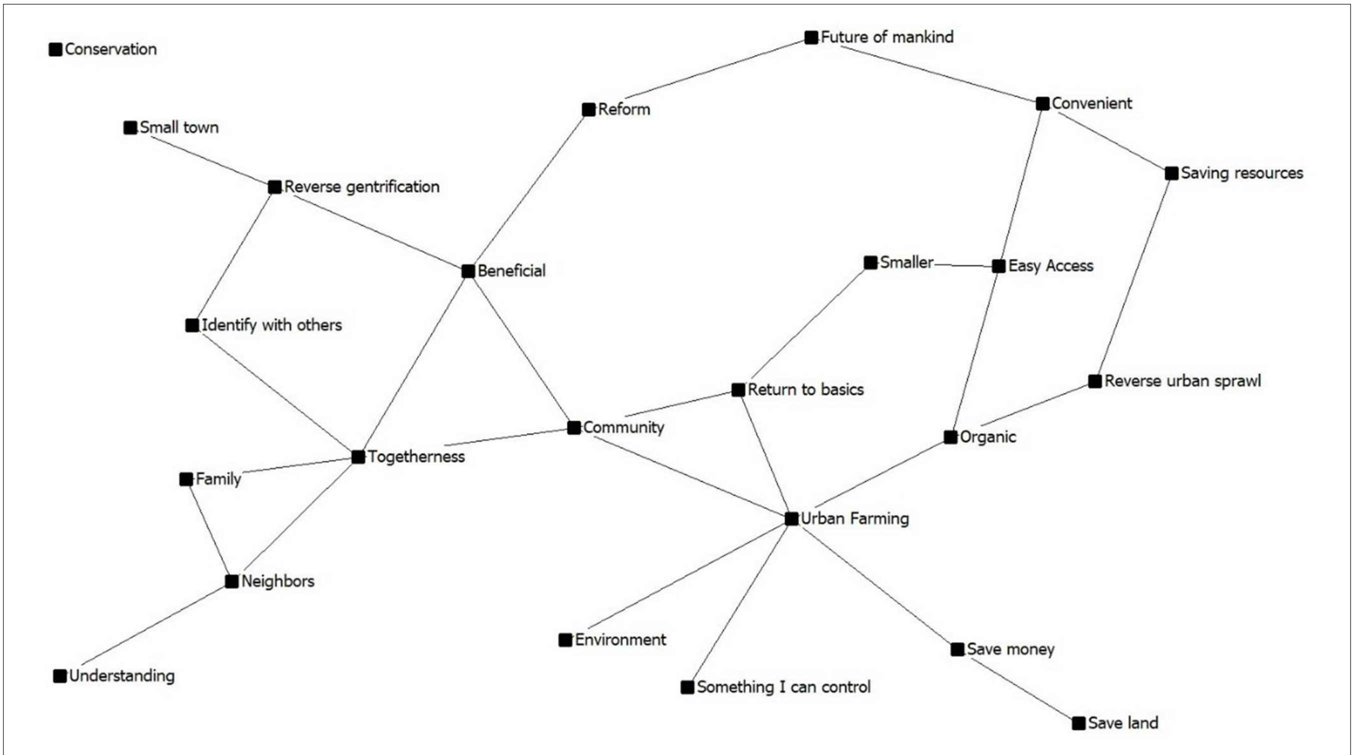

FIGURE 6 | Example of an individual network 4 (location 2, ID 17).

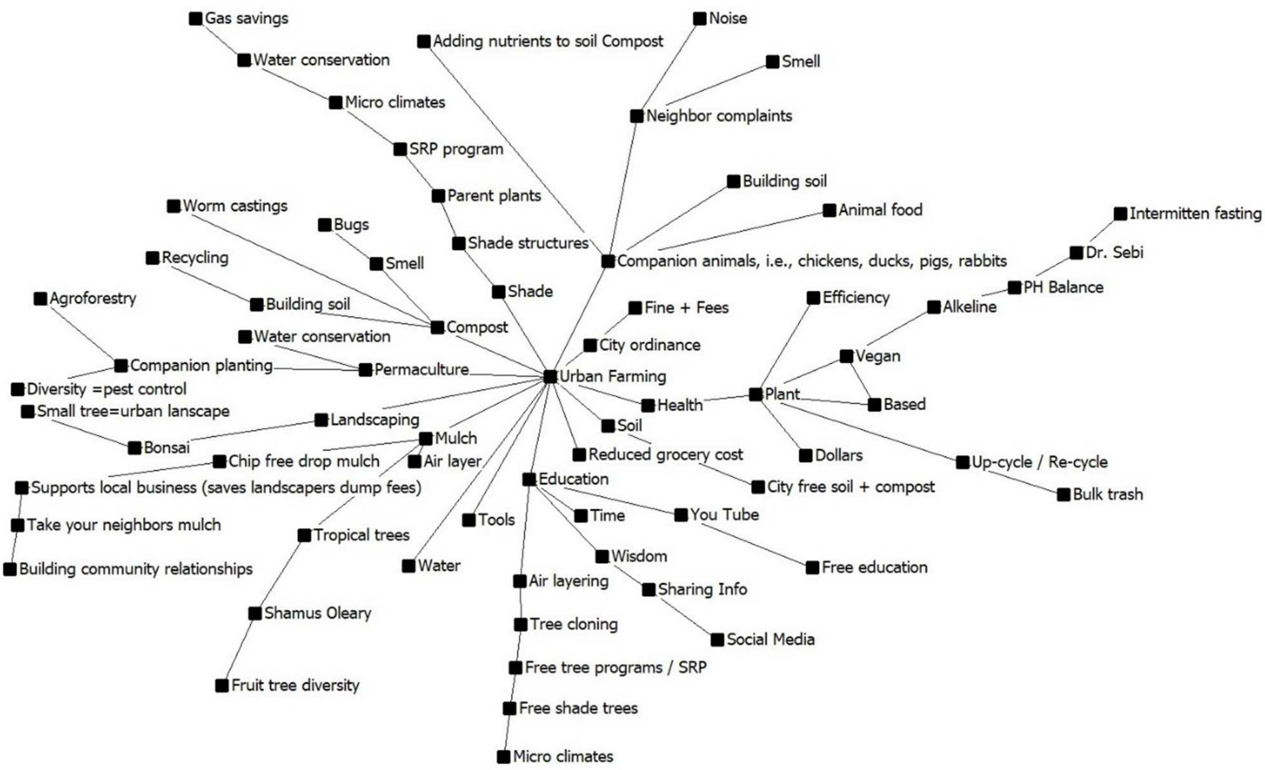

FIGURE 7 | Example of an individual network 5 (location 1, ID 12).

can save money, land, and resources in general. The individual also associates organic and easy access, i.e., convenience with urban farming. Community is linked to urban farming and then has links to togetherness and beneficial. Togetherness, in turn, is linked to family and neighbors which are both connected to understanding. This suggests that urban farming could play a role in the communication of people living together, the family and the neighbors.

Figure 7 displays the most complex semantic network of the participants with over 60 associations. In this case, a lot of activation would be needed so that the individual would access all stored information regarding urban farming. For example, between intermittent fasting and urban farming, six other associations need to be activated and processed before intermittent fasting is accessed. This individual points out less favorable associations, such as "neighbor complaints," which are related to "smell" and "noise." Overall, this concept map is highly differentiated and complex.

These examples are by no means exhaustive. There is a wide variety of different network structures among the 19 individuals. However, there are few visual differences observed between the concept maps of the two groups in terms of shapes and structures. Each group varies in complexity. Some participants have complex cognitive structures using a great number of associations, while others hold simple cognitive structures, i.e., semantic networks, which can be explained by the use of key information. In this case, urban farming is related to several key associations, so that the activation of a lower amount of stored information is sufficient for its perception. The rather simple network structures can also result from low familiarity with urban farming or a potential lack of interest by some individuals.

CONCLUSION

Urban agriculture offers a promising opportunity to provide direct access to fresh produce close to urban residents. This may enhance dietary quality and food diversity while addressing consumers' preference for local food. However, urban agriculture will only be successful if it is accepted and perceived positively by those living in close proximity. Therefore, one must account for consumer perception. Hence, our research provides an exploratory analysis of consumer perception regarding urban farming catering to the success of urban agriculture.

To better evaluate consumers' perception, we employ the method of concept mapping in an exploratory and qualitative study of 19 participants from the Phoenix Metropolitan Area. This analysis provided 333 associations with urban farming. Using content analysis, five categories—Environment, Food and Attributes, Society, Economy and Other—were distinguished to group the concepts/associations in a meaningful way. Participants offered a great variety of perceptions, such as organic, local, community, family, agriculture, and sustainability. One of the overarching themes that emerged from our study was the myriad positive perceptions, e.g., fresh, local, and green. Though negative associations exist, e.g., expensive, possible disease, and pollution, these were fewer in comparison. From a marketing standpoint, highlighting those positive aspects of urban agriculture could incite a more favorable perception and willingness to accept urban agriculture. This could also present opportunities for cities to offer incentives to households who do perceive urban farming negatively. The negative associations also deserve further research as they have the potential to deter the further development of urban agriculture.

In terms of individual semantic networks concerning urban farming, we found that there are vast differences regarding how many associations individuals hold and how connected the associations are. Generally, the more associations and the more links in a network the greater the expertise and involvement. Investigating this more deeply could be used to infer educational strategies.

The use of concept mapping offers detailed insight into participants' semantic networks. It serves as an important, theoretically motivated tool to demonstrate what individuals think and how different concepts are related to each other. Individuals' evaluations of positive and negative associations enables the researcher to determine if the researched area (e.g., urban farming) is perceived favorably or not. That said, knowledge structures are complex, and, with increasing sample sizes, analysis on topics that induce many associations – both positive and negative – can quickly become computationally intensive.

This research is not without limitations. While our findings are encouraging toward acceptance of farming in the city, it should be kept in mind that this is an exploratory study. The present study analyzes stored information, i.e., semantic networks regarding urban farming using qualitative methods for a small sample size from only two study locations, so the results might be dependent on the study area. A more robust approach would be sampling from different regions in the U.S. Future research should include a larger number of participants and expand to more study sites. In doing so, recommendations to stakeholders can be made for the successful integration of sustainable urban agriculture. Garnering an understanding of regional perceptions is of importance, as minimizing the length of the supply chain is associated with a number of benefits, especially in resource-limited environments like the Southwest, and improved well-being at the individual level. Future research could examine the multi-scalar dynamics of urban agriculture, shedding light on market opportunities for agricultural producers and regulators, while simultaneously identifying those factors that could lead to market rejection, e.g., consumer reactance, or practices that may reduce the long-term environmental sustainability of the urban farm. Ultimately, there is a need for interdisciplinary research, for instance, between social scientists, economists, and agroecologists to provide insight into different perspectives that underscore the future success and adoption of urban agriculture.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/**Supplementary Material**.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Arizona State University IRB, Study Number STUDY00010463. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

CG contributed to conception and design of the study, organized the database, performed the analysis, and wrote the first draft of the manuscript. LC served as secondary writer of the manuscript and contributed to study design. LC and RM contributed to initial discussions of methods and the review of the concept categorization. RM reviewed and revised the draft for important intellectual content and created **Figure 1**. AM contributed to conception and design of the study. All authors contributed to manuscript revision, read, and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2020.00079/full#supplementary-material

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Making Urban Agriculture an Intentional, Equitable City Redevelopment Strategy

*Christina D. Rosan**

Geography and Urban Studies, Temple University, Philadelphia, PA, United States

Keywords: urban agriculture, vacant land, "green gentrification", "growth machine", redevelopment

INTRODUCTION

Urban agriculture is exciting. Growing food on formerly vacant lots in U.S. cities brings with it the promise of solving multiple problems at once by addressing concerns about community engagement, vacant land reuse, climate resiliency, heat island effects, property values, food justice, food security, mental and physical health, green infrastructure, environmental education, and empowerment of low-income communities, etc. (Wekerle, 2004; Heckert and Mennis, 2012; Carlet et al., 2017; Horst et al., 2017; Rosan and Pearsall, 2017). While these benefits are numerous and exciting, in the U.S. increasingly scholars and policy-makers need to focus on the complicated and contradictory role that urban agriculture plays in urban redevelopment processes. Urban agriculture fits into a larger, tension-ridden, narrative of inequitable urban redevelopment that highlights the fraught history of American cities marked by suburbanization, redlining, disinvestment, neoliberal policies, structural racism, lack of access to capital, toxic legacies, environmental injustice, power imbalances, and now a return to cities marked by a push for sustainable planning and very real concerns about gentrification, "green gentrification," and displacement of people of color (Rosan and Pearsall, 2017; Rothstein, 2017; Anguelovski et al., 2018; McClintock et al., 2018b).

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Helda Morales,
The South Border College (ECOSUR), Mexico

Reviewed by:
Laura Saldivar,
Independent Researcher, Mexico City, Mexico

***Correspondence:**
Christina D. Rosan
cdrosan@temple.edu

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FROM "CIVIC ECOLOGY" TO "GREEN GENTRIFICATION"

Urban agriculture is a "shape shifter" and in some ways a victim of the "success" of gentrifying cities: the scholarly understanding of urban agriculture has quickly shifted from being about community led self-sufficiency and resilience, what Krasny and Tidball (2012) refer to as "civic ecology" to being more nefariously associated with "environmental gentrification" (Dooling, 2009) "green gentrification" (Pearsall, 2010; Anguelovski et al., 2019), "ecogentrification" (McClintock et al., 2018a), and "green aesthetics" (Aptekar and Myers, 2020).

Urban agriculture highlights the tensions associated with the "growth machine" paradigm of urban planning that Logan and Molotch (1987) describe where land is valued for its exchange over use value and cities seek to maximize the exchange value of land and subsequent associated tax revenue. Recognizing the economic "drain" that vacant land has on cities, urban agriculture has been historically discussed as a means of stabilizing neighborhoods and capitalizing on disinvestment by putting the land to "good use" (Carlet et al., 2017). However, in many U.S. cities, urban agriculture is a strange animal in the urban "growth machine" story because historically the need and possibility of urban agriculture comes about due to structural racism and the systematic devaluation of urban land. We need to acknowledge that the vacant land in American cities is a result of systematic racism and we need to actively work to make sure that "our solutions" to urban vacancy do not repeat history. Today, the effectiveness of urban agriculture at addressing community concerns and its ability to address racism and actively meet equity goals are limited by the "revaloration" of urban land through gentrification (Ernwein, 2017; Rosan and Pearsall, 2017; Anguelovski et al., 2018).

Relying on urban agriculture to "fix" neighborhoods obscures the historical questions about neighborhood decline and disinvestment: Why is land vacant in black and brown communities in the first place? Who was disenfranchised? What role did redlining play in racialized access to homeownership and access to capital? There are also important questions that need to be asked about who will benefit from "fixing" neighborhoods. Is the hope that the neighborhood becomes "stabilized"? If so, for whom and by whom? Are policy-makers supporting urban agriculture anticipating that a new group of people will come to the city who will help raise property taxes or do we have mechanisms to protect low-income peoples' right to live in their neighborhoods and shape their futures, particularly when they have contributed their unpaid labor to urban agricultural and other "stabilization" initiatives? To what extent is equity and social justice a goal of urban agriculture planning, if there is planning at all? When we are thinking about redeveloping and reusing vacant urban space, is this when we should be asking questions about community control, and turning to more "radical" solutions like cooperative land ownership models and community land trusts? In what ways can we promote economic and racial justice with community planning for urban agriculture and other uses? Who gets to decide about the reuse of vacant land in cities and what communities need? Do we have mechanisms such as affordable housing, rent restrictions, and income based property taxes to protect residents from associated rising rents and property values?

Perhaps it is no surprise that conversations about urban agriculture find themselves mired in debates about urban land development and the "right to the city" since urban agriculture is inextricably linked to the value of urban land and the value of land is a reflection of larger historical, structural changes in cities and regions (Harvey, 2003; McClintock, 2014; Tornaghi, 2014; Kumnig, 2017). With a growing "return" by higher income (and often white residents) and an interest in urban and more "sustainable" living, U.S. cities are seeing rapid redevelopment and reuse of vacant land (Anguelovski, 2015). As once vacant and undervalued land becomes more valuable, we see increases in property values, taxes, rents, and the resulting gentrification and displacement of low-income residents. "Improvements" in the urban environments associated with the shifting demographics painfully highlight the historical and *current* inequities in the way that communities of color have been treated by both scholars and city officials. While low-income and minority communities have lived for decades in neighborhoods with high rates of crime, disinvestment, environmental injustice, and a lack of urban environmental, social, and economic amenities, when the demographics change to include wealthier residents, we see a reorienting of the relationship between these neighborhoods and the rest of the city (Heckert and Rosan, 2016). Higher income residents demand the same access to services in these neighborhoods that have been a "given" in higher income urban neighborhoods and American suburbs. They have the political capital and capacity to be heard; the fact that the urban land now brings in higher property taxes is used as an excuse by city officials to finally pay attention to these demands and take action, notwithstanding the fact that they systematically ignored community concerns in these same neighborhoods for years. At the same time, the very important community building work that has been done by low-income, minority residents, is at risk as these same communities find themselves at risk of displacement (Wekerle, 2004; Tornaghi, 2014; Anguelovski, 2015; Anguelovski et al., 2018). In effect, we see an erasure of the important and often traumatic history of urban communities of color and the important leadership role they played in community stabilization in the face of systematic racism and disinvestment. In the new condo developments with green amenities and urban gardens, we often only see a palimpsest of a racist American historical urban experience that systematically excluded many low-income, primarily African American communities for generations.

As the neighborhood demographics change in U.S. cities, so too does the conversation about urban agriculture and its role in the urban environment. The new, more privileged and politically powerful (and increasingly white) residents of the city want to be able to enjoy gardening and growing their own food in a community garden (Anguelovski, 2015). They also want environmental justice concerns addressed. Urban agriculture in these "revalorized" neighborhoods is seen as an urban amenity, but the wealthier residents are not satisfied with the notion that this is where they should get their food from. Here is where we expose the neoliberal bias of some of the past writings about urban agriculture (McClintock, 2014). Whereas urban agriculture was seen as a way to address "food deserts" and a lack of access to services and amenities in low-income communities, as the neighborhood gentrifies, grocery stores arrive, vacant lots are cleaned up, and trash removal is expected (Meenar and Hoover, 2012). Scholars today are rarely writing stories of how wealthy residents in gentrifying neighborhoods are empowered through urban agriculture and "community" is created in urban gardens. City officials and non-profits are not lauding the notion that higher income residents are growing their own food to survive. Instead of questioning the neoliberal narrative that communities need to essentially "fix themselves" when they have been systematically discriminated against (McClintock, 2014), many scholars have shifted their attention to neoliberal critiques of "green gentrification" (Gould and Lewis, 2016).

COORDINATED PLANNING TO BUILD EQUITABLE COMMUNITIES, NOT "FIXING" PLACE

The notion that greening and gentrification are related should not be a surprise to scholars who have been writing for years about the "benefits" of greening and urban agriculture to urban communities. Did we not anticipate that as neighborhoods improved, they would be revalorized? However, policy-makers and scholars alike have been surprised by the speed at which "green gentrification" has contributed to a remaking of the urban landscape. Unfortunately, the "green gentrification" literature has surprisingly few answers to whether it is possible to improve neighborhoods and keep low-income and minority communities in place. Perhaps the strongest argument is the notion of "just green enough," an approach that argues that particular types of green space development may be able to improve neighborhoods without significantly driving gentrification and displacement (Wolch et al., 2014). I argue that this "just green enough" is not enough and that we need to rethink the way we plan our cities to deliberately and comprehensively address affordability and actively prevent displacement. We need a more "radical" narrative around urban agriculture and greening and redevelopment in U.S. cities that is guided by the need to develop policies that address racial discrimination, disenfranchisement, loss of community control, and displacement of low-income, often minority residents. If we want urban agriculture and urban greening to do everything we hope it will (and not promote "green gentrification"), *and* the goal is to promote racial and socio-economic equity in cities, it needs to be viewed as a part of a much larger, much more intentional, and much more "radical" approach to creating equitable and sustainable cities. We need to acknowledge our troubled urban history: the deep systematic exclusion and racism that make urban agriculture both necessary and possible. We need more scholars and policy-makers to propose and implement innovative and radical ideas about how to use community land trusts, and cooperative ownership of land that provide alternatives to the "exchange over use value," "growth machine" paradigm. We also need collaborative urban governance where urban agriculture, urban greening, affordable housing, and other community infrastructure like schools, public transit, parks, hospitals, and grocery stores are planned for together. Together, these are the building blocks of sustainable, equitable, and resilient communities, which will be critical as we face the climate challenges ahead. They are the types of community amenities that higher-income residents expect as a matter of course and lower-income residents deserve. This requires working with policy-makers to rethink traditional siloed urban governance strategies that focus on "fixing" places through greening and growing and fail to build in safeguards to protect residents' right to live in thriving urban communities. We owe it to the residents of these communities, who have been victims of historical, systematic discrimination and disenfranchisement, to work collaboratively with them to make sure *they* define what "fixing" the neighborhood entails and ensure that long-term residents of all income groups can stay in their neighborhoods once they are "fixed." This will require new approaches to planning guided by achieving equity as an outcome. If we fail, urban agriculture will not be the great exciting experiment that we hoped it would be. Instead, it will a part of a story of "green gentrification." It will be a palimpsest: a photo of an urban farm located in the condo gym that replaced it.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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Modeling the Potential Productivity of Urban Agriculture and Its Impacts on Soil Quality Through Experimental Research on Scale-Appropriate Systems

*John R. Taylor**

Department of Plant Sciences and Entomology, University of Rhode Island, Kingston, RI, United States

Urban agriculture could play a central role in local and regional food sovereignty in developed countries, but in many cities, a lack of space and competition with other land uses limit production. Options for meaningfully advancing food sovereignty goals include sustainable intensification of existing urban farms and gardens; (2) expansion of production into interstitial and other underutilized spaces undevelopable for other purposes; and (3) expansion of production in protected environments. Observational studies suggest that–like smallholder agriculture in the Global South–urban home, community, and market gardens in the developed world can be highly productive–but often are not. Research on scale-appropriate systems and outreach to urban agriculturalists are needed to help them grow more food, more sustainably. This replicated, long-term trial is addressing this need—and a dearth of experimental, normative research on urban agriculture—by evaluating the yield performance and impact on soil quality of four different systems of small-scale food production in Rhode Island, the second most densely populated state in the United States and a potential model for the development of sustainable urban food systems. Systems are modeled on vernacular systems in Providence, RI and Chicago, IL and on the scholarly and gray literature on sustainable intensification. They differ in soil management practices and nutrient sources. Results from the first 3 years of data collection indicate all four systems can be highly productive, with varying tradeoffs in terms of their sustainability and impacts on soil quality. While total marketable food yields were relatively modest compared to those reported in the gray literature for biointensive agriculture–2.22–2.96 kg m^{-2} averaged over three summer growing seasons compared to 4.64 kg m^{-2} for the "low end" of biointensive production—yields for individual crops generally exceeded—and often far exceeded—regional averages and, for most crops and systems, national averages, without a loss in soil quality. In addition to demonstrating the high productivity of small-scale systems compared to commercial farms, the study establishes a framework for conducting normative, experimental research that can help to guide practice. It also offers more reliable yield estimates for modeling the production potential of cities than do observational studies and agronomic experiments on monocultures.

Keywords: urban agriculture, sustainable intensification, ecosystem services, self-provisioning, urban food garden, home garden

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United States
Nicolas Jelinski,
University of Minnesota Twin Cities,
United States*

***Correspondence:**
*John R. Taylor
jr_taylor@uri.edu*

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INTRODUCTION

Planners, academics, and food activists in developed countries increasingly recognize the potential role of urban to peri-urban agriculture in increasing local, state, and regional food sovereignty (Alkon and Mares, 2012; Heynen et al., 2012; Tornaghi, 2017). In the United States, New England's 50 by 60 plan, for example, calls for meeting 50% of food needs through regional production by the year 2060 (Donahue et al., 2014). The projected agricultural acreage required to meet this ambitious goal includes 20,000 acres of urban and 210,000 acres of suburban land (Donahue et al., 2014), much of it in the Northeast Megalopolis stretching from Washington, D.C., to Boston and sheltering 18% of the U.S. population on 2% of the land base (Yaro and Carbonell, 2018). While some U.S. cities, e.g., Oakland (McClintock et al., 2013), Chicago (Taylor and Lovell, 2012), and Detroit (Beniston and Lal, 2012) may have large expanses of vacant land due to cycles of investment and disinvestment, such land is relatively scarce in other urbanized and urbanizing regions—including New England, the site of this research–because of development pressure. The city of Providence, Rhode Island, for example, was estimated to have ∼476 city-owned vacant lots in 2013 (Asen et al., 2014) compared to ∼19,500 city-owned parcels in Chicago (City of Chicago., 2020). Land-based urban production in more land-starved regions may be limited to fragmented interstitial and other underutilized spaces, including residential lots. Existing production at this scale appears already to make a far larger contribution to urban food systems than larger scale agroecosystems, such as urban farms (Taylor and Lovell, 2012).

Given constraints on land availability in many regions, options for meaningfully advancing food sovereignty goals through urban agriculture include: (1) intensifying production of existing farms and gardens; (2) expanding the acreage of existing production through dispersed, small to very small-scale home and market gardens and farms on already developed land, on residential lots and in interstitial and other unproductive, leftover spaces; and (3) expanding production in protected environments ranging from unheated greenhouses (high tunnels) to more technologically sophisticated–and resource-demanding–systems including hydroponic or aquaponic greenhouses and vertical farms. Except for the use of high tunnels, increasing local food production through the third option is unlikely to increase food sovereignty as defined by La Via Campesina: "the right of farmers, peasants to produce food and the right of consumers to be able to decide what they consume, and how and by whom it is produced" (Via Campesina, 2003). Protected production can be capital intensive, particularly when established in central business districts (Benke and Tomkins, 2017), and potentially concentrates control over the food system in yet fewer hands.

The value of urban agriculture at any scale lies in its multifunctionality (Lovell, 2010). Growing food in cities makes little social, economic, or environmental sense if the sole or even primary goal is production. Privileging production may, in fact, lead to ecosystem disservices, including reduced soil quality, nutrient loading of stormwater runoff, reduced non-crop plant diversity, and reduced vegetative structure leading to a reduction in ecological niches and, consequently, biodiversity at higher trophic levels (Dewaelheyns et al., 2014; Taylor and Lovell, 2015; Taylor et al., 2017). At the same time, the literature suggests that the productivity, safety, and sustainability of urban agriculture could be improved without sacrificing—or even with enhancing—its cultural and ecological functions through scale-appropriate, systems-based research, outreach to urban gardeners and farmers, and planning interventions designed to encourage small-scale production (Beck et al., 2001; Witzling et al., 2011; Hunter et al., 2020).

Unfortunately, agronomists, horticulturists, and other plant scientists have been largely absent from the scholarly discourse on urban agriculture, and experimental agronomic research that could inform sustainable food production practices in cities is thin despite repeated calls for such research (Wortman and Lovell, 2013; Taylor and Lovell, 2014, 2015; Wagstaff and Wortman, 2015). Fully replicated research on land-based, urban-scale production systems in the U.S. is limited to just four studies. Miernicki et al. (2018) conducted a 2-years, *ex situ* factorial experiment evaluating the impacts of different urban production systems on the yield of a limited number of crops (radish, kale, cilantro, pepper, and garlic) from very small plots (1.5 m^2). Wagstaff and Wortman (2015) evaluated the performance of ten vegetable crops and measured variation in environmental variables at six sites, with replication, along an urban to peri-urban transect in metropolitan Chicago. Beniston et al. (2016) evaluated the impacts of diverse amendments on soil quality and the yield of three crops (tomato, chard, and sweet potato) in a replicated, *in situ* experiment conducted over a 2-years period in a small U.S. city, Youngstown, OH. Small et al. (2017) examined the effect of compost made from varying ratios of barley mash to woodchips on nutrient recycling efficiency and yield of two crops, arugula and tomato, in a raised bed system over a single growing season.

Much larger is the literature based on observational studies conducted by ecologists, entomologists, sociologists, geographers, and others. These studies have been productive in characterizing the social, economic, and environmental conditions of urban agriculture and the vernacular production systems that have developed in response to those conditions. Observational research indicates that land-based urban agriculture offers myriad challenges—and opportunities–which make it distinct from rural agriculture. Research on commercial production in monoculture–the focus of most programs at U.S. land grant universities–cannot simply be scaled down to an urban lot. Urban crops may be more light-limited than those grown in rural agroecosystems; shading from trees and adjacent buildings can reduce urban crop yields by up to 50% (Wagstaff and Wortman, 2015). Higher temperatures in cities (Pickett et al., 2011) may benefit some crop plant species but limit the productivity of others, while higher vapor pressure deficits can lead to drought stress and reduced photosynthesis (Wortman and Lovell, 2013). Air pollution may reduce yields, and use of pesticides may be limited due to proximity to residential areas (Wortman and Lovell, 2013). Highly heterogeneous in nature, urban garden soils are of variable quality and are often contaminated with heavy metals and organic compounds

(Witzling et al., 2011; Taylor and Lovell, 2015) but may be less compacted than agricultural soils (Edmondson et al., 2011). Soil contamination may require the use of raised beds or a cap-and-fill system in which the entire lot is capped with a geotextile or an impermeable material followed by a layer of woodchips or gravel and then a layer of compost-loam mix. Mix depth can range from 12.5 to more than 38 cm, and percent organic matter may exceed 30% (more than seven times that of typical field soils) (Taylor and Lovell, unpublished data). These mixes add further complexity to the urban growing environment (Wortman and Lovell, 2013).

At a time when rural growers are increasingly using tools such as precision agriculture technology to improve nutrient use efficiency in field crops, nutrient management in land-based urban systems is relatively unsophisticated (Taylor and Lovell, 2015; Small et al., 2019). Regular soil testing and the use of organic fertilizers on urban farms appear to be rare, and the use of synthetic chemical fertilizers is undocumented (Moskal and Berthrong, 2018). Instead, growers apply pure compost to growing beds as frequently as once a year to attempt to meet the nitrogen requirements of crops and to "feed the soil" (Taylor and Lovell, 2015; Moskal and Berthrong, 2018). Depending on compost inputs, this practice may lead to the accumulation of excessive levels of some nutrients, such as phosphorus (Taylor and Lovell, 2015; Moskal and Berthrong, 2018; Small et al., 2019) but may not provide sufficient nitrogen for adequate crop yields. The range of nutrient management practices appears to be even greater among urban home gardeners. Some gardeners may apply water-soluble synthetic fertilizers one or more times a week, while others rely solely on bagged compost or manures to restore soil fertility (Taylor and Lovell, 2015; Small et al., 2019). The resulting excessively high levels of nitrogen and phosphorus in soils and media may create pollution hotspots in the urban environment (Small et al., 2019).

The cropping practices of urban growers also appear to differ significantly from those of rural producers, though data are scarce. Plots are small, and gardeners and farmers may be reluctant or unable to leave areas fallow to allow the soil to recover from intensive production, to rotate crops to break pest cycles, or to plant cover crops to reduce soil erosion and to improve soil quality. In home and community gardens, crops may be grown in mixed polycultures, with two or more crops growing in intimate association (Airriess and Clawson, 1994; Woods et al., 2016; Taylor et al., 2017). Even if crops are grown in single-species rows or blocks, plots represent polycultures compared to the scale of commercial field production, with many of the potential advantages and disadvantages of intercropping, including increased or decreased yields, reduced pest pressure, high knowledge demand, and increased labor (Lithourgidis et al., 2011; Yu et al., 2015).

While some have argued for the collection of yet more observational data on the productivity of urban agriculture for use in modeling current and potential production (Pollard et al., 2017), the value of devoting more resources to such efforts is questionable. Existing studies consistently indicate large variations in crop yields in the same city or region (Pollard et al., 2017). Variability in a single study may be due to one or, more likely, a combination of factors: participation in the study by gardeners with a wide range of experience, skill, and education; variation in environmental conditions (Ackerman, 2012); the sheer diversity of crops and production systems in possibly all but the most culturally homogeneous cities; and inconsistencies in data collection. Collecting representative data for even a single city demands large sample sizes and multi-year data collection, but existing studies fail to meet these criteria. Sample sizes are small due to participant burden and attrition, ranging from 10 to 50 final participants (Reeves et al., 2014; CoDyre et al., 2015; McDougall et al., 2019). Data collection periods are short, often spanning a single growing season but occasionally extending to up to 2 years.

The convenience samples on which observational studies are based may fail to represent important urban gardening groups. In some cities, immigrants make a substantial but often unrecognized contribution to home and community garden production (Taylor and Lovell, 2012, 2015; Buchthal et al., 2019). Language barriers may militate against their inclusion in study samples. The gardening population—at least in the United States—also skews older. The digital divide may result in lower participation rates for these gardeners if recruitment is primarily conducted through the Internet or if data collection requires access to or use of handheld digital devices and applications. In addition, data collection procedures are inconsistent across studies and are inadequately documented. It is often unclear whether the area of failed crops or unproductive garden spaces, e.g., paths between community garden plots or between production beds, are included in the calculation of average yields or whether production has been graded for quality, as it is in agronomic experiments. Researchers may also estimate crop yields for a large area based on self-reported yields from a very small sample of gardeners (Gittleman et al., 2012), potentially biasing and inflating estimates.

All of these factors undermine the reliability, representativeness, and general usefulness of data collected through observational research for modeling urban agricultural production capacity or informing practice. What are needed are not more observational studies documenting the successes and failures of existing production systems but the development and promulgation of normative systems of urban agriculture based on experimental evidence and a systems-based, adaptive approach to research.

This paper describes the first 3 years of a long-term trial of intensive vegetable production systems suitable for urban market production or home provisioning. These 3 years constituted the primary exploratory and learning phase of the trial. Practices including weed management, tillage, and fertilization and crop mix evolved over this period of the experiment, as the researcher developed more knowledge of the systems, and will continue to evolve. In this way, the trial reproduces the adaptive approach of beginning and experienced growers, who constantly revise, refine, and adapt their production systems based on ongoing observation of system dynamics.

The overall goal of the project is to evaluate, in a replicated experiment, the long-term, relative performance of four different systems of small-scale vegetable production appropriate to urban to peri-urban agriculture in the U.S. state of Rhode Island. As the second most densely populated state in the U.S., with a population density almost ten times that of the United States as a whole, Rhode Island offers a potential model for the development of sustainable food systems and the expansion of regional food sovereignty through urban agriculture in the Northeast and elsewhere. In addition to comparing system performance, the project is intended to provide insights into challenges and opportunities in small-scale food production, to generate hypotheses for future research on urban agricultural systems, and to provide management guidelines for production in similar systems for dissemination through the University of Rhode Island's Cooperative Extension Service. The trial also serves as a training site for undergraduate research fellows in the University of Rhode Island's Sustainable Agriculture and Food Systems Program and the Department of Plant Sciences and Entomology major.

The first 3 years of data collection—as reported in this paper—focused on system productivity (measured by crop yield and value) and changes in soil quality. In future years, the range of system variables tracked will be expanded to include water use, labor, soil microbial composition and diversity, and other measures of sustainability and ecosystem services.

MATERIALS AND METHODS

Site and Soil

The trial is being conducted at the University of Rhode Island's Gardner Crops Research Center, West Kingston, Rhode Island, USA (lat. 41° 29′, long. 71° 32′W) ∼28 km SSW of the state capital, Providence. The site is ∼36 m above sea level. A small coastal state in southern New England, Rhode Island has a humid climate with a relatively even distribution of precipitation throughout the year and large seasonal variations in temperature (RI DEM, 2020). Weather data have been collected continuously at the Gardner Crops Research Center since 1931. The average annual precipitation for the past decade was 135.3 cm, during which time the average maximum and minimum temperatures were 4.8° and −6.8° C in January and 29.5° and 16.9° C in July. The average length of the frost-free growing season was 172 days, with the last spring frost occurring on May 13 and the first fall frost on October 17, on average.

Experimental plots were established in 2017 on an Enfield silt loam (coarse–silty over sandy or sandy–skeletal, mixed, active, mesic Typic Dystrudept) (NRCS, 2020). The majority of the site was fallow during the 2016 growing season, with a mixture of volunteer red clover and self-sown grasses. In early May 2017, the site was moldboard plowed and then disked twice. The trial employs a randomized complete block design with 4 replicates; each plot measures 6.4 × 15.24 m (21 × 50 ft) and is subdivided into 6 growing beds, 0.76 × 15.24 m (2.5 × 50 ft), separated by a path 0.30 m (1 ft) in width. Bed width is typical for small-scale intensive systems (Fortier and Bilodeau, 2014; Coleman, 2018); path width is somewhat narrower than that recommended in the gray literature but minimizes unproductive space while still permitting movement through the plot.

Production Systems

The four systems evaluated were initially modeled on practices observed by the author during research on urban gardens and farms in Chicago, Illinois, and Providence, Rhode Island. System design also drew on the scholarly literature on urban agriculture, sustainable agriculture and agroecological practice (Wezel et al., 2014; Garbach et al., 2017) and on the gray literature on small-scale intensive vegetable production (Fortier and Bilodeau, 2014; Coleman, 2018). The systems differ in soil management practices and nutrient sources but all employ a permanent bed design, rely on only pesticides approved by the Organic Materials Institute (OMRI) for the control of insects and fungal diseases, have no fallow period, incorporate cover crops when practicable, rotate the same suite of crops at the same planting densities on an identical rotation schedule, and irrigate with drip tape. While these system characteristics are fixed, others are allowed to change over time in keeping with the adaptive management philosophy of the trial. Pest management, tillage, and fertilization and crop mix evolved over the initial learning phase of the experiment described in this article, as the researcher developed more knowledge of the systems.

System Descriptions

Conventional

This system features synthetic fertilizers and conventional tillage with a rototiller. Solid fertilizer is incorporated into the soil prior to planting, and additional, water-soluble nitrogen (urea) is applied during the growing season, per the crop-specific recommendations found in the *New England Vegetable Management Guide*, a collaborative effort of Cooperative Extension vegetable programs in the six New England states (Campbell-Nelson, 2020). The conventional system, which serves as the control, reproduces the production practices that an agricultural extension agent might recommend to a conventional, small-scale market gardener or to a home gardener based on the research literature. The synthetic fertilizers used in this system have several advantages from a production standpoint; they are easily procured, are very inexpensive compared to other nutrient sources, act quickly, and require very little labor to apply, unlike compost. Compared to other machines for small-scale gardening and farming such as walk-behind tractors, rototillers are relatively inexpensive. Even urban home gardeners may own and use a rototiller. In the United States, rototillers can also be rented from various outlets on an hourly or daily basis.

Precision organic

This system differs from the conventional system in relying on minimal tillage (to a depth of 7.6 cm with a rotary power harrow) for bed preparation and OMRI-approved fertilizers as a nutrient source. Solid fertilizers are applied per the initial application rates prescribed in the *New England Vegetable Management Guide*. Though bulkier, solid organic fertilizers are, like synthetic fertilizers, easy to procure and to apply but are typically much more expensive than synthetic fertilizers and, because they require mineralization by soil microorganisms, slower-acting (and consequently less vulnerable to leaching). To reduce subsequent nutrient input costs and to tailor nitrogen inputs to plant needs, the application of additional (water-soluble) OMRI-approved fertilizer is scheduled based on the evaluation of crop nitrogen status during the growing season using a Minolta SPAD-502 chlorophyll meter (Konica Minolta, Inc., Tokyo, Japan). While use of such a meter would not be cost effective for small scale growers, lower cost alternatives such as the atLEAF chlorophyll meter (FT Green LLC, Wilmington, DE, USA) could be.

Compost-only

This system seeks to minimize inputs from outside Rhode Island and to close open nutrient loops. It is modeled on organic market gardening and community gardening practices and has transitioned from full tillage (2016) to deep tillage (broadforking in 2018) to no-till (2019). Local, organic-approved yard waste compost from the Rhode Island Resource Recovery Center (RIRRC) in Johnston, RI serves as the primary source of nutrients, with additional, regionally-sourced, OMRI-approved water-soluble fertilizer applied at the time of transplanting. Each year, compost has been surface applied by volume at a rate of 0.29 m^3 per 0.76 × 15.24 m bed, which is comparable to the annual application rate recommended by the Southside Community Land Trust (A. Cook, personal communication), Rhode Island's largest urban agriculture service provider, to community gardeners and growers and by Fortier and Bilodeau (Fortier and Bilodeau, 2014) to market gardeners.

Urban cap-and-fill

(**Figure 1**). This system is modeled on practices for mitigating urban soil contamination. In the absence of any published recommendations or best management practices for such systems, system specifications were developed based on observations of urban farms in Chicago and Providence. Each plot was covered with a woven geotextile fabric meeting American Society for Testing and Materials (ASTM) standards specified for contaminant mitigation on urban agriculture sites by the Boston Public Health Commission (Boston Public Health Commission, 2013). On top of this cap, 0.76 m wide and 0.38 m high windrows of a 50:50 mix of RIRRC compost and loam were shaped by tractor and by hand to create planting beds. The narrow, 0.30 m wide swales between windrows were filled with woodchips from University of Rhode Island campus sources to create paths almost level with the tops of the planting beds. Each year, OMRI-approved water-soluble fertilizer is applied at the time of transplanting.

Nutrient Inputs

A fertilizer solution was applied at the time of planting to transplants in all four systems at a rate of 9.4 kg of P ha^{-1}. Jack's 9-45-15 water soluble fertilizer (JR Peters, Inc., Allentown, PA, USA) was applied to crops in the conventional plots. Neptune's Harvest Tomato and Vegetable Formula 2-4-2 (Neptune's Harvest, Gloucester, MA, USA) was applied to crops in the precision organic, urban cap-and-fill, and compost-only systems. No additional fertilizer was applied to the urban cap-and-fill or compost-only plots.

Pre-plant fertilizers were applied to the conventional and precision organic plots at the crop-specific rates recommended in the *New England Vegetable Management Guide*. Granular, synthetic 19-19-19 or 23-12-18—depending on the phosphorus needs of the crop–was applied to the conventional beds prior to rototilling. Pro-Gro 5-3-4 (North Country Organics, Bradford, VT, USA) was applied to the precision organic plots prior to harrowing. Crops in the conventional plots were sidedressed with urea (46-0-0) at the times and rates recommended in the management guide.

Sidedressing–with a water-soluble, OMRI-approved fertilizer (Alaska 5-1-1 Liquid Fish Fertilizer, Pennington Seed, Inc., Madison, GA, USA)–was adaptive and crop dependent in the precision organic plots. Prior to sidedressing, the nitrogen status of the 5 core vegetable crops (tomato, eggplant, zucchini, chard, and kale) was evaluated using a Minolta SPAD-502 chlorophyll meter. In each crop subplot, SPAD readings were taken for the youngest fully mature leaf from 7 randomly selected plants and averaged. If the average was <95% of the reference value for the crop, the subplot was fertilized at a rate of 28 kg ha^{-1}. Reference values were derived from plantings of the core crops established in an adjacent reference plot. Each crop was represented in the plot by 7 plants, which were fertilized at a rate equal to 120% of the total nitrogen rate recommended for the crop in the *New England Vegetable Management Guide*. Reference values for each crop were calculated using the same sampling method used to determine the nitrogen status of crops in the precision organic plots. Other crops were sidedressed at the rates and according to the schedule described in the management guide.

Weed Management

In 2017, three warm-season, transplanted crops—tomato, eggplant, and zucchini—were grown in black plastic mulch in the control, precision organic, and compost-only systems. Other crops remained unmulched and were weeded by hand or by hoe. In 2018 and 2019, a reusable woven weed barrier (DeWitt

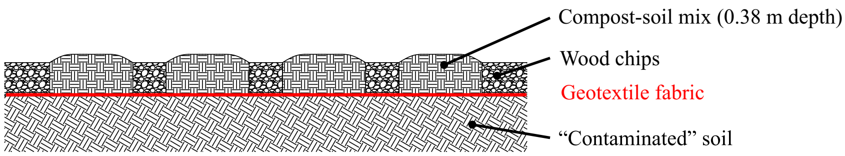

FIGURE 1 | Urban cap-and-fill system.

SBLT4300 Sunbelt Ground Cover Weed Barrier, DeWitt Co., Sikeston, MO, USA) was used for these three crops plus melon and basil (2018) and basil, sweet potato, and acorn squash (2019) in the control and precision organic systems. Use of plastic mulch was discontinued in the compost-only system after 2017 to reduce dependence on external inputs and, potentially, to allow for intercropping. No plastic mulches were used in the urban cap-and-fill system during the study period, following practices observed on urban farms in Chicago and Providence.

Irrigation

All crops were irrigated using drip tape (Aquatraxx, Toro Co., Bloomington, MN) with two emitter lines per bed. Tape with an emitter spacing of 30.5 cm (12 in) was used in 2017 and 2018; spacing was reduced to 15.2 cm (6 in) in 2019 for better coverage of planting beds. Irrigation was scheduled using the feel and appearance method (NRCS, 1998), since this was deemed to be the most accessible method for urban growers for scheduling irrigation. Irrigation water was sourced from the University of Rhode Island Water System, which draws from three high volume wells fed by an aquifer that extends beneath the study site. The water is chlorinated and potable. The volume of water applied to each plot was not tracked during the study period.

Cover Cropping

Cover cropping is relatively infrequent in urban gardens in the author's experience and others' (Gregory et al., 2016) but could have a positive impact on soil quality while reducing erosion, scavenging nutrients at the end of the growing season, and, if leguminous crops are used, offsetting external inputs of nitrogen for subsequent food crops (Gregory, 2017). At the end of the 2017 and 2018 growing seasons, half of the beds in each system—corresponding to the same crops the following growing season–were cover cropped with cereal rye, sown at a rate of 90 kg ha^{-1} the first week in October. The cover crop was terminated in the spring at the soft dough stage by mowing followed by occultation with a black plastic tarp following Fortier and Bilodeau (2014). Conventional and precision organic plots were tilled after occultation. All vegetable beds in each experimental plot were cover cropped with rye in October 2019.

Crop Assemblages

Crops were selected based on their popularity, relative ease of cultivation, and nutritional value. The crop mix became increasingly diverse over the 3-years period, expanding from six crops in 2017 to 20 in 2019 (**Table 1**). Five core crops—eggplant (*Solanum melongena* "Orient Express"), tomato (*Lycopersicon esculentum* "Mt. Fresh Plus"), zucchini (*Cucurbita pepo* "Raven"), chard (*Beta vulgaris* subsp. *vulgaris* "Bright Lights"), and kale (*Brassica oleracea* "Toscano")—were planted each season to support comparisons of yields across all 3 years of the study. Cut flowers—zinnia (*Zinnia elegans* "Benary's Giant") and rudbeckia (*Rudbeckia hirta* "Indian Summer")—were added to the crop mix in 2018 because they can be a profitable crop for market gardeners, support pollinators, and improve plot aesthetics, a potentially important function in urban environments, where food production may be perceived to be transgressive. By 2019, a final 3-years vegetable crop rotation was established (**Table 1**). Of the six 0.76×15.24 m beds, five are dedicated to vegetable production. Each bed is divided into three subplots, yielding a three-by-five grid of 15–0.76 × 5.08 m subplots. The sixth bed, divided into five 0.76 × 3.05 subplots, is dedicated to cut flower production. In 2019, three perennial cut flowers—purple coneflower (*Echinacea* "Cheyenne Spirit"), delphinium (*Delphinium elata* "Magic Fountains Mix") and lupine (*Lupinus* "Tutti Frutti")—were added to the crop assemblage but will not contribute to production until 2020. To maximize comparability with 2018 data, the area of these 3 subplots was subtracted from the total plot area when total value of food and flower crops was

TABLE 1 | Crop assemblages, 2017–2019.

2017	2018	2019
Chard (*Beta vulgaris* subsp. *vulgaris*) "Bright Lights"	Basil (*Ocimium basilicum*) "Genovese"	Acorn squash (*Cucurbita pepo*) "Table Gold"
Edamame (*Glycine soja*) "Tohya"	Cabbage (*Brassica oleracea*) "Tiara"	Basil (*Ocimium basilicum*) "Genovese"
Eggplant (*Solanum melongena*) "Orient Express"	**Chard (*Beta vulgaris* subsp. *vulgaris*) "Bright Lights"**	Cabbage (*Brassica oleracea*) "Tiara"
Kale (*Brassica oleracea*) "Toscano"	Dry bean (*Phaseolus vulgaris*) "Maine Sunset"	**Chard (*Beta vulgaris* subsp. *vulgaris*) "Bright Lights"**
Tomato (*Lycopersicon esculentum*) "Mountain Fresh Plus"	**Eggplant (*Solanum melongena*) "Orient Express"**	Chinese cabbage (*Brassica rapa* var. *pekinensis*) "Minuet"
Zucchini (*Cucurbita pepo*) "Raven"	**Kale (*Brassica oleracea*) "Toscano"**	Delphinium (*Delphinium elatum*) "Magic Fountains Mix"
	Melon (*Cucumis melo*) "Savor"	Edamame (*Glycine soja*) "Tohya"
	Pepper (*Capsicum anuum*) "Ace"	**Eggplant (*Solanum melongena*) "Orient Express"**
	Rudbeckia (*Rudbeckia hirta*) "Indian Summer"	Green bean (*Phaseolus vulgaris*) "Jade"
	Tomato (*Lycopersicon esculentum*) "Mountain Fresh Plus"	**Kale (*Brassica oleracea*) "Toscano"**
	Zinnia (*Zinnia elegans*) "Benary"s Giant"	Lupine (*Lupinus* hybrid) "Tutti Frutti"
	Zucchini (*Cucurbita pepo*) "Raven"	Pepper (*Capsicum anuum*) "Ace"
		Purple coneflower (*Echinacea hybrid*) "Cheyenne Spirit"
		Rudbeckia (*Rudbeckia hirta*) "Indian Summer"
		Sweet potato (*Ipomoea batatas*) "Covington"
		Tomato (*Lycopersicon esculentum*) "Mountain Fresh Plus"
		Tomato (*Lycopersicon esculentum*) "New Girl"
		Tomato (*Lycopersicon esculentum*) "Polbig"
		Zinnia (*Zinnia elegans*) "Benary's Giant"
		Zucchini (*Cucurbita pepo*) "Raven"

Core crops planted every year are in boldface.

calculated for 2019. The opportunity cost associated with the loss of production from the subplots will be taken into account in future economic analyses.

Vegetable crops are graded for marketability according to the United States Department of Agriculture's grade standards for the specific crop (Agricultural Marketing Service, 2005). Crops meeting the criteria for U.S. No. 2 or Commercial and higher grades are considered to be marketable. Flower crops are graded according to their appearance, including freedom from pest damage and deformity. Yield per square meter is calculated based on bed width (0.76 m) plus the width of the interbed space (0.30 m). It does not include alleys between research plots. This method of calculating yield is comparable to that used by the United States Department of Agriculture's vegetable surveys, which collect data from growers on harvested acreage and yield for each crop at the farm level (NASS, 2019). Nonproductive areas outside production fields are not included in the denominator when calculating yield per area. Interbed or interrow spaces within fields are.

Soil Sampling and Analysis

Baseline soil samples were collected from each plot in May 2017, after initial field preparation (with a moldboard plow and disk) and plot layout but before the application of fertilizer or compost. A total of 10 cores 15 cm in length were collected in a grid with a 2.22 cm diameter AMS soil probe (AMS Inc., American Falls, ID, USA) and composited to create a single sample per plot. In May and October of 2018 and 2019, a total of 18 subsamples—three 15 cm cores per bed—were collected from each plot and composited. All composited soil samples were air dried, sieved to <2 mm and sent to Brookside Laboratories in New Bremen, OH, USA and analyzed for: percent organic matter through loss on ignition at 360 degrees C (Schulte and Hopkins, 1996); pH with a 1:1 water dilution method (McLean, 1982); cation exchange capacity (Ross and Ketterings, 2011); potassium, phosphorus, manganese, zinc, boron, copper, iron, aluminum, calcium, magnesium, and sodium with a Mehlich-III extraction (Mehlich, 1984); and estimated nitrogen release based on percent organic matter. The October 2019 samples were also analyzed for permanganate oxidizable carbon, a measure of biologically active carbon (Weil et al., 2003), and bulk density. To estimate bulk density, the composite sample from each plot was oven-dried at 105°C for 48 h then weighed. Bulk density was calculated by dividing the oven-dry weight (g) of each sample by the total volume of the 18 cores constituting the sample.

A double-ring infiltrometer (Turf-tec International Tallahassee, FL, USA) was used in October 2019 in a randomly selected location in each experimental plot to determine the rate of water infiltration. Both inner and outer rings of the infiltrometer were filled with water, allowed to drain, and then immediately refilled. The decline in the level of water in the inner ring over a ten-minute period was measured.

Statistical Analysis

Based on marketable yield data, summary variables (total food yield, total food value, and total value of food and flower production) were calculated for each plot. Crop value was determined based on unit prices collected from a local farmer's market and a local grocery store in summer and fall 2019. Data for summary variables, individual crop yields, and soil physical properties were analyzed by GLIMMIX procedure in SAS University Edition software (SAS Institute Inc., Cary, NC, USA). Treatment, year, and their interaction were treated as fixed effects, and replication was a random effect. If there was no interaction between treatment and year, data were pooled across years. Prior to all analyses, data were evaluated for normality and homogeneity of variance by UNIVARIATE procedure in the software and ln-, cube-, or square root-transformed, if necessary, with back-transformed values for means reported in the text and tables. Dunnett's test was used to determine differences between the least squares means of the three experimental treatments (compost-only, precision organic, and urban cap-and-fill) and the control treatment (conventional) at a significance level of $\alpha = 0.05$ for summary variables and individual crop yields. The Tukey-Kramer multiple comparisons tests was used to separate means for soil chemical properties in 2017 and soil chemical and physical properties in 2019. Differences in soil chemical properties between spring 2017 and fall 2019 for each treatment were evaluated using the TTEST procedure in the SAS software. To compare soil properties across treatment plots, non-metric dimensional scaling (NMDS) ordinations of plots were performed (PROC NMDS in the SAS software) using Bray–Curtis dissimilarity matrices for 2017 and 2019 soil data.

RESULTS

Productivity

Pooled across the 3 years of the study, average marketable food yield was significantly lower only for the compost-only treatment (2.22 kg m^{-2}) compared to the conventional (control) treatment (2.96 kg m^{-2}); yields in the precision organic (2.87 kg m^{-2}) and urban cap-and-fill (2.61 kg m^{-2}) treatments did not differ significantly from the average yield of the conventional treatment (**Table 2**). For all treatments, yields declined from 2017 to 2018 and then increased from 2018 to 2019. Yield loss from 2017 to 2018 was greatest in the in-ground treatments, ranging from 25.1% (conventional) to 39.8% (compost-only), and smallest in the urban cap-and-fill treatment (9.6%).

The compost-only treatment yielded significantly less than the conventional treatment in 2017 and 2018, as did the urban cap-and-fill treatment in 2017. Yields did not differ from the control for any of the other treatments during the 3-years period. Average marketable food yield for the compost-only treatment increased 86% between 2018 and 2019, from 1.47 to 2.74 kg m^{-2}, and was not significantly different from average yield for the control in 2019.

Yields for individual core crops grown every year of the study did not necessarily track year-to-year changes in total food yield (**Tables 3**, **4**). Yields of the highest yielding crop on a weight per square meter basis, tomato "Mt. Fresh Plus," declined for all three in-ground treatments from 2017 to 2018, from 41.8% (compost-only) to 44.0% (precision organic); average yield was almost unchanged for the urban cap-and-fill treatment. Yields rebounded in 2019 for the compost-only and precision organic

TABLE 2 | Marketable system yield and value of system production by year and pooled across years when the treatment-by-year interaction was not significant ($p > 0.05$).

Treatment	Marketable food yield kg/m³				Marketable food value USD/m³				Total value of food + flower production USD/m³	
	2017	2018	2019	Ave.	2017	2018	2019	Ave.	2018	2019
Conventional	3.35	2.51	3.01	2.96	16.65	13.50	15.85	15.33	16.70	17.34
Compost-only	2.44*	1.47*	2.74	2.22*	12.11*	7.94*	15.00	11.68*	9.90*	16.67
Precision organic	3.21	2.33	3.07	2.87	15.86	12.64	16.10	14.87	15.86	17.25
Urban cap-and-fill	2.59*	2.34	2.90	2.61	13.23*	13.61	16.03	14.29	17.18	18.25
SE	0.18	0.12	0.16	0.19	0.87	0.56	0.89	0.88	0.91	0.95

Asterisks indicate significant differences compared to the control, Conventional, according to Dunnett's test (α = 0.05). SE, standard error for comparisons of treatment least squares means.

TABLE 3 | Marketable yields by year for three core crops with a significant ($p < 0.05$) treatment-by-year interaction.

Treatment	Eggplant "Orient Express" kg/m³			Chard "Bright Lights" kg/m³			Tomato "Mt. Fresh Plus" kg/m³		
	2017	2018	2019	2017	2018	2019	2017	2018	2019
Conventional	1.12	2.15	4.96	4.00	3.30	3.31	8.91	5.00	4.24
Compost-only	0.71	0.67*	1.98*	2.38*	1.56*	6.20	6.31*	3.67	5.86
Precision organic	1.20	1.71	3.11	3.27	2.71	4.64	8.75	4.90	6.51*
Urban cap-and-fill	0.44*	1.63	3.47	5.35*	3.86	5.71	5.22*	5.01	6.43*
SE	**	0.25	0.74	0.42	0.43	1.14	0.73	0.59	0.78

***Data were ln transformed for normality and backtransformed for presentation of means, but standard errors cannot be backtransformed.*
Asterisks indicate significant differences compared to the control system, Conventional, according to Dunnett's test (α = 0.05). SE, standard error for comparisons of treatment least squares means.

plots–but not the conventional plots–despite the negative impact of early blight on the tomato crop in 2019. In 2019, average tomato yield was significantly higher than the control for both the precision organic and urban cap-and-fill treatments and no different for the compost-only treatment. Unlike tomato yields, eggplant yields consistently increased across all treatments from 2017 to 2019 (with the exception of the compost-only treatment between 2017 and 2018), by as much as 343% in the case of the conventional treatment. Tracking total food yields, kale yields declined in all treatments from 2017 to 2018 and then increased in 2019. Chard and zucchini yields showed more complex patterns across the 3 years. When pooled, zucchini yields were significantly lower in the compost-only and urban cap-and-fill systems than in the conventional system. Across all treatments, average yields for individual crops grown for two or more years far exceeded 2016-2018 average yields reported for New England (USDA, 2019) and met or exceeded "good" yields based on national averages (Campbell-Nelson, 2020) for every crop in every treatment, with the exception of zucchini and eggplant (**Figure 2**).

Total food value was significantly lower than the control for the compost-only treatment in 2017 and 2018—but not 2019—and when pooled across the three reporting years. It was not significantly different in 2019 (**Table 2**). Total food value was not significantly different from the control for any of the other three treatments, for individual years or when pooled except for the urban cap-and-fill treatment in 2017. Flower production (zinnias and rudbeckia) had a large positive impact on total production value at the system level across all four treatments, increasing average value per square meter in 2018 by 23.7% to 26.2% and in 2019 by 7.1% to 13.8% despite the relatively small harvested area in each plot in each year (10.8 m^2 in 2018 and 6.5 m^2 in 2019, corresponding to 11.1% of total plot area in 2018 and 7.4% in 2019). Total flower production as measured by number of stems in the compost-only system was significantly lower than the control in 2018 and 2019. Flower production was not significantly different from the control in either of the other two systems in either year.

Soil Quality

In the base year, 2017, soil chemical properties prior to fertilization or compost application did not differ significantly by in-ground treatment, indicating that blocking was effective for controlling variations in soil characteristics across the experimental plots (**Table 5**). Reflecting the site's long history of agricultural management as part of the experiment station, phosphorus levels were relatively high, averaging 114–122 mg kg^{-1}.

Soil chemical properties subsequently diverged by system type over the 3-years study period. Change was, of course, most rapid for the urban-cap-and fill plots, in which a premade 50:50 mix, by volume, of yard waste compost and offsite topsoil was placed over a geotextile cap over the native soil, reproducing a common soil remediation technique in urban agriculture.

TABLE 4 | Marketable yields for two core crops by year and pooled across years due to an insignificant ($p > 0.05$) treatment-by-year interaction.

Treatment	Kale "Toscano" kg/m³				Zucchini "Raven" kg/m³			
	2017	2018	2019	Ave.	2017	2018	2019	Ave.
Conventional	4.67	3.34	4.30	4.10	2.58	3.26	2.56	2.80
Compost-only	3.28	2.68	3.66	3.21*	2.31	2.30*	1.14*	1.92*
Precision organic	4.53	3.09	3.82	3.81	2.61	2.95	2.02	2.52
Urban cap-and-fill	4.97	3.24	3.82	4.01	1.76	3.03	0.85*	1.88*
SE	0.56	0.34	0.39	0.34	0.55	0.28	0.29	0.31

Asterisks indicate significant differences compared to the control, Conventional, according to Dunnett's test (α = 0.05). SE, standard error for comparisons of treatment least squares means.

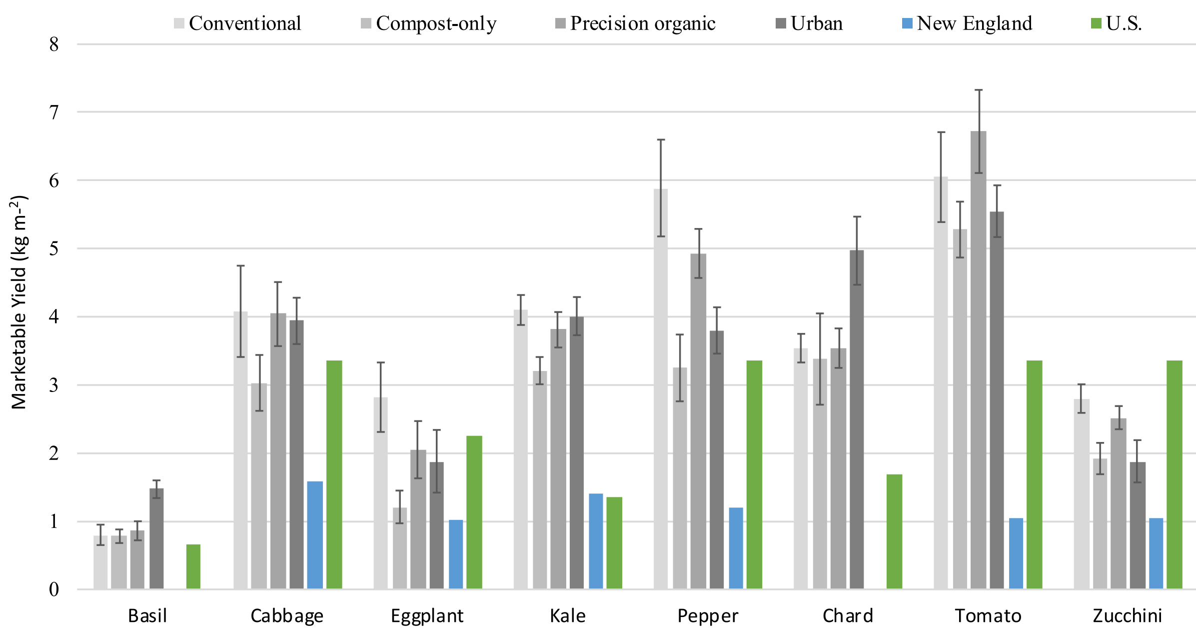

FIGURE 2 | Average yields of eight crops grown for two or more seasons, by system, vs. regional and U.S. averages. Error bars represent standard deviations of the means.

Chemical properties of the 50:50 compost-soil mix reflected the combined properties of the mix's constituents (**Table 6**). On average, all soil chemical characteristics but pH were significantly higher in the urban plots compared to all other treatments at baseline (**Table 5**). The organic matter content of the urban mix averaged 9.18% compared to 3.45–3.81% for the in-ground treatments prior to fertilization or compost application in 2017, with an estimated rate of nitrogen release of 134 kg ha^{-1}. Other plant macronutrients were present to excess in the urban treatment. Levels of phosphorus, a potential environmental pollutant, were more than twice as high, on average, than the already high levels found in the mineral soils of the in-ground treatments, and potassium levels in the urban plots averaged more than four times the levels found in the in-ground plots. Levels of sulfur, calcium, and magnesium were all, on average, two to three times higher for the urban treatment.

Nonmetric multidimensional scaling (NMDS) was used to visualize differences between plots based on soil chemical characteristics. NMDS facilitates visualization by representing the relationships between plots in a reduced number of dimensions (axes). Plot ordination was based on a Bray-Curtis dissimilarity matrix based on soil chemical characteristics (CEC, pH, OM, P, K, S, Ca, Mg, Na, Fe, Mn, Cu, Zn, and Al). The badness of fit criterion for each NMDS (0.009546 for the 2017 ordination and 0.005114 for 2019) indicates that the data fit the model extremely well. In the 2017 NMDS, the urban cap-and-fill plots cluster separately from the in-ground plots in ordination space based on these characteristics (**Figure 3**). In the 2019 NMDS, the compost-only plots cluster more closely with the urban cap-and-fill plots than with the other in-ground plots, indicating that the soils of the compost-only plots are becoming more like those of the cap-and-fill

TABLE 5 | Baseline chemical properties of soils prior to application of fertilizer or compost but after establishment of urban cap-and-fill plots (May 2017).

Treatment	pH	CEC	OM	*P*	K	S	Ca	Mg	Na
		meq/100 g	%	mg/kg					
Conventional	6.2b	6.99b	3.55b	113.8b	113.2b	13.5b	924.2b	99.0b	26.8b
Compost-only	6.2b	6.88b	3.45b	110.5b	94.0b	14.7b	930.2b	91.8b	30.2b
Precision organic	6.3ab	6.96b	3.81b	121.5b	116.0b	14.4b	932.0b	101.8b	25.2b
Urban cap-and-fill	6.4a	16.37a	9.18a	258.8a	494.0a	51.4a	2016.8a	307.5a	66.0a
SE	0.05	0.87	0.23	13.19	28.85	**	127.10	6.44	3.52

***Data were ln transformed to equalize variances and backtransformed for presentation of means, but standard errors cannot be backtransformed.*
Different letters within columns indicate significant differences between mean values according to the Tukey-Kramer multiple comparisons test (α = 0.05). SE, standard error for comparisons of treatment least squares means.

TABLE 6 | Compost properties, 2017–2019.

Year	Bulk density	pH	OM	Total N	*P*	K	S	Ca	Mg	Na
	g/cm^3		%	% (Dry weight basis)						mg/kg
2017	0.74	7.7	44.3	0.9	0.30	0.56	0.15	1.40	0.25	310
2018	0.68	7.3	39.7	1.3	0.34	0.55	0.15	1.17	0.23	366
2019	0.68	7.3	40.9	1.5	0.40	0.68	0.17	1.32	0.25	283

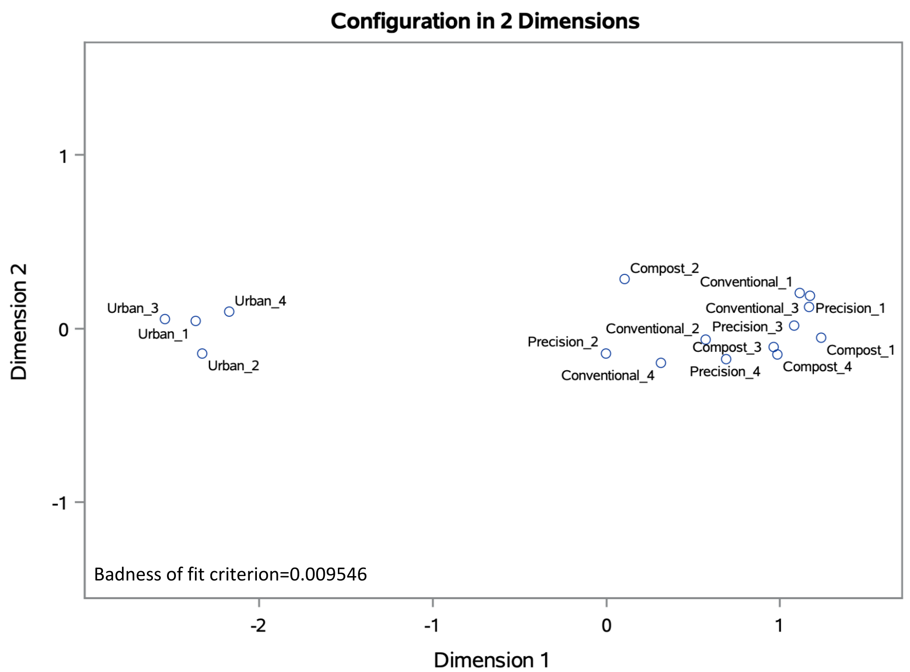

FIGURE 3 | NMDS ordination based on Bray-Curtis dissimilarity matrix for 2017 soil chemical characteristics (CEC, pH, OM, P, K, S, Ca, Mg, Na, Fe, Mn, Cu, Zn, and Al) of 16 experimental plots, four replicates per treatment.

plots due to 3 years of annual application of compost to plot beds (**Figure 4**).

Driven by the annual addition of compost, average values for pH, CEC, soil organic matter, phosphorus, potassium, sulfur, calcium, and magnesium had all increased significantly in the compost-only plots by 2019 compared to 2017 (**Tables 7**, **8**). Average potassium level in the compost-only treatment more than doubled over three growing seasons while average phosphorus increased a more modest 21.5%. Phosphorus did not change significantly between 2017 and 2019 in any other treatment. In contrast, potassium levels declined significantly in all other treatments. The decline in potassium was particularly

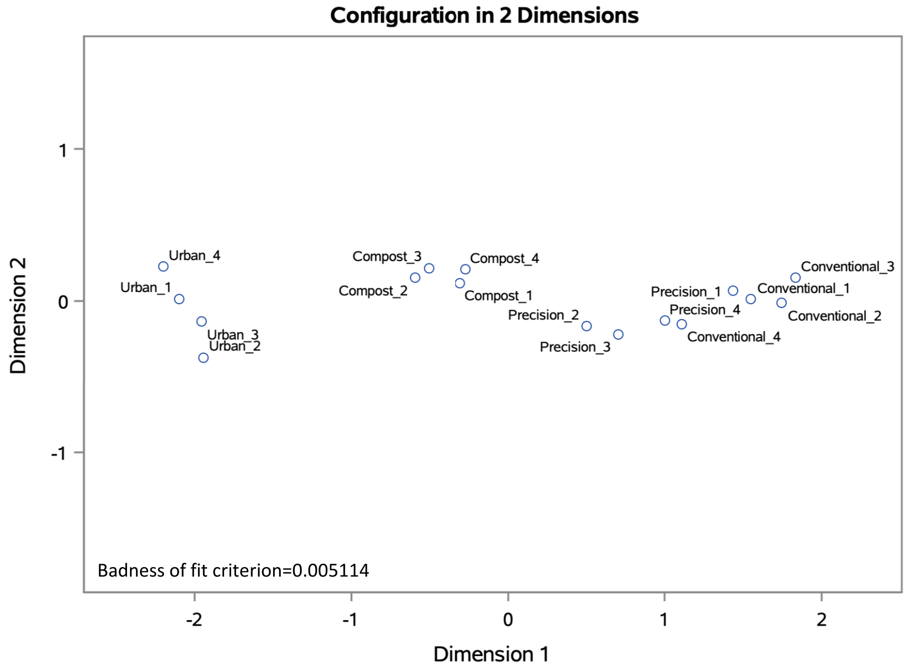

FIGURE 4 | NMDS ordination based on Bray-Curtis dissimilarity matrix for 2019 soil chemical characteristics (CEC, pH, OM, P, K, S, Ca, Mg, Na, Fe, Mn, Cu, Zn, and Al) of 16 experimental plots, four replicates per treatment.

TABLE 7 | Chemical properties of soils after three growing seasons (October 2019).

Treatment	pH	CEC	OM	*P*	K	S	Ca	Mg	Na
		meq/100g	%	mg/kg					
Conventional	6.1c	5.46c	3.42c	121.8b	66.5b	11.0b	705.5c	68.2c	27.0c
Compost-only	6.8a	10.98b	5.64b	134.2b	214.2a	12.5b	1566.0b	201.5b	39.8ab
Precision organic	6.5b	7.09c	3.74c	121.8b	85.8b	18.5a	1007.0c	97.2c	42.5a
Urban cap-and-fill	6.4b	15.54a	9.11a	243.0a	177.5a	17.0a	2118.2a	275.5a	33.0bc
SE	0.10	0.71	**	9.19	15.09	0.87	108.29	11.64	2.84

***Data were ln transformed to equalize variances and backtransformed for presentation of means, but standard errors cannot be backtransformed. Note that variances could not be equalized for Na through transformation.*

Different letters within columns indicate significant differences between mean values according to the Tukey-Kramer multiple comparisons test (α = 0.05). SE, standard error for comparisons of treatment least squares means.

steep in the case of the urban cap-and-fill plots, dropping from 494.0 mg kg^{-1} on average in 2017, after bed formation, to 177.5 mg kg^{-1} in October 2019.

No significant changes were observed in percent organic matter in the conventional, precision organic, or urban treatments over the 3-years study period despite tillage in the first two treatments and the lack of additions of exogenous organic matter in all three. Not surprisingly, the average level of permanganate oxidizable carbon (POXC) in the compost-only treatment in 2019 was significantly higher than in either the conventional or the precision organic treatment but significantly lower than the average POXC level of the urban treatment. Compost additions have a larger impact on POXC than does crop rotation or cover cropping, which were the same across all treatments (Hurisso et al., 2016).

Compost additions also drove changes in soil physical properties. In 2019, the bulk density of the compost-soil mix in the urban cap-and-fill beds was significantly lower, on average, than that of the soil in the conventional or precision organic plots and was lower than typical bulk densities for mineral soils (**Table 9**). After three yearly applications of compost, the bulk density of the soil in the compost-only plots was significantly lower than that of the other in-ground treatments—which were not significantly different from one another—and higher than but not significantly different from the bulk density of the compost-soil mix in the urban plots. Water infiltration rates in 2019 followed the same pattern (**Table 9**). They were lowest in the conventional and precision organic treatments (167 and 135 mm hr^{-1}, respectively), intermediate in the compost-only plots (724 mm

TABLE 8 | Changes in mean values for soil chemical properties between baseline (May 2017) and October 2019, after the third growing season.

Treatment	pH	CEC	OM	*P*	K	S	Ca	Mg	Na
		meq/100g	%	mg/kg					
Conventional	−0.18	−1.54	−0.12	8.0	−46.8*	−2.5*	−218.8	−30.8*	0.2
Compost–only	0.60*	4.11*	2.23*	23.8*	120.3*	−2.2*	635.8*	109.8*	9.5
Precision organic	0.22	0.13	−0.06	0.2	−30.2*	4.0*	75.0	−4.5	17.2*
Urban cap-and-fill	0.00	−0.82	−0.04	−15.8	−316.5*	−36.2*	101.5	−32.00	−33.0*

Asterisks indicate significant differences between 2017 and 2019 mean values according to paired sample t-tests (α = 0.05).

TABLE 9 | Soil physical properties and permanganate oxidizable carbon concentration after three growing seasons (October 2019).

Treatment	Bulk density	Water infiltration	Permanganate oxidizable carbon
	g/cm^3	mm/h	mg/kg
Conventional	1.23a	167b	313.30c
Compost-only	1.06b	724a	476.77b
Precision organic	1.20a	135b	361.92c
Urban cap-and-fill	0.96b	1313a	740.00a
SE	**	**	31.49

***Data were cube transformed (bulk density) or square-root transformed (water infiltration) to equalize variances or to increase normality and backtransformed for presentation of means, but standard errors cannot be backtransformed.*
Different letters within columns indicate significant differences between mean values according to the Tukey-Kramer multiple comparisons test. SE = standard error for comparisons of treatment least squares means.

h^{-1}), and highest in the urban-cap-and fill treatment (1313 mm hr^{-1}).

DISCUSSION

Productivity

Results from the first 3 years of data collection indicate that all four systems of intensive, small-scale, land-based production can be highly productive, with different potential environmental benefits and drawbacks. While total marketable food yields were relatively modest compared to those reported in the gray literature for biointensive agriculture—2.22–2.96 kg m^{-2} averaged over 3 years in this study compared to 4.64 kg m^{-2} for the "low end" of biointensive production (Gittleman et al., 2012)—yields for most individual crops far exceeded regional averages based on reports from over 2,000 New England vegetable producers (USDA, 2019) and, for most crops and systems, national averages (Campbell-Nelson, 2020). Average total marketable food yields were also 55% to 107% higher than the average yield (1.43 kg m^{-2}) reported by CoDyre et al. (2015) for an observational study of 50 backyard gardeners in Guelph, Ontario, Canada, which relied on self-reported yields.

In this study, marketable yield per square meter was calculated based on planted bed width plus the unplanted space between beds, which is comparable to the method used in agronomic studies. Failed plantings were also included in the calculation of total yield per square meter at the plot level. Unfortunately, comparisons with yields reported by observational studies—including CoDyre et al. (2015)—are fraught. Observational studies consistently fail to specify whether total area—including interbed spaces and failed plantings–or only productive area is used to calculate yield per area (Rabin et al., 2012). Similarly, they neglect to specify what is meant by "yield." In agronomic studies in the United States, vegetables and fruit are graded based on standards issued by the U.S. Department of Agriculture—as they were in this study–and yields are reported as either "marketable" or "total" yield. For example, USDA standards for No. 1 and Commercial kale—what would be considered to be marketable in an agronomic study—must be "free from decay and from damage caused by yellow or discolored leaves, seedstems, wilting, bud burn, freezing, dirt, disease, insects, or mechanical or other means" (Agricultural Marketing Service, 2005). A gardener-citizen scientist participating in an observational study, in contrast, might include kale with minor damage when reporting yields from their garden. This underspecification of "yield" makes it difficult to tell whether yields reported in observational studies are equivalent to those reported in agronomic studies. That said, "marketable" yield may not be the most appropriate measure of the productivity of urban agriculture sites, particularly those with the primary purpose of self-provisioning, but even those of a commercial character. Given concerns about food waste, consumers may perceive the purchase of "ugly" vegetables to be a responsible act, particularly if the vegetables are marketed as a sustainable option (van Giesen and de Hooge, 2019). In this context, "edible" yield may be a more appropriate measure and may, in fact, be what is being measured in observational studies. However, without consistent application of some mutual standard for measuring yield in urban agriculture, yields from agronomic studies cannot generally be compared to those from observational studies.

Total food yields in this study declined from year 1 to year 2 and then rebounded in year 3, underscoring the need for both experimental trials and observational studies with durations that adequately capture long-term system dynamics. Two years is the norm for many agronomic studies, while observational studies of urban agriculture seldom capture production data beyond a single growing season–a full year at most. Several factors may have contributed to the significant declines observed in this study in average yield across all in-ground treatments in 2018 compared to 2017. Lower total precipitation in June and

July 2018 compared to 2017 (99.7 mm vs. 162.6 mm) may have reduced yields in 2018 despite increased irrigation frequency with the drip irrigation system. Irrigation was scheduled based on the feel and appearance method (NRCS, 1998) in all three study years because this was deemed to be the method most accessible to small-scale growers. Measurement of soil moisture using tensiometers or other more objective methods and tracking of water use at the plot level would have helped to illuminate the possible relationship between water availability and yield in 2017 and 2018.

Differences in tillage between 2017 and 2018 may have also contributed to observed differences in total food yields. Full tillage of the site in 2017 prior to establishment of the experiment may have temporarily reduced soil bulk density and increased nitrogen availability. Subsequent consolidation and compaction of the mineral soil over the winter may have reduced soil porosity, root penetration, and nitrogen availability during the following growing season, reducing yields. While the conventional plot was tilled in 2018 with a rotary tiller, tillage depth was relatively shallow compared to initial tillage in 2017 with a moldboard plow. Sainju et al. (2000) found that, compared to moldboard plowing, no-till reduced tomato yields by 44% in 1 year of a 2-years study, a yield loss almost identical to that observed in this study for tomato yields in in-ground treatments. With a much higher organic matter content, the growing medium in the cap-and-fill plots may not have been as vulnerable to the same processes of compaction hypothesized to have occurred in the mineral soils in the in-ground plots after initial tillage in 2017.

Particularly striking was the 86% increase in average marketable food yield for the compost-only treatment between 2018 and 2019, from 1.47 kg m^{-2} to 2.74 kg m^{-2}. This dramatic increase may reflect higher nutrient levels and higher rates of mineralization after 3 years of compost application and the eventual reestablishment of the soil microbial community responsible for mineralization following tillage in 2017. In conventional field crop systems, recovery of the microbial community may require 1–3 years following such tillage (Wortmann et al., 2008). At the same time, nutrient insufficiency may account for the lack of an increase in average food yield for the conventional treatment in 2019 compared to 2018. Soils in conventional plots were more vulnerable to nutrient leaching from very high levels of precipitation in June and July 2019 (301.4 mm total) because of the application of highly water-soluble synthetic fertilizers to these plots and the use a woven weed barrier rather than water-impermeable plastic film.

Crop Mix

Urban agriculture occurs within a specific social, cultural, economic, and political context which shapes farmers' and gardeners' motivations for growing food in the city. These motivations, in turn, influence the composition and diversity of crop plant assemblages (Taylor and Lovell, 2015; Pearsall et al., 2017; Taylor et al., 2017). Growers may prioritize the production of culturally-appropriate, high food-value, and/or high market-value crops. Experimental research can complement and inform efforts to model and design crop and crop-livestock assemblages that address urban growers' objectives, whether to maximize yield, profit, yield stability, sustainability, or other functions, such as ecological services (Ward and Symons, 2017).

Much as it might in a vernacular system, crop mix evolved over the 3-years data collection period, from six vegetable crops in 2017 to 15 vegetable and 5 cut flower crops in 2019, to better reflect the diversity of urban production systems (Clarke and Jenerette, 2015; Taylor and Lovell, 2015) and to increase system resilience through greater crop response diversity to environmental stressors (Gaudin et al., 2015). Though the original focus of the study was edible crops, the addition of cut flowers to the crop mix in 2018 was found to have a large, positive impact on the value of production at the system level because of the higher value per square meter of cut flowers compared to vegetable crops. Cut flower production, of course, does not directly address issues of food sovereignty and security. However, low income is a major determinant of food insecurity in the United States (Gundersen et al., 2011), and, as a lucrative side crop, the sale of cut flowers can help to subsidize food production in the urban market garden or farm or support the purchase of food from outside sources. For contaminated sites that would require costly remediation for food production, floriculture may be a more economically viable and socially acceptable option that generates income for urban growers (Manikas et al., 2019). Even in urban systems with the sole goal of self-provisioning, the addition of ornamental flowering plants to the food garden can have ecological and cultural benefits. Bee diversity and pollination services are correlated with floral diversity and abundance in urban neighborhoods (Lowenstein et al., 2014), and concentrating floral resources near sites of food production may be the best strategy for increasing pollination services to urban agriculture (Davis et al., 2017). In addition, food gardening in urban areas can be contentious when it transgresses residential landscape norms, e.g., the American front lawn. Incorporating flowering ornamentals into residential food gardens may increase their social acceptability much as floral enrichment enhances the perception of native plant landscapes (Nassauer, 1995).

Soil Quality and Nutrient Dynamics

Application of organic amendments in urban production systems can rapidly improve soil quality (J. Beniston and Lal, 2012; Small et al., 2017; Miernicki et al., 2018). In this study, three indicators of quality—bulk density, water infiltration rate, and permanganate oxidizable carbon, an indicator of soil microbial activity (Weil et al., 2003) and of stable pools of soil carbon (Hurisso et al., 2016)—were significantly higher in the compost-only treatment compared to the conventional and precision organic treatments after the gradual addition of yard waste compost over a 3-years period. Cation exchange capacity had also increased significantly in the compost-only treatment by October 2019 as had pH and levels of phosphorus, potassium, sulfur, calcium, and magnesium. After 3 years, soils in the compost-only plots were more similar to the 50:50 compost-soil mix in the urban cap-and-fill plots in terms of chemical and physical properties than they were to the soils in the conventional and precision organic plots. In 2017, compost-only plots were indistinguishable from the latter plots based on their chemical soil properties.

Amendment with compost can be a key strategy for rehabilitating urban soils—which may be low in organic matter and nutrients, compacted, and contaminated—for food production (Beniston and Lal, 2012; Brown et al., 2016). Compost dilutes soil contaminants and may, depending on soil and compost characteristics, reduce the bioaccessibility of lead to food crops (Attanayake et al., 2014). By increasing crop growth, it also helps to reduce contaminant concentrations in crop biomass (Attanayake et al., 2014). Adding compost to urban agricultural soils with low levels of contamination is a potentially more cost-effective mitigative method than removal of the contaminated soil or capping and filling the site. In this study, annual application of compost in the compost-only treatment cost \$0.52 m^{-2}; the compost-soil mix used in the urban cap-and-fill treatment, in contrast, cost \$10.14 m^{-2}, almost 20 times as much.

Compost was surface applied each year to the compost-only plots. Little mixing of the compost with field soil occurred in 2018, when a broadfork was used to "crack" the soil after compost application, and even less in 2019, when the only mixing that occurred was due to soil disturbance from planting. Surface application of compost may not be as effective in reducing contaminant bioavailability or diluting contaminants as tilling the compost into the soil. However, as a mulch, compost has the benefit of reducing soil splashing from rain. Soil splashing and subsequent consumption of surface-contaminated plant parts may be a more significant pathway for lead ingestion from garden produce than plant absorption of soil lead (Brown et al., 2016).

In contrast to these benefits, use of compost in urban production systems may have negative agronomic and environmental consequences. Compost potentially increases soil water holding capacity through increased surface area, important in drier soil, and increased porosity, important in wetter soil (Cogger, 2005). Soil porosity increases at two scales, at the scale of capillary pores (30 to 50 μm in diameter) and transmission pores (50–500 μm in diameter) (Pagliai et al., 1981; Cogger, 2005). An increase in porosity at the former scale potentially increases plant available water; increased porosity at the scale of transmission pores increases infiltration rates. Despite the apparent positive impact of compost on soil water holding capacity, the evidence for a corresponding increase in plant available water is equivocal (Cogger, 2005). Moreover, depending on the soil type and rate of compost application, the increase in transmission pores may lead to excessively high infiltration rates.

In this study, the average water infiltration rate for the urban cap-and-fill treatment was 1,313 mm h^{-1}, 8–10 times the rate for the unamended treatments and almost twice as high as the average rate for the compost-only plots. Similarly high infiltration rates have been observed in experimental plots mimicking compost-amended urban production systems (Miernicki et al., 2018) and *in situ*, in home food gardens in Chicago (Taylor and Lovell, 2015). High rates of water infiltration due to reduced density and increased transmission pore space can exacerbate nutrient leaching and may increase water use (Miernicki et al., 2018). Water management is a key agronomic concern in urban agriculture due to constraints related to the availability, cost, and sustainability of irrigation water (Wortman and Lovell, 2013). Growers may not have access to a water source or may rely on expensive municipal water to irrigate their crops. Leaching of nitrogen and phosphorus and nutrient loading of stormwater runoff are of particular environmental concern, but leaching of mobile nutrients in general from compost-amended soils also has agronomic implications. In this study, average potassium increased by 128% in the compost-only plots due to annual additions of compost but declined by 64% in the urban cap-and-fill treatment. While some urban farmers mine the compost-soil mixes in their cap-and-fill systems for nutrients, this study suggests that, over time, losses of potassium and other nutrients due to leaching and plant withdrawals—particularly in locales with high levels of precipitation, such as the study site—may lead to a need for potassium supplementation in the form of sidedressing during the growing season to maintain yields.

Repeated applications of compost in urban production systems to meet the nitrogen needs of crops can also lead to the accumulation of excessively high levels of phosphorus (Small et al., 2017, 2019). In its first 3 years, this project followed a common heuristic for community and market gardeners of adding 2.5 cm of compost to gardens beds annually. This practice resulted in a 21.5% increase in average soil phosphorus in the compost-only treatment over three growing seasons. While such heuristics reduce the cognitive load of nutrient management for urban growers, they are likely to have negative environmental consequences because of the resulting nutrient loading of stormwater runoff. These simplistic heuristics also waste nutrients and money. Urban agriculture service providers need to refine their nutrient management recommendations to growers based on soil tests, plot management history, local soil conditions, and compost properties.

Phosphorus accumulation can also be problematic in urban and rural systems relying on synthetic and organic fertilizers. Adherence to published recommendations for phosphorus application rates in the conventional and precision organic treatments resulted in average phosphorus levels in 2019 that were not significantly higher than base year levels, though they were still much higher than sufficiency levels. However, despite applications of potassium at recommended rates, potassium levels had declined significantly in the conventional and precision organic beds because of leaching and plant uptake, by 41.2% and 26.0%, respectively. Precision organic beds may have retained more potassium in water insoluble forms such as greensand, a component of the solid organic fertilizer applied to the beds prior to planting. Use of a reusable woven geotextile as a weed barrier instead of disposable plastic film may have increased the vulnerability of soil nutrients to leaching in both systems. While regional guidelines recommend split applications only for nitrogen, they may also be needed for potassium to increase use efficiency (Römheld and Kirkby, 2010).

The sustainability of nutrient inputs in this project varied by system. Yard waste compost sourced from the Rhode Island Resource Recovery Center was the sole nutrient source for the compost-only and urban cap-and-fill plots, with the exception of a regionally-produced organic liquid fertilizer used at transplanting. While production of the compost requires expenditure of fossil fuels for transportation of compost stocks, turning of windrows, and compost delivery, it is arguably a more sustainable source of nutrients and organic matter than purchased, bagged compost from distant sources. The solid fertilizer used in the precision organic system is sourced from a regional manufacturer and consists of a wide range of ingredients, some of which may be from renewable regional sources, such as crab meal and fish meal, and others, including alfalfa, cocoa, cotton seed, peanut, and soybeans meals and greensand, phosphate rock, and natural nitrate of soda, which definitely are not. The conventional system uses synthetic mineral fertilizers from distant, non-renewable sources. Each of these nutrient inputs comes with tradeoffs which warrant further investigation beyond the scope of this paper. Compost is bulky to transport and more difficult to apply than synthetic or organic fertilizers. Urban gardeners and farmers may not have access to bulk supplies of compost or access to sufficient compost feed stocks to meet the nutrient needs of their crops. Nutrient availability is more difficult to predict for compost and organic fertilizers than for synthetic fertilizers, which are water soluble and are not dependent on mineralization by soil microbial communities. The cost of inputs used in the study varied greatly. The synthetic nitrogen from the urea used in the conventional system, for example, cost \$4.35 kg^{-1} retail while the organic nitrogen from the solid fertilizer used in the precision organic system cost 5 times as much, \$21.37 kg^{-1}.

Cover cropping with cereal rye in all systems may have helped to scavenge and retain system nutrients at the end of each growing season, with additional benefits including reduced soil erosion and increased water infiltration through winter vegetative cover and maintenance of soil organic matter. Use of a leguminous cover crop such as hairy vetch instead of or in combination with cereal rye could reduce system reliance on external sources of nitrogen by providing a nitrogen credit to summer vegetable crops. However, cover cropping comes at a cost and is seldom practiced in urban agriculture. Maximizing the nitrogen credit from legumes and the contribution of cover crop biomass to soil organic matter requires delaying cover crop termination as late as possible in the spring, until at least late May in Rhode Island, followed by a 2-weeks fallow period for the cover crop to decompose and, if rye is used, for allelopathic chemicals to degrade. While delayed planting may not be an obstacle to cover cropping for home gardeners, for market gardeners who benefit from the price premium associated with an early harvest it can be a competitive disadvantage.

Local recovery and use of nutrients from household waste, e.g., food waste, could reduce outside nutrient and organic matter inputs and increase system sustainability but is unlikely to meet crop demands. More radical strategies for nutrient recovery including composting of human feces and nutrient extraction from human urine could potentially meet crop needs. Wielemaker et al. (2018) estimate, in the context of the Dutch city of Rotterdam, that the nutrient outputs from such New Sanitation strategies could meet 100 percent of the phosphorus inputs and a significant portion of the nitrogen and organic matter needs of a sufficient area of urban agriculture to meet the fruit and vegetable requirements of the human population that is the source of the nutrients.

Limitations

The research has several limitations in terms of its generalizability. The project is being conducted not *in situ* but at the experiment station of a U.S. land grant university, in an open field without many of the socioeconomic and physical limitations found in urban environments, including limited light, anthropogenic soils, air pollution, and limited access to materials, equipment, and agronomic information. The project is evaluating the performance of a relatively narrow assemblage of commonly grown vegetable crops in a particular rotation and spatial arrangement. Many urban agriculturalists are immigrants who grow crops integral to traditional foodways. The cultural needs of these crops have seldom been assessed in traditional agronomic experiments let alone urban system trials such as that described in this article. Immigrant gardeners and farmers may also grow these crops in diverse systems not represented in agronomic research, such as the vertically-layered annual polyculture systems observed in the home gardens of Chinese-origin households in Chicago (Taylor and Lovell, 2015; Taylor et al., 2017). More observational and experimental research on these unique urban systems is required to establish normative production practices, including form and rates of nutrient inputs, tillage practices, and optimal plant species and varieties.

Only a single crop turn was grown in the system due to labor and time constraints, and the majority of crops were harvested over a relatively narrow 3-months period, from early July through the end of September. Use of low-cost season extension techniques such as low tunnels could expand the production window by a month or more in both the spring and summer, increasing yield per square meter on an annual basis. This phase of the project also did not evaluate the sustainability of material inputs to each system, track water use, or record labor inputs by system. In an observational study of 13 urban, small-scale organic production sites in Sydney, Australia McDougall et al. (2019) found that although these sites were twice as productive as Australian commercial vegetable farms, they were inefficient in their use of labor and materials. CoDyre et al. (2015) similarly found that backyard gardens in Ontario, Canada, were highly unsustainable economically, with the production of \$4.58USD kg^{-1} of food requiring \$10.82USD kg^{-1} in inputs, not including labor. Future phases of the project will address these limitations, by including spring and fall production cycles, analysis of input sustainability, and tracking of water use and labor inputs by system to create a fuller picture of the economic and environmental sustainability and labor productivity of each system.

CONCLUSION

While the potential contributions of small-scale, land-based urban production systems to enhancing food sovereignty in the United States have been dismissed by some (O'Sullivan et al., 2019), such systems have always been a part of urban life. In the aggregate, they already make a much larger contribution to urban food systems in the U.S. than the urban farms that have garnered so much attention and investment (Taylor and Lovell, 2012). Experimental research is needed to enhance the productivity, efficiency, and sustainability of these systems, and outreach is needed to communicate that research to urban growers. Paradigms for such research are underdeveloped, in part due to the lack of engagement of crop scientists in the scholarly and popular discourse on urban agriculture. This study is developing one possible framework for experimental research at a scale appropriate to urban agriculture. While not participatory in nature, its methods are based on close observation of vernacular urban production systems and a synthesis of the gray and scholarly literature on sustainable intensification. The research approach is adaptive. It recognizes that even small-scale gardens and farms are dynamic social-ecological systems. Rather than being an *a priori* expert on system dynamics, the researcher is—much like a farmer or gardener—a humble student, constantly learning from the system. To quote Thomas Jefferson, "no occupation is so delightful to me as the culture of the earth, and no culture comparable to that of the garden. such a variety of subjects, some one always coming to perfection, the failure of one thing repaired by the success of another, and instead of one harvest a continued one thro' the year. under a total want of demand except for our family table I am still devoted to the garden. but tho' an old man, I am but a young gardener" (Oberg and Looney, 2008).

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

AUTHOR CONTRIBUTIONS

JT was responsible for all aspects of this research and manuscript.

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Rooftop Farm Soils for Sustainable Water and Nitrogen Management

Yoshiki Harada[1]*, *Thomas H. Whitlow*[1], *Nina L. Bassuk*[1] *and Jonathan Russell-Anelli*[2]

[1] *Horticulture Section, School of Integrative Plant Science, College of Agriculture and Life Sciences, Urban Horticulture Institute, Cornell University, Ithaca, NY, United States,* [2] *Soil and Crop Sciences Section, School of Integrative Plant Science, College of Agriculture and Life Sciences, Cornell University, Ithaca, NY, United States*

Rooftop farming intends to diversify options for enhancing sustainability of cities. From a policy perspective, vegetable production and stormwater management are among important goals of rooftop farming for bolstering public funding and policy support. However, crops with high value and market demand like salad greens often have high irrigation requirements, which risks increasing drainage output of water and nutrients. To date, no studies have compared various soil mixes intended for rooftop farms in terms of stormwater retention and yield of drought-sensitive crops constrained by regional precipitation patterns. Here, we report the results of a 5-week greenhouse experiment with leaf lettuce comparing five soil mixes made of coconut coir, biochar, and animal manure compost, plus a commercial rooftop farm soil using expanded shale, using an irrigation rate mimicking average growing season precipitation for New York City, USA. Three soil mixes had good yield, with water retention rates ranging up to 100%, while levels of drainage nitrogen output were <13% of current levels at the Brooklyn Grange, an operational rooftop farm in NYC. This finding suggests that improved soil design could enhance sustainability of rooftop farming in terms of water and nutrient management. Further research is needed for adjustment of nitrogen mineralization rates, long-term amendment plan, locally available waste inventory for substituting coconut coir, and leachate and rainwater harvesting systems.

Keywords: urban agriculture (UA), rooftop agriculture, soilless media, stormwater management (SWM), green roof, green infrastructure (GI), urban ecology, ecosystem services (ES)

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Mariana Benítez, National Autonomous University of Mexico, Mexico

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Giorgio Prosdocimi Gianquinto, University of Bologna, Italy

****Correspondence:***
Yoshiki Harada
yh535@cornell.edu

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INTRODUCTION

Agriculture is an emerging component of twenty first century urban planning to achieve diverse goals of sustainability. Efficient food supply chain and urban food security are among the goals specific to urban agriculture, while urban green space, including urban agriculture, are integral components of "green infrastructure" projects in a wide range of practices including stormwater management, energy conservation, biodiversity restoration, and waste management by using soils made of recycled materials (Mougeot, 2006; Lovell, 2010; Ackerman et al., 2013; Specht et al., 2014; Thomaier et al., 2015; Ahern, 2016; Grard et al., 2017; Harada et al., 2017). Horticultural technologies can expand options for adapting agriculture to urban planning. For example, green roof technologies for growing ornamentals on urban rooftops have been applied to intensive vegetable production systems, known as rooftop farms, which are retrofitted to underutilized roofs, incentivized by funding subsidies and policy supports for enhancing the sustainability of built environments (Ackerman et al., 2013; Harada et al., 2017). As a part of the New York City's 20-year stormwater management plan, for example, the Community-Based Green Infrastructure Program provided $592,730 for the construction of the Brooklyn Grange, a 0.61-ha rooftop farm atop an 11-story building of the former Brooklyn Navy Yard (NYC DEP, 2011). Furthermore, NYC's new zoning code known as "Zone Green" allows modification of rooftops for enhancing urban sustainability such as photovoltaic power generation and vegetated roofs including rooftop farms. These sustainable building solutions will be mandated by the Climate Mobilization Act of NYC in 2024, which could offer further opportunities for rooftop farming (NYC DCP, 2012; New York City Council, 2019).

Leafy vegetables, such as mustard greens (*Brassica juncea*) and leafy lettuce (*Lactuca sativa*), are in demand in cities, making them important crops for urban agriculture (Buehler and Junge, 2016; Baudoin et al., 2017). However, these leafy vegetables are drought-sensitive, and require that minimum soil water potential be maintained above 6–10 kPa to maintain growth and quality (Shock and Wang, 2011). This management regime can increase drainage loss of water and nutrients, posing negative impact on water quality, while increasing the costs of irrigation and nutrient subsidies (Shock and Wang, 2011). Rooftop farming may have advantages for achieving precise water and nutrient management similar to greenhouse production systems. For example, both systems use shallow ($<$500 mm) synthetic soils made of organic materials, such as peat moss, coconut coir, biochar, and compost, blended with mineral materials, such as vermiculite, sand, and expanded shale (Bunt, 2012; Harada et al., 2017). Furthermore, measurements of readily available water (RAW, the amount of water plants can extract from soil without drought stress) can be specific to each crop. In agriculture using field soils, RAW is estimated by the moisture release between 10 and 100 kPa of soil water tension (Gradwell and Birrell, 1979). Greenhouse agriculture focuses on RAW between 1 and 5 kPa or between 1 and 10 kPa, while moisture release up to 30 kPa is sometimes considered as available water (de Boodt and Verdonck, 1971; Fonteno, 1988; Milks et al., 1989; Argo, 1998; Bunt, 2012). Methods and concepts of greenhouse agriculture for growing drought-sensitive crops using shallow synthetic soils could be useful for improving hydrologic performance of rooftop farm soils.

Despite these readily available technologies, current rooftop farming practices have not focused on sustainable water and nutrient management. For example, studies of the Brooklyn Grange report that drainage output of water and nitrogen (N) was 197 and 83% of irrigation and fertilizer input during the growing season respectively, because preferential flow and hydrophobicity of the soil components reduced the water holding capacity of the soil (Harada et al., 2018a,b). These hydrologic properties of soil can be specific to levels of moisture fluctuations in outdoor environments, which are not traditionally studied for synthetic soils in greenhouse agriculture. Conversely, synthetic soils are not the traditional subjects of agriculture using field soils. Another factor reducing water holding capacity of the rooftop farm soils is blending expanded shale with animal manure and spent soils from mushroom production for manufacturing Rooflite Intensive Ag (Rooflite hereafter), the commercial mix used at the Brooklyn Grange (Kong et al., 2015; Skyland USA LLC, 2015; Harada et al., 2018b). In vegetated rooftops, including ornamental green roofs and rooftop farms, mineral aggregates, such as expanded shale, crushed bricks, pumice, are often used to promote rapid drainage in order to avoid exceeding the bearing capacity of the roof structures (Ampim et al., 2010). It must be recognized that these soils were originally developed for growing drought-tolerant ornamentals like sedum species, and may not contribute to the water holding capacity necessary for growing drought-sensitive crops (Oberndorfer et al., 2007; Eksi et al., 2015; Harada et al., 2017). Synthetic soils made of organic materials, known as potting soils or container mixes, can have higher water holding capacity and less bulk density than those using mineral aggregates. Studies of rooftop farms using potting soils report satisfactory yield and quality (Cho, 2008; Cho et al., 2010; Orsini et al., 2014; Grard et al., 2015, 2017; Sanyé-Mengual et al., 2015b), but none have specifically studied the effects soil composition and depth have on water and nutrient budgets.

Environmental planning addressing rooftop agriculture at the intersection of science and planning can provide specific benchmarks for evaluating the ecological performance of rooftop farms. In NYC's green infrastructure master plan, for example, the stormwater retention target is 25 mm day^{-1} for a variety of sites, including rooftop farms (NYC DEP, 2010). Given that NYC's monthly normal rainfall is 102 $\pm$ 9 mm during the growing season (**Table 1**), the stormwater management scenario means that project sites could retain rainfall events of 25 mm day^{-1} occurring four times a month. Furthermore, the observed precipitation exceeded evapotranspiration (ET) during the growing season at the Grange, suggesting that the farm could be self-sufficient in terms of water use (Harada et al., 2018b). This is important from an urban planning perspective because supplemental irrigation uses potable water, posing possible conflicts with human demands for water consumption. There are studies of rooftop farming aiming to inform urban planning by estimating possible contributions to city-wide fresh vegetable demands, competitive production costs in regional economy, and life-cycle costs including water, fertilizer, electricity, and building material consumption (Orsini et al., 2014; Grard et al., 2015, 2017; Sanyé-Mengual et al., 2015a,b), but none of these studies have focused on the role soil plays in this system. The objective of this study is to compare various soil mixes intended for rooftop farms in terms of stormwater retention and yield of drought-sensitive leafy greens, using an irrigation rate mimicking average growing season precipitation for New York City, USA.

METHODS AND MATERIALS

During a 5-week greenhouse experiment, 6 mixes $\times$ 2 soil depths $\times$ 5 replicates = 60 experimental units (pots) were compared in terms of the water retention, drainage N output, and yield of leaf lettuce. All treatment units were received 25 mm of irrigation once a week, equivalent to the stormwater retention capacity of

TABLE 1 | Monthly normal rainfall during the growing season 1981–2010 in New York City, USA, reported by NOAA*.

Month	Monthly precipitation depth (mm month^{-1})			
	Brooklyn	Manhattan (Central park)	Queens (JFK airport)	Queens (La Guardia airport)
April	105	114	98	102
May	103	106	100	96
June	106	112	98	100
July	123	117	104	114
August	106	113	93	105
September	94	109	89	95
October	97	112	92	96
November	90	102	84	87
Average	102 ± 9			
	NOAA station details			
Station ID	USC00305796	USW00094728	USW00094789	USW00014732
Latitude	40.59389°	40.77898°	40.6386°	40.7792°
Longitude	73.98083°	−73.96925°	−73.7622°	−73.88°

*National Oceanic and Atmospheric Administration National Centers for Environmental Information (https://www.ncdc.noaa.gov/cdo-web/datatools/normals).

the NYC's stormwater management scenario within the context of monthly normal rainfall.

Laboratory Measurements of Moisture Release

Soil composition was based on the moisture released of the components at 0.93, 10, and 30 kPa tension (**Table 2**) using the method of Harada et al. (2018b). Briefly, volumetric water contents (VWC) at 0.93 kPa were measured by stacking, saturating, and draining soil rings filled with samples, while VWC at 10 and 30 kPa were measured by using a sand table. Coconut coir released the most water of 42% between 0.93 and 10 kPa (**Table 2**), and was selected as base material for all experimental mixes. Biochar was included in the mixes because it released the most water between 10 and 30 kPa (19%) and between 0.93 and 30 kPa (48%) (**Table 2**), suggesting that biochar could maintain yield within a broader range of moisture levels in comparison to coconut coir. Another material included in soil composition treatments was food waste and animal manure compost (FA compost) because, when mixed with coconut coir, moisture release levels of FA compost exceeded those of food and paper waste compost (FP compost) between 0.93 and 10 kPa and between 0.93 and 30 kPa (**Table 2**).

Soil Composition Treatments

Four experimental mixes, one commercial potting mix, and one commercial rooftop farm mix using expanded shale comprised a total of six soil composition treatments summarized in **Table 3**, while **Table S1** provides soil property details. Coconut coir, biochar, and FA compost were used for experimental mixes (C_{100}, CCp_{50}, CB_{50}, $CBCp_{33}$). Each experimental mix received 1 g L^{-1} of commercial organic fertilizer (Pro-Start 2-3-3, North Country Organics, Bradford, VT) followed by 8-weeks of storage in open plastic buckets which were turned manually to promote aeration, while pH was adjusted by adding elemental sulfur at various rates summarized in **Table S2**. Of two commercial mixes, GreenTree Mix with biochar (GB) is a commercial mix using the same coconut coir and biochar in experimental mixes, while Rooflite (RL) is a commercial blend developed specifically for rooftop farming and used at the Brooklyn Grange.

Greenhouse Experiment

Experimental treatments and schedule are summarized in **Table 3** and **Figure 1**, respectively. Six soil composition treatments × two soil depth treatments (10 vs. 30 cm) × five replicates consisted a total of 60 experimental units (pots) for 5-week greenhouse experiment at Guterman Bioclimatic Laboratory, Cornell University (Ithaca, NY USA). Cylindrical pots made of high-density polyethylene (product ID: TP1020R, Stuewe and Sons, Inc., Tangent, OR USA) were cut to the soil depth, randomly arranged on a greenhouse bench. A class-A evaporation pan was used to measuring evaporation. At time 0, each pot was irrigated to container capacity, or the maximum level of soil water required to produce a trace leachate sample. Each pot received 40 seeds of the leaf lettuce variety used at the Grange (Product ID: 2301.25, Johnny's Selected Seeds Inc., Winslow, ME USA), and germination rate was determined and reduced to 8 seedlings per pot after 1 week. Pots were weighed each week before and after 25 mm irrigation was applied and leachate samples were collected. At week 5, pots were weighed and all leaves were collected. Unvegetated pots were irrigated to container capacity to produce leachate samples, weighed and used as soil samples. The number of pots in which roots had reached the bottom of the soil column was determined.

Samples and Analyses

Soil leachate, soil, and leaf samples were analyzed by three different methods (**Table 4**). The Saturated Media Extract method (SME) (Lang, 1996; Dole and Wilkins, 1999) was used for producing water extracts from soil pastes. NO_3-N and NH_4-N concentrations of soil leachate samples and SME water extracts were analyzed by colorimetric method (SEAL AutoAnalyzer 2; SEAL Analytical GmbH, Norderstedt, Germany), while phosphorus (P), calcium (Ca), magnesium (Mg), and potassium (K) concentrations were analyzed only for SME water extracts by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES). Total N and carbon (C) concentrations of soil and leaf samples oven-dried at 60°C were analyzed by combustion (Vario El Cube CHNOS Elemental Analyzer; Elementar Analysensysteme GmbH, Langenselbold, Germany).

Soil Samples

Before the experiment, subsamples were collected from each soil composition treatment and ingredients of experimental mixes. Each subsample was halved for total N and C concentration analysis and SME. After the experiment, a soil sample from each pot was halved and either preserved

TABLE 2 | Moisture release of commercial mixes and basic ingredients.

		Bulk density g/cm^3	Volumetric water content cm^3/cm^3 (%)			Moisture release cm^3/cm^3 (%)			
			0.93 kPa	**10 kPa**	**30 kPa**	**0.93–10 kPa**	**10-30 kPa**	**0.93–30 kPa**	**Rank**
Commercial mixes	Cornell mix	0.19 ± 0.02	70 ± 4	39 ± 2	33 ± 2	31	6	37	1
	Lambert 111	0.14 ± 0.004	73 ± 2	41 ± 3	37 ± 3	32	4	36	2
	GreenTree mix with biochar	0.16 ± 0.02	66 ± 1	41 ± 2	36 ± 3	25	5	30	3
	GreenTree mix	0.15 ± 0.006	67 ± 2	45 ± 2	41 ± 3	22	4	27	4
	Rooflite	0.62 ± 0.04	50 ± 1	39 ± 2	37 ± 2	11	2	13	5
Basic ingredients	Biochar	0.14 ± 0.02	73 ± 7	44 ± 7	25 ± 4	29	19	48	1
	Coconut coir	0.11 ± 0.005	80 ± 7	39 ± 2	34 ± 2	42	5	46	2
	Peat moss	0.12 ± 0.003	75 ± 2	38 ± 2	34 ± 3	37	4	42	3
	Vermiculite	0.21 ± 0.03	62 ± 8	43 ± 2	40 ± 2	19	3	22	4
	Expanded shale	0.76 ± 0.06	30 ± 3	18 ± 2	17 ± 2	12	1	12	5
	FP compost	0.59 ± 0.06	54 ± 1	48 ± 1	44 ± 3	6	4	10	6
	FA compost	0.36 ± 0.01	60 ± 1	56 ± 2	54 ± 2	4	2	6	7
Mixed Samples*	Coconut coir + Biochar	0.13 ± 0.009	73 ± 4	38 ± 2	29 ± 3	35	9	44	1
	Rooflite + Coconut coir	0.35 ± 0.01	63 ± 1	41 ± 2	37 ± 3	22	4	26	2
	Coconut coir + Biochar + FA compost	0.21 ± 0.02	71 ± 1	50 ± 2	47 ± 2	21	3	24	3
	Rooflite + Biochar	0.47 ± 0.02	61 ± 2	47 ± 2	45 ± 2	13	2	16	4
	Coconut coir + FA compost	0.22 ± 0.01	64 ± 1	52 ± 2	50 ± 2	12	2	14	5
	Coconut coir + FP compost	0.40 ± 0.01	60 ± 1	51 ± 2	47 ± 2	9	4	13	6
	Expanded shale + FA compost	0.61 ± 0.05	50 ± 1	41 ± 3	39 ± 3	9	2	11	7
	Expanded shale + FP compost	0.89 ± 0.04	52 ± 2	45 ± 2	42 ± 2	6	3	9	8

Sample description

Commercial mixes	Lambert 111	Sphagnum peat moss + perlite Lambert Peat Moss Inc, Rivière-Ouelle, Canada
	Cornell peat-lite mix	Sphagnum peat moss + horticultural vermiculite Cornell University, Ithaca, NY
	Rooflite (rooftop agriculture mix)	Heat-expanded shale + spent mushroom media + animal manure Skyland USA LLC, Avondale, PA
	GreenTree mix	Coconut coir + organic compost using food waste, animal manure, and earthworm GreenTree Garden Supply LLC, Ithaca, NY
	GreenTree mix with biochar	GreenTree Mix + biochar GreenTree Garden Supply LLC, Ithaca, NY
Basic ingredients	Peat moss	Sphagnum peat moss used in Lambert 111 Lambert Peat Moss Inc, Rivière-Ouelle, Canada
	Coconut coir	Coconut coir used in Ithaca Basic and Biochar Blends GreenTree Garden Supply LLC, Ithaca, NY
	Biochar	Biochar used in Ithaca Biochar Blend GreenTree Garden Supply LLC, Ithaca, NY
	Vermiculite	Horticultural vermiculite used in Cornell Peat-Lite Mix
	Expanded shale	Heat-expanded shale used in Rooflite Skyland USA LLC, Avondale, PA
	FA compost	Food waste and animal manure compost Cornell University Agricultural Experiment Station, Ithaca, NY
	FP compost	Food and paper waste compost P and S Excavating LLC, Trumansburg, NY

Bottom table shows sample descriptions.
**Each sample was mixed by the same volume.*

TABLE 3 | Treatments of the greenhouse experiment*[1] (bottom table shows detailed moisture release levels for each soil composition treatment).

Soil composition						Depth (cm)	Irrigation and crop	Replication
Soil type	**Substrate ID**	**Volumetric mixing ratio**			**Additives**			
		Coconut coir	**Biochar**	**FA compost**				
Experimental mixes	C_{100}	100	0	0	commercial organic fertilizer (Pro-Start 2-3-3)*[2] + elemental sulfur (pH adjustment)*[3] + 8-week storage	10 30	25 mm week^{-1} irrigation and growing leaf lettuce from seeds	5 (= total of 60 pots)
	CCp_{50}	50	0	50		10 30		
	CB_{50}	50	50	0		10 30		
	$CBCp_{33}$	33	33	33		10 30		
Commercial mixes	GB (GreenTree mix with biochar)			as-sold	None	30		
	RL (Rooflite)			as-sold		10 30		

	Volumetric water content cm^3/cm^3 (%)										
	0 kPa	0.31 kPa	0.93 kPa	1.55 kPa	2.17 kPa	2.79 kPa	3.41 kPa	6.5 kPa	10 kPa	20 kPa	30 kPa
C_{100}	93 ± 2	88 ± 3	80 ± 7	66 ± 3	54 ± 4	48 ± 2	45 ± 1	42 ± 1	39 ± 2	36 ± 2	34 ± 2
CCp_{50}	85 ± 1	75 ± 4	64 ± 1	66 ± 0.1	60 ± 2	54 ± 2	54 ± 3	53 ± 2	52 ± 2	51 ± 2	50 ± 2
CB_{50}	92 ± 1	86 ± 2	73 ± 4	58 ± 4	53 ± 5	52 ± 2	49 ± 3	40 ± 2	38 ± 2	31 ± 2	29 ± 3
$CBCp_{33}$	87 ± 2	80 ± 3	71 ± 1	69 ± 1	68 ± 3	63 ± 3	57 ± 2	52 ± 2	50 ± 2	49 ± 2	47 ± 2
GB (Ithaca biochar blend)	82 ± 2	72 ± 3	66 ± 1	66 ± 0.1	64 ± 2	56 ± 2	51 ± 1	44 ± 2	41 ± 2	38 ± 2	36 ± 3
RL (Rooflite)	61 ± 1	54 ± 1	50 ± 1	50 ± 1	48 ± 1	46 ± 1	45 ± 1	41 ± 1	39 ± 2	38 ± 2	37 ± 2

*[1] *Soil property details are summarized in* ***Table S1****.* *[2] *Addition rate was 1 g l^{-1}. Made of plant, animal, fish byproducts, natural potassium sulfate, phosphate rock, and natural magnesium sulfate (North Country Organics, Bradford, VT).* *[3] *Addition rates are summarized in* ***Table S2****.*

at 4°C for later SME and total N and C concentration analysis, or oven dried to determine the dry soil weight of each pot. Details of soil analyses are summarized in **Table S1**.

Leaf Samples

At the end of the experiment, leaf samples from each pot were weighed, and oven-dried at 60°C to determine dry weight followed by total N and C concentration analysis.

Soil Leachate Samples

Leachate samples were collected from pots after each irrigation for measuring volume, pH, and EC, followed by 4°C storage for later analysis of NO_3-N and NH_4-N concentrations. At time 0 and at the end of the experiment, soil was irrigated up to container capacity, producing trace leachate for measurements of pH and EC. The number of pots producing leachate samples in each irrigation event is summarized in **Table S5**.

Unit Conversion and Estimation Methods

$$\textit{Soil Water Volume} = \textit{Soil Wet Weight} - \textit{Soil Dry Weight} \tag{1}$$

$$\textit{Volumetric Water Content} = \frac{\textit{Soil Water Volume}}{\textit{Soil Volume}} \times 100 \tag{2}$$

$$\textit{Water Retention Rate} = \frac{\textit{Irrigation Depth} - \textit{Leachate Depth}}{\textit{Irrigation Depth}} \times 100 \tag{3}$$

$$\textit{Evapotranspiration} = \frac{\Delta \textit{Soil Water Volume}}{\textit{Pot Section Area}} \tag{4}$$

$$\textit{Crop Coefficient } (K_c) = \frac{\textit{Evapotranspiration}}{\textit{Pan Evaporation} \times \textit{Pan Coefficient } (K_p)} \tag{5}$$

$$\textit{Drainage N Output} = \frac{\textit{Leachate Volume} \times \textit{Leachate } (NO_3 + NH_4)\ \textit{N Concentration}}{\textit{Pot Section Area}} \tag{6}$$

$$\textit{Plant N Output} = \frac{\textit{Leaf Dry Weight} \times \textit{Leaf Total N Concentration}}{\textit{Pot Surface Area}} \tag{7}$$

$$\textit{Yield} = \frac{\textit{Leaf Weight}}{\textit{Pot Section Area}} \tag{8}$$

Where *Soil Volume* = 1,344 cm^3 for 10 cm pot, and 4,032 cm^3 for 30 cm pot; *Pot Surface Area* = 134.4 cm^2. *Crop Coefficient* is estimated by using K_p of 0.6 and 0.8, respectively, for light wind speed (Allen et al., 1998).

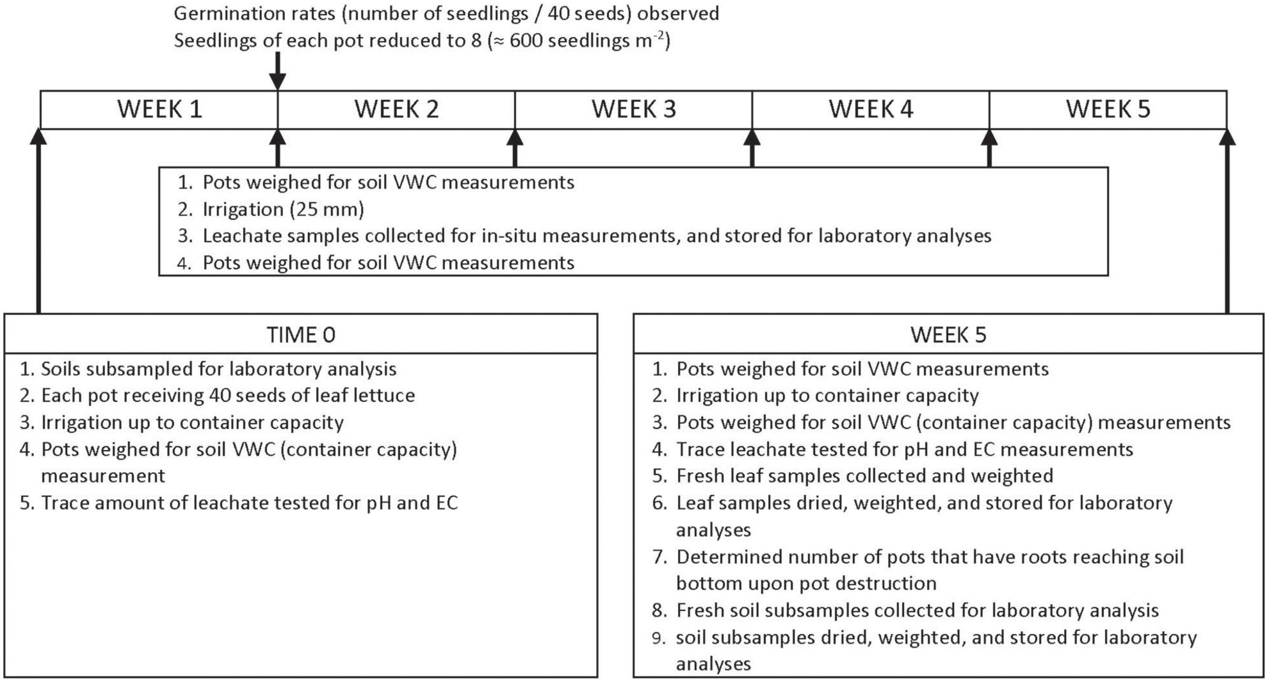

FIGURE 1 | Schedule of the greenhouse experiment.

TABLE 4 | Summary of sample types and analyses.

Sample type	*In-situ* measurements	Sample preparation	Laboratory measurements	Sample storage	Sample for analysis	Analytical result	Analytical method
Soil leachate	Volume, pH, EC	None	None	4°C	Soil leachate (as-sampled)	NO_3-N and NH_4-N concentrations	Colorimetric method (SEAL AutoAnalyzer 2)
Soil	None	Saturated Water Extract (SME)	pH, EC	4°C	Water extract	NO_3-N and NH_4-N concentrations	Colorimetric method (SEAL AutoAnalyzer 2)
						P, Ca, Mg, and K concentrations	ICP-AES
	None	Dried in oven at 60°C	Dry weight	4°C	Dried sample	Total N and C concentrations	Combustion method (Vario El Cube CHNOS Elemental Analyzer)
Leaves	Fresh weight	Dried in oven at 60°C	Dry weight	4°C	Dried sample	Total N and C concentrations	Combustion method (Vario El Cube CHNOS Elemental Analyzer)

RESULTS

Results for the entire study period and weekly results are summarized in **Figures 2A–H**, and in **Figures 3A–H**, respectively, while details of the results are summarized in **Tables S3–S5**. Yield for greens mix (lettuce and mustard greens) reported by a field study of the Brooklyn Grange ($3.5\,kg\ m^{-2}$ $226\ days^{-1} = 0.54\,kg\ m^{-2}\ 5\ weeks^{-1}$) (Harada et al., 2018a) is used as reference for determining satisfactory yield. Drainage output of N ($336\,kg\ N\ ha^{-1}\ 226\ days^{-1} = 5.2\,g\ N\ m^{-2}\ 5\ weeks^{-1} = 1.0\,g\ N\ m^{-2}\ week^{-1}$) (Harada et al., 2018a) and ET ($3.47\,mm$ day-1 $= 121\,mm\ 5\ weeks^{-1} = 24.3\,mm\ week^{-1}$) (Harada et al., 2018b) at the Brooklyn Grange are shown in **Figures 2E,G**, **3A,B,G,H**, respectively, as reference levels for general comparison.

Yield

Yield ranged from 0.02 to $4.92\,kg\ m^{-2}\ 5\ weeks^{-1}$. For both depths, GB and C_{100} had the highest and the lowest levels of yield, respectively. Levels of yield for CCp_{50}, $CBCp_{33}$, and GB for both depths were satisfactory, ranging between 0.70 and $4.92\,kg\ m^{-2}\ 5\ weeks^{-1}$, or 130 and 911% of the reference yield at the Brooklyn Grange ($0.54\,kg\ m^{-2}\ 5\ weeks^{-1}$) (**Figure 2C**). For those three mixes having satisfactory yield, soil depth had positive effects on

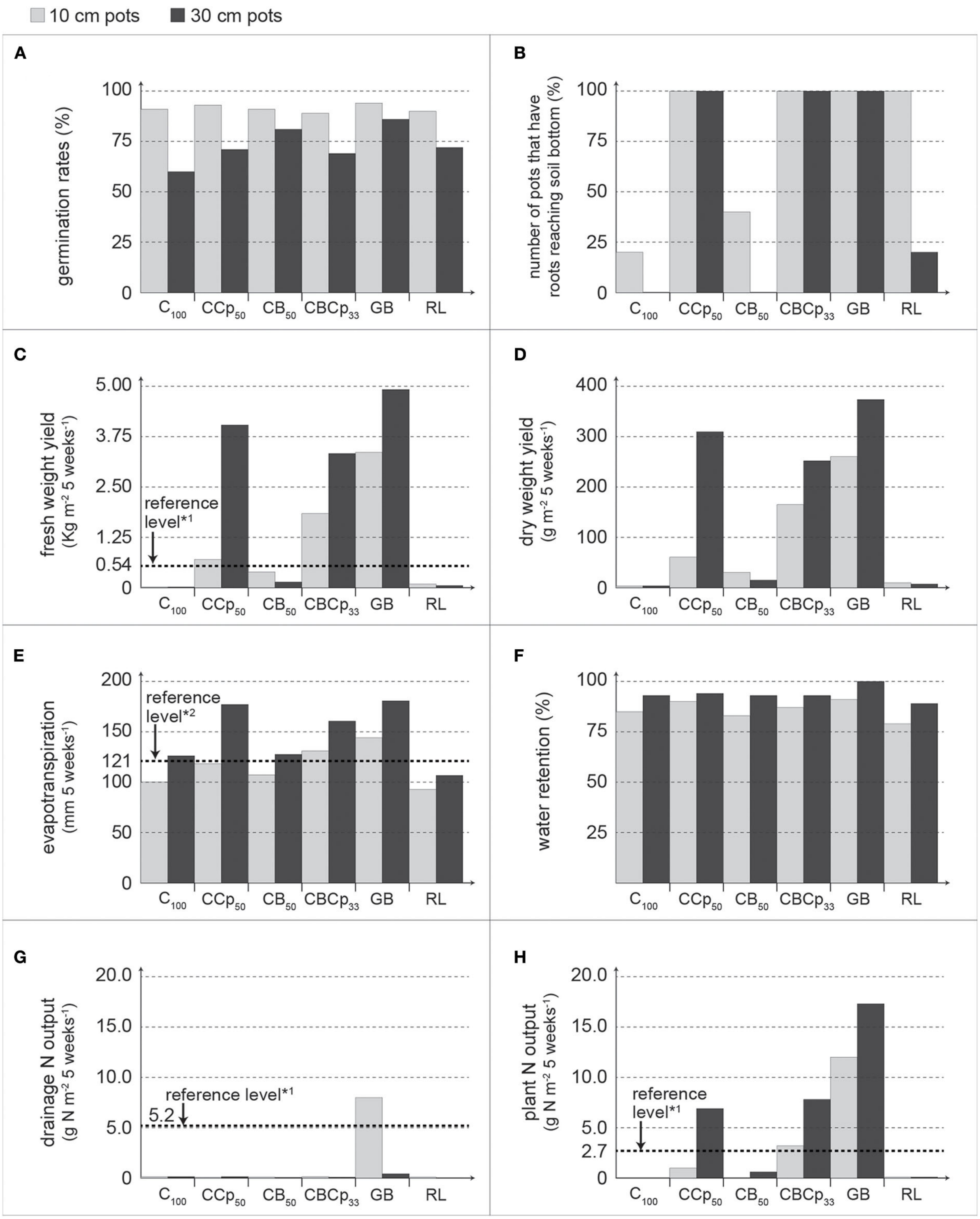

FIGURE 2 | Cumulative results of the greenhouse experiment for the entire 5-week study period. **(A)** Germination rates, **(B)** Number of pots that have roots reaching soil bottom, **(C)** fresh weight yield, **(D)** dry weight yield, **(E)** evapotranspiration, **(F)** water retention, **(G)** drainage N output, **(H)** plant N output. *[1]Levels of the Brooklyn Grange, reported by Harada et al. (2018a), *[2]levels of the Brooklyn Grange, reported by Harada et al. (2018b).

yield, while yield's sensitivity to soil depth, or the ratio of yield for 30 cm soil to that of 10 cm soil, was highest for CCp_{50} (577%), followed by $CBCp_{33}$ (181%) and GB (146%). Yield for all other mixes (C_{100}, CB_{50}, RL) for both soil depths were unsatisfactory, including RL, the actual mix used by the Brooklyn Grange. Yield of C_{100} and RL for both soil depths ranged only between 0.02 and

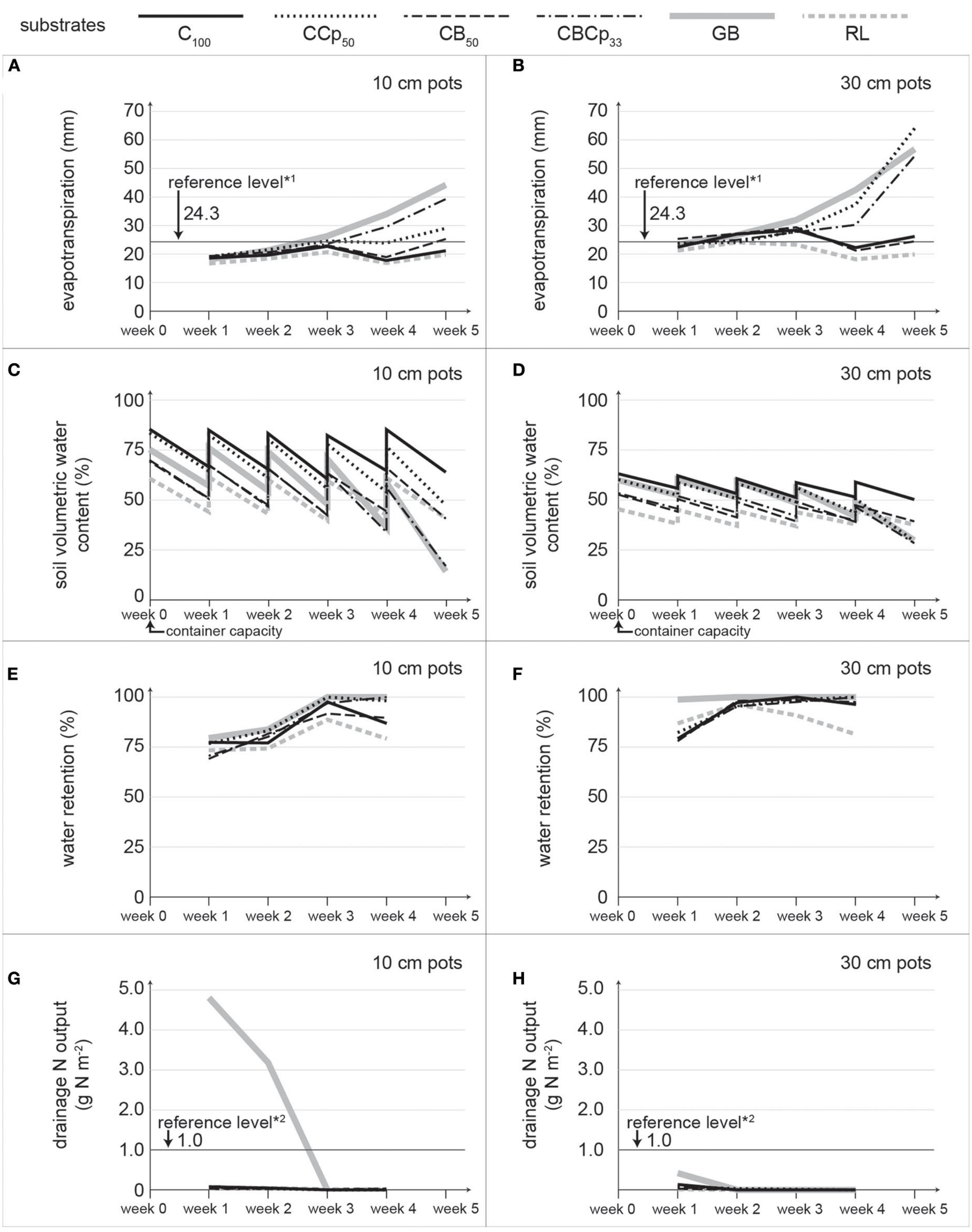

FIGURE 3 | Weekly results of the greenhouse experiment. **(A)** Evapotranspiration for 10 cm pots, **(B)** evapotranspiration for 30 cm pots, **(C)** soil volumetric water content for 10 cm pots, **(D)** soil volumetric water content for 30 cm pots, **(E)** water retention for 10 cm pots, **(F)** water retention for 30 cm pots, **(G)** drainage N output for 10 cm pots, **(H)** drainage N output for 30 cm pots. *[1]Levels of the Brooklyn Grange, reported by Harada et al. (2018a), *[2]levels of the Brooklyn Grange, reported by Harada et al. (2018b).

0.09 kg m^{-2} 5 $weeks^{-1}$, or between 4 and 17% of the reference yield at the Brooklyn Grange, due to the stunted growth upon germination. Yield of CB_{50} for both soil depths ranged only between 0.14 and 0.39 kg m^{-2} 5 $weeks^{-1}$, or between 26 and 72% of the reference yield at the Brooklyn Grange, due to the chlorotic leaf discoloration in week 2 onward.

Water Retention

Cumulative water retention rates over the entire study period ranged between 79 and 100%. In both soil depths, GB and RL had the highest and lowest rates of water retention, respectively. For all mixes, 30 cm deep soils retained more water than 10 cm deep soils, with water retention rates ranging 79–91% for 10 cm deep soils, and between 89 and 100% for 30 cm deep soils, respectively. For those three mixes having satisfactory yields, retention rates ranged between 87 and 100% including both soil depths. If soils retain water as intended in NYC's green infrastructure master plan (NYC DEP, 2010), then all irrigation must be retained (water retention rate = 100%). This standard was met only by the highest performing treatment, 30 cm deep GB if small amount (0.03 ± 0.07 mm) of leachate in week 1 is ignored (**Figure 3F**).

Drainage N Output

Cumulative drainage N output over the entire study period ranged between 0.03 and 7.99 g N m^{-2} 5 $weeks^{-1}$, or between 0.6 and 154% of the reference level of the Brooklyn Grange (5.2 g N m^{-2} 5 $weeks^{-1}$). In both soil depths, GB and RL had highest and lowest drainage N output, respectively. The ranking of drainage N output between 30 and 10 cm soil depths was inconsistent across mixes. Of all treatments, 10 cm deep GB had the highest drainage N output (7.99 g N m^{-2} 5 $weeks^{-1}$), and was the only treatment exceeding the reference level of the Brooklyn Grange due to the high N concentration of leachate in week 1 (NO_3-N: 933.3 mg l^{-1}, NH_4-N: 7.5 mg l^{-1}) and week 2 (NO_3-N: 792.3 mg l^{-1}, NH_4-N: 2.7 mg l^{-1}), respectively (**Figure 3G**), while drainage N output of all other treatments ranged only between 0.03 and 0.41 g N m^{-2} 5 $weeks^{-1}$, including RL, the same mix used in the Brooklyn Grange. Although, water retention rate of 30 cm deep GB was 100%, small amount of leachate produced in week 1 had high N concentration (NO_3-N: 1207.7 mg l^{-1}, NH_4-N: 58.8 mg l^{-1}), making drainage N output of GB highest in 30 cm deep soils.

ET

Over the study period, cumulative ET ranged between 92.7 and 180.8 mm 5 $weeks^{-1}$, or between 77 and 149% of ET at the Brooklyn Grange (121 mm 5 $weeks^{-1}$). In both soil depths, GB and RL had the highest and lowest ET, respectively. For all mixes, 30 cm deep soils had more ET than 10 cm deep soils, while ET's sensitivity to soil depths, or the ratio of ET for 30 cm soil to that of 10 cm soil, ranged from 115% (RL) to 150% (CCp_{50}). In terms of weekly ET, both soil depths for three mixes having satisfactory yields (CCp_{50}, $CBCp_{33}$, and GB) had the highest ET in week 5 (29.1–64.1 mm $week^{-1}$). All mixes had crop coefficients (Kc) between 0.2 and 0.3 during germination and from 0.1 to 0.6 for week 5 when leaf area was maximum.

Soil Water

Across treatments, VWC at container capacity ranged between 45 and 85%. Differences among the mixes remained nearly constant during the study. In greenhouse agriculture, VWC at water column pressure of half the soil depth is interpreted as container capacity, meaning that container capacity for 30 cm deep soil can be estimated by the soil VWC at 15 cm H_2O, or 1.5 kPa. Difference between soil VWC at 1.55 kPa and container capacity for soil depth of 30 cm ranged from 3% for C_{100} to 17% for $CBCp_{33}$. Lowest VWC for CCp_{50}, $CBCp_{33}$, and GB including both soil depths, were 29, 17, and 14% f, all of which exceeded soil water tension of 30 kPa, while having satisfactory yields.

DISCUSSION

Sustainability of Rooftop Farming

The irrigation rate (25 mm $week^{-1}$) in this study was only 69% of total water input at the Brooklyn Grange (irrigation + rainfall = 36.4 mm $week^{-1}$). This irrigation rate was equal to the stormwater retention specification of the NYC's stormwater management scenario within the context of monthly normal rainfall of NYC. Three mixes (CCp_{50}, $CBCp_{33}$, GB) had yield exceeding the Grange by up to 911% while retaining up to 100% of irrigation. Except for the 10 cm deep GB treatment, drainage N output was <13% of that observed at the Grange, indicating a real possibility that these mixes could increase the sustainability of rooftop farming in terms of both water and nutrient management. At the Grange, the fact that precipitation alone exceeds ET demonstrates the potential for reducing supplemental irrigation. To achieve self-sufficient water use within rooftop farming systems, improved soil design could be complemented by recycling leachate from drainage outfalls. Also, rainwater can be harvested from uncropped roof surfaces (35–60% of total roof area) and stored for use during rainless periods (Orsini et al., 2014; Harada et al., 2018a). An example of this strategy is a rooftop greenhouse near Barcelona, Spain where the irrigation system from an adjacent rooftop satisfies 80–90% of the total water demand (Sanjuan-Delmás et al., 2018). Possible problems for recycling leachate from drainage outfalls include salt accumulation and increases in pathogens along with increased construction monetary costs of rooftop farming (Vallance et al., 2011; Sanyé-Mengual et al., 2015b).

Soil Depth

Water accumulates at the bottom of bounded soil columns (Bunt, 2012), which can make water more available to crops in 10 cm deep soils than in 30 cm deep soils. Cho (2008) report that the transpiration rates of lettuce in 5 cm pots exceeded rates in 10 and 20 cm. Three of our mixes (CCp_{50}, $CBCp_{33}$, GB) had satisfactory yields, however, the 30 cm deep pots had higher yield, ET, and water retention than 10 cm deep soils perhaps because total amount of available soil water (VWC × soil depth) is greater. For those three mixes, water depths of 30 cm deep soils at container capacity ranged from 217 to 240% of those in 10 cm deep soils, while weekly minimum water depths for 30 cm deep soils ranged between 186 and 630% of those in 10 cm deep soils. Roots reached the bottom of the soil column in both pot depths, so plants could extract water from the entire profile. Another possible factor for increased yield in 30 cm deep pots is higher air filled porosity (AFP) and oxygen availability to roots (Bunt, 2012). Greater VWC in 10 cm deep pots could reduce AFP, while top 20 of 30 cm deep soils could have much higher oxygen levels for root development. For example, the ratio of yield in 30 cm deep soil to that of 10 cm was highest for CCp_{50}, which had highest proportion of compost, suggesting that small particles of compost reduced AFP and yield of 10 cm deep CCp_{50}. In summary, 30 cm deep soil produced higher yield of drought-sensitive crops under restricted water supply.

N Management

Non-synthetic N was the only N source for all mixes in this study because organic cultural practices are an important marketing strategy for urban agriculture (Ackerman et al., 2013; Pölling et al., 2016, 2017; Harada et al., 2018a). Total inorganic N (TIN $= NO_3$-N + NH_4-N) is readily available to plants, while non-synthetic N contains organic N, which must be microbially converted to TIN for enhancing the levels of yield, making the control of N mineralization an integral part of soil management (Cameron et al., 2013). The only difference between the C_{100} and CCp_{50} mixes was the addition of compost to CCp_{50}, while water extractable TIN decreased over the experiment only for C_{100}, suggesting that the low rates of N mineralization was inadequate in C_{100}. However, increasing TIN would increase N output in the leachate (Cameron et al., 2013) as evidenced by the fact that water extractable TIN for the unused GB mix (1041.1 TIN mg l^{-1}) was much higher than all other mixes (1.5–16.9 TIN mg l^{-1}). It is likely that animal manure and earthworm castings used in compost for GB increased TIN concentration, making 10 cm deep GB the only treatment exceeding the Brooklyn Grange in terms of drainage N output. Drainage N output of 30 cm deep GB did not exceed that of the Brooklyn Grange, because only a small amount of leachate was produced, while if drainage occurs under field conditions, then drainage N output of 30 cm deep GB could also exceed that of the Brooklyn Grange.

Water extractable TIN for used CCp_{50} ranged up to 1,207% of that for unused CCp_{50}, suggesting the rates of N mineralization exceeding the net N output including drainage, plant uptake, and denitrification. High rates of N mineralization could require increased addition of organic N addition over time, while also increasing the risk of high levels of drainage N output after winter fallow periods. N mineralization rates could be adjusted by reducing the addition rates of compost and organic fertilizer. Drainage volume and N output can increase when plant N and water uptake is reduced or eliminated during the episodes of seeding and germination, crop failure, and winter fallow periods. Possible solutions include the use of cover crops during fallow periods, and desynchronized seeding and harvest by cropping mixed species (Malézieux et al., 2009; Cameron et al., 2013).

Based on the general nutrient management guideline of container mixes (Warncke and Krauskopf, 1983; Bunt, 2012), water extract NO_3-N concentration of unused mixes exceeded the optimum range (100–199 NO_3-N mg l^{-1}) only for GB, while those for CCp_{50} and $CBCp_{33}$ were below the acceptable range (40–99 NO_3-N mg l^{-1}). From the perspective of stormwater management, however, much lower range of water extractable N could be recommended. For example, Berghage et al. (2008) studied 30 ornamental green roofs for establishing reference soil specification of best stormwater management practices, and recommended water extractable TIN between 1.5 and 3.0 TIN-N mg l^{-1} for reducing drainage N output while maintaining crop performance. In summary, we recommend the CCp_{50} and $CBCp_{33}$ mixes for rooftop farming to achieve satisfactory yield while reducing N output in the drainage water.

Soils Using Expanded Shale

At the Brooklyn Grange farm, satisfactory yields of leaf lettuce were maintained at VWCs of 20% in 25 cm deep Rooflite. In this study, leaf lettuce in Rooflite failed for both soil depths despite VWCs ranging from 37 to 61%. This suggests that low surface water content is a possible culprit. In a radically different cultural system using sedum, Rowe et al. (2014) compared growth using overhead sprinklers, drip, and subsurface irrigation in soils using coarse mineral aggregate like expanded shale. Yield was highest for the overhead sprinkler treatments because of increased moisture at the soil surface, while drip and subsurface irrigation treatments had lower surface moisture because capillary rise is limited by the large pore size in mixes using expanded shale. This means that soils using expanded shale can require frequent irrigation for growing drought-sensitive crops because ET rates exceeding water movement from deeper soil strata can easily reduce surface moisture. At the Brooklyn Grange overhead sprinklers are used up to 5 times a day for maintaining a moist soil surface, suggesting that the weekly irrigation used in this study did not maintain sufficient levels of surface moisture. In summary, soils using coarse mineral aggregates may not be suitable for rooftop farming aiming to maximize the use of soil water storage for stormwater management growing drought-sensitive crops.

Implications for Long-Term Management

In this short term study container capacity and soil depth remained constant, while these soil properties would change in rooftop farms where they are used indefinitely. In an experimental rooftop farming system, for example, Grard et al. (2015) grew lettuce and tomatoes in compost mixes made of prunings, crushed wood, and ground coffee wastes in Paris, France, and report that initial soil depth of 30 cm decreased to 20–15 cm over 2 years. This suggests that volumetric half-life of potting soils in the rooftop environments can be only 2 years. While coconut coir is used as base material for mixes is commonly used in horticultural as environmentally sound substitute for peat moss (Abad et al., 2002, 2005), further research is needed for substituting coconut coir with locally available wastes, such as saw dust, prune waste, and other lignocellulosic wastes (Barrett et al., 2016).

Unlike peat moss and coconut coir, biochar can be stable in soil (Lehmann et al., 2009), while maintaining moisture release between 10 and 30 kPa, making it potentially useful ingredient of rooftop soils. The biochar used in this study had high pH (10.0) and pH failed to stabilize in the CB_{50} mix which contained the highest proportion of biochar. Altland and Krause (2010) reported that pH adjustment for potting soils by using elemental sulfur can take up to 4 weeks to stabilize pH. In our study, the pH of CB_{50} continued to decrease from time 0 (6.0–6.3) to week 5 (4.1–5.1), following an 8-week pH stabilization period. In summary, pH adjustment of soils using biochar require further research, while long-term field research is necessary for establishing the management practices.

CONCLUSIONS

Under the irrigation rate equivalent to the stormwater retention capacity of the NYC's stormwater management scenario, three potting soils had satisfactory yield, with water retention rates ranging up to 100%, while levels of drainage N output were as much as 13% lower than that observed for the Brooklyn Grange, suggesting that mixes resembling potting soils could enhance the sustainability of rooftop farming in terms of water and nutrient management. Further research is required for (1) optimum addition rates of compost and organic fertilizer for adjusting N mineralization rates to plant N uptake; (2) optimum depths specific to soil composition; (3) vegetation strategies for reducing unvegetated periods; (4) long-term amendment plan and locally available waste inventory for substituting coconut coir; pH adjustment in mixes using biochar; and (5) leachate and rainwater recycling system design.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/**Supplementary Material**.

AUTHOR CONTRIBUTIONS

YH: experimental design, experiment, sample analysis, and manuscript preparation. TW: experimental design and manuscript preparation. NB and JR-A: experimental design. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2020.00123/full#supplementary-material

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More Than Food: The Social Benefits of Localized Urban Food Systems

Lucy O. Diekmann[1], Leslie C. Gray[2] and Chan Le Thai[3]*

[1] University of California Cooperative Extension, San Jose, CA, United States, [2] Department of Environmental Studies and Sciences, Santa Clara University, Santa Clara, CA, United States, [3] Department of Communication, Santa Clara University, Santa Clara, CA, United States

Localized urban food systems are gaining attention from policy makers, planners, and advocates for benefits that go well beyond food production and consumption. Recognizing that agriculture, and food systems more broadly, provide multiple, integrated services, this study measures the social, educational, civic, and nutritional impacts of four common types of local food system activity in an urban setting. Specifically, we examine the outcomes of two common types of urban agricultural production (home gardens and community gardens) and two common types of direct markets (farmers' markets and Community Supported Agriculture programs or CSAs) through a survey of 424 gardeners and 450 direct market shoppers in California's San Francisco Bay Area. Our comparative analysis focuses on four commonly discussed functions of agricultural production and direct marketing in urban areas: access to high-quality, fresh produce; food and agriculture education; social connections; and civic engagement. While impacts on nutrition were consistently high, some of the largest differences between types of local food system activity were in social interaction and civic engagement. For example, gardeners had a mean score of 3.77 on the social interaction scale compared to direct market participants, who had a mean score of 3.03. These findings confirm that different types of local production and direct marketing have distinct impacts on participants. Generally, gardens, which involve more sustained engagement with other people and the natural world, were sites of greater learning, connection, and civic participation than either type of direct marketing.

Keywords: urban agriculture, community gardens, home gardens, community supported agriculture, farmers' markets

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****Correspondence:***
Leslie C. Gray
lcgray@scu.edu

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INTRODUCTION

Localized urban food systems are gaining attention from policy makers, planners, and advocates for benefits that go beyond food production and consumption to include community building, diversified economies, civic engagement, and climate resilience (Pothukuchi and Kaufman, 1999; Horst et al., 2017; Ballamingie et al., 2020). In addition, urban consumers are a significant source of sales for much US local food system activity (Low et al., 2015). Also referred to as alternative agrifood initiatives and civic agriculture, local food systems aim to create an alternative to the existing food system by rooting food production and marketing in a particular place in a way that is economically viable, ecologically sound, and socially just (Allen et al., 2003).

To account for the social, cultural, educational, and environmental impacts of localized urban food systems, a framework is needed that incorporates the multiple, integrated services that agriculture can provide. Lovell (2010) and Poulsen et al. (2017) have argued for multifunctionality, a concept that recognizes agricultural land uses can provide, within a particular space, many functions beyond the production of food and fiber (Wilson, 2008; Lovell, 2010; Zasada, 2011). When a multifunctional lens is extended to urban food systems, this framing allows us to incorporate the social, educational, and environmental functions of local food production and marketing. Furthermore, a comprehensive examination of urban agriculture's many functions helps to move beyond the debate over whether urban agriculture should be celebrated for its many benefits or critiqued for reinforcing neoliberalism by examining how it actually functions in different contexts (McClintock and Simpson, 2018).

In cities, common manifestations of local food systems include direct markets, like farmers' markets and CSA programs, and alternative types of production such as community gardens and urban farms. Taken together, these types of alternative food practice have the potential to make local food available, support the local food economy, educate people about food and agriculture, and build community (Poulsen et al., 2017). Notably, stakeholders often value these other functions as much as the capacity to produce food or generate revenue (Lovell, 2010; Vitiello and Wolf-Powers, 2014; Poulsen et al., 2017). While multifunctionality is a hallmark of localized production systems, there are few tools for measuring or communicating its social functions and explorations of how various functions relate to one another are relatively rare.

This study takes a comparative approach, examining the intersection of localized urban food systems' diverse forms and functions in the southern San Francisco Bay Area in California. We assess four commonly discussed functions of agricultural production and direct marketing in urban areas—access to high-quality, fresh produce, food and agriculture education, social connections, and civic engagement—and we compare these impacts across two types of urban agricultural production, home gardens and community gardens, and two types of direct markets: farmers' markets and CSAs. Specifically, we ask:

1. What are the demographic characteristics of people who participate in the four types of urban production and direct marketing?
2. What are the motivations of people participating in the four types of urban production and direct marketing?
3. What are the impacts of the four different types of urban production and marketing on participants? Are there differences between direct production and marketing practices?

THE MULTIPLE FORMS AND FUNCTIONS OF LOCALIZED URBAN FOOD SYSTEMS

Urban residents can participate in the local food system in many ways: by volunteering, by participating in farm- or garden-based community events, and as gardeners or farmers themselves. They can also access and support local and regional farmers at farmers' markets, through CSAs, and at other outlets that carry or serve regionally grown food. While at its core, urban agricultural production is about growing food in the city, food distribution is essential for urban agricultural products to reach people, particularly if it is to improve food access (Siegner et al., 2018). Urban agricultural products are distributed through both formal and informal channels, including donations, gifting to others, and personal consumption. More formal distribution channels, like farmers' markets and CSAs, bring produce and other agricultural products to a wider audience (Opitz et al., 2016). Farmers' markets and CSAs are important outlets for urban farms (Rangarajan and Riordan, 2019), but do not exclusively serve urban farms, so shoppers or CSA members also encounter peri-urban and rural farms in these venues. Below we describe characteristics of local food production and marketing in urban areas, while acknowledging that these elements of the food system are interconnected.

Production: Urban Agriculture in Community and Residential Gardens

An umbrella term, urban agriculture contains within itself diverse actors, organizational types and practices (e.g., McClintock, 2014; Bosco and Joassart-Marcelli, 2017; McClintock and Simpson, 2018). It includes many types of production, such as urban farms; home, community, educational, and institutional gardens; vertical and indoor farming systems; aquaponics and hydroponics; and urban beekeeping and backyard chickens (e.g., Santo et al., 2016). Our focus is on home and community gardens, the two most widespread forms of urban production. Community gardens are places where a group of people garden within a shared space. While these spaces can be cultivated collectively, at all the sites included in our study, gardeners managed individual plots. Assessments of community gardens find that they are more widespread and, in aggregate, produce larger quantities of food than urban farms (Vitiello and Wolf-Powers, 2014). As defined by Taylor and Lovell (2014, p. 286), a home garden is "a fruit and/or vegetable garden on leased, owned, or borrowed land directly adjacent to the gardener's residence." While less discussed in the literature because they are more difficult to study, home gardens are an even more extensive urban land use than community gardens. A study in Chicago found that there was three times as much land in home gardens as community gardens (Taylor and Lovell, 2012) and the National Gardening Association (2014) survey estimates that 35% of urban residents participate in some kind of food gardening.

Direct Marketing: Farmers' Markets and CSAs

Like other alternative food practices, direct markets socially embed aspects of the food economy by cultivating relationships between producers and consumers (Galt et al., 2019). Just as social relationships are a defining characteristic of urban farms and gardens, direct markets—as alternatives to the conventional food supply chain where relationships are distant and anonymous—are characterized by, and compete on, close social relationships between regional producers and urban consumers (Hinrichs, 2000). Hinrichs (2000) argues that farmers' markets and CSAs are the quintessential types of direct local markets and share four key features: (1) a structured organizational form, (2) people congregating and meeting in particular settings, (3) a strong identification with a particular place, and (4) personal encounters between farmers and consumers. The relationship between farmer and consumer, involving reciprocity and trust, is the basis for claims that these market types are socially embedded.

A common feature of the local food movement, the number of farmers' markets has quadrupled in the last two decades, reaching more than 8,700 in the United States (Bosco and Joassart-Marcelli, 2017). CSAs make up a smaller segment of the local food market than farmers' markets, accounting for 6.4% of direct sales compared to farmers' markets, which represent 35.8% of direct sales (Smith et al., 2019). However, several authors theorize that CSAs are a more socially embedded form of direct market (Hinrichs, 2000; Obach and Tobin, 2014). CSAs are a "direct-to-consumer farm share membership/subscription program" (Galt et al., 2016, p. 492). The roots of the American CSA model are usually traced to two New England farms in the 1980s, but Booker T. Whatley, a professor at the Tuskegee Institute, was a pioneer of the CSA concept, promoting the idea of a "clientele membership club" as part of the formula for a successful small farm. At least a decade earlier, women in Japan, concerned with mercury poisoning, created the "Seikyou Movement" purchasing milk directly from farmers in the 1960s (Wallace, 2003; Bowens, 2015; Penniman, 2018). CSAs now number more than 4,000 and serve hundreds of thousands of members (Galt, 2011). Particularly in the past 10 years, CSAs have changed their models in response to market conditions and customer demand for local produce and convenience (Smith et al., 2019). Initially, customers shared the risk of production with farmers by paying upfront at the start of the season for a regular supply of the farm's harvest (Feagan and Henderson, 2009; Galt et al., 2019). Now farmers have adopted more flexible payment systems (e.g., monthly, biweekly, pay-as-you-go), online order systems, increased customization, and at-home delivery. While farmers continue to see CSA as a useful strategy to improve farm viability and to educate consumers about farming's importance, challenges, and impacts (Smith et al., 2019), the changes to the model have the potential to reduce members' long-term commitment to the farm and have changed both the financial and social relationship between farmer and consumer.

Local Food System Functions: Growing Food, Education, Community, and Engagement

Food

While local food system leaders consciously evoke the multiple, intersecting goals of their projects, access to high-quality, fresh food is a common thread that runs across types and organizations (McClintock and Simpson, 2018). Studies of home and community gardeners demonstrate that gardeners prize their produce for its freshness, taste, and quality (Pourias et al., 2016) and show that gardening has a positive effect on fruit and vegetable consumption (Litt et al., 2011; Carney et al., 2012; Gray et al., 2014; Algert et al., 2016). Farmers' market shoppers also prioritize access to fresh, high-quality produce, although they also appreciate other social interactions and other aspects of the market (Lockeretz, 1986).

Education

Education is a specific goal of many local food systems projects, which set out to reconnect people to their food, food production, and food producers. Education is one of the motivations for CSA farmers (Smith et al., 2019), who may provide information to members through regular newsletters and farm visits. While this type of learning is more focused on the acquisition of content by an individual (Krasny and Tidball, 2009), gardens can create a setting where interactive learning takes place. As described by Krasny and Tidball (2009, p. 2), this type of learning occurs "through the participation of the learner in the social and biophysical processes taking place in a particular environment." A novice gardener may become more skilled "through interaction with the environment and with more experienced gardeners during the act of gardening" (ibid., 2). Social learning may also take place among a group of gardeners or other stakeholders who come together to address management and policy issues. Thus, the education that takes place in gardens can be a precursor to greater food advocacy and democratic engagement with the food system.

Community

The emphasis placed on community building in different forms of urban production is evident in the tagline of the American Community Gardening Association: "Growing Communities Across the US and Canada" (American Community Gardening Association, 2000). Through the process of creating and using community gardens, gardeners have extensive interactions with other community members, often making new social connections and strengthening social ties (Glover, 2004; Alaimo et al., 2010). Some community gardeners value gardens more as sites for social and cultural gatherings than as sites of agricultural production (Saldivar-Tanaka and Krasny, 2004). Both community and home gardens can provide participants a connection to their cultural heritage, in particular helping immigrants to maintain farming traditions and uphold traditional foodways in their new communities (Schmelzkopf, 1995; Baker, 2004; WinklerPrins and de Souza, 2005; Carter et al., 2013). Thus, cultivation can deepen social and cultural relationships in the construction of place-based identities (Mares and Peña, 2011).

Just as home and community gardens are not only sites of production, CSAs and farmers' markets are not only spaces of economic exchange. The social experience of the market is one of the factors that motivates farmers to participate in farmers' markets (Hinrichs, 2000). Similarly, CSA farmers are motivated in part by a desire to build community and foster connection (Perez, 2004). Farmers' markets are often social spaces that bring people together and represent a venue where the strong bonds of community can be formed and performed (Obach and Tobin, 2014). When compared to shopping experiences at grocery stores, exchanges at farmers' markets are "embedded in social ties, based on proximity, familiarity, and mutual appreciation" (Hinrichs, 2000, p. 298). CSAs also forge ties between farmers and their customers, and provide additional opportunities for socializing at CSA pick-up sites and at occasional farm work days or community events.

Civic Engagement

Some types of localized food systems lead to political engagement and activism. Community gardens have a history of grassroots political activism against capitalistic forces of development that threaten garden spaces (Schmelzkopf, 1995; Ernwein, 2014). Community garden membership can also empower some gardeners to become more active in their communities (Blair et al., 1991; Saldivar-Tanaka and Krasny, 2004; Wakefield et al., 2007). Barron (2017, p. 7) asserts that community gardeners "cultivate a variety of social and political skills as well as critical perspectives that enable them to participate in promoting food democracy, and also motivate and enable democratic engagement at other scales." This political activity extends to home gardeners as well; Gray et al. (2014) provide a case study of home gardeners organizing for food justice. Direct markets can also have a political edge. Studies of what motivates farmers to offer a CSA reveal that they are moved by an "intense desire to positively change societal and environmental relationships" (Smith et al., 2019, p. 5).

In the next section, we look at how these four functions of local food system play out in a particular place.

CONTEXT AND METHODS

Study Area

This study took place in Santa Clara County, the southernmost part of the nine-county San Francisco Bay Area and the geographic heart of California's Silicon Valley. An agricultural center in the late 19th and early 20th centuries, much of the area's farmland has been lost to residential and commercial development since World War II (Diekmann et al., 2013). Despite these losses, the county retains a significant agricultural economy; the gross value of agricultural production was $896 million in 2018 (County of Santa Clara Division of Agriculture, 2019). Particularly since the 2007–2009 financial crisis, local food activities in Santa Clara County have increased. Local educational institutions have developed their own farms and gardens to educate students and provide fresh produce to their food service programs; non-profit organizations have developed urban farms to engage neighbors around food production; and urban garden networks have arisen to teach food insecure residents to grow their own vegetables and advocate for food system change.

Santa Clara County is diverse, with no majority racial or ethnic group. The county is roughly one-third Asian, one-third Latinx, and one-third white. Home to many immigrants, 38% of the population was born outside the US and 53% speak a language other than English at home (Data USA, 2020). As part of Silicon Valley, Santa Clara has enjoyed a strong economy driven by the high-tech industry. However, the benefits of this economy are not shared evenly and income inequality is growing. Several of the county's urban agriculture projects specifically aim to address persistent food insecurity.

Participants and Procedures

To investigate the relationship between participation in different types of local production and marketing, we surveyed home gardeners, community gardeners, farmers' markets shoppers, and CSAs members. We fielded three different versions of the survey for gardeners, farmers' market shoppers, and CSA members. Each version of the survey had questions that were similar, but with wording tailored to the specific type of local food system activity (e.g., "Since you started gardening…" vs. "Since you started shopping at a farmers' market…"). A survey question asking which other local food system activities (e.g., gardening, belonging to a CSA, composting, etc.) respondents engaged in showed that respondents typically engaged in more than one local food system activity. We did not control for this because each participant was independent of one another and because the version of the survey they completed (for gardening, farmers' markets, or CSAs) was considered their primary form of local food system engagement. Since respondents answered questions about the impacts of a specific type of local production and direct marketing, we expect their responses pertain to that type, regardless of whether they also participated in other local food system activities.

To create a sampling frame for local food system activities, we generated a list of all 16 CSAs, 36 certified farmers' markets, and 32 public community gardens operating in the county in 2015. Our inventory of community gardens leaves out those that take place at churches, schools, workplaces, housing developments, or other locations, which are harder to identify and can be more ephemeral. To compile a list of CSAs serving the county, we consulted Local Harvest's online database (localharvest.org) and CAFF's Buy Fresh, Buy Local Guide (2014) for Santa Clara Valley. CSAs that sold limited specialty products or were large third-party aggregators were excluded. There is no list of home gardeners, so we used three gardening networks–Master Gardeners, La Mesa Verde, and Valley Verde–to contact home gardeners in our study area. Master Gardeners are community volunteers who receive training through the County Cooperative Extension Office. La Mesa Verde and Valley Verde are programs focused on community food security and food justice that provide gardening materials and education to help low-income families grow their own organic vegetables.

We stratified the county geographically, and selected 8 farmers' markets and 10 community gardens to survey. Five farmers' markets were selected randomly. We also sampled three farmers' markets within San Jose that specifically aim to serve low-income neighborhoods. We surveyed four CSA programs. We invited both urban farms that had a CSA to participate and also randomly selected two other CSAs, growing outside of the county but delivering to customers in Santa Clara County. If a randomly selected CSA declined to participate, we went back to the list and selected another. Community gardeners received the survey via email. Farmers' markets shoppers were contacted at the market and asked to complete a paper survey. Members of three CSA programs completed surveys online, while at the fourth, members completed the survey on paper while picking up their farm share. To reach home gardeners, we distributed the survey to Master Gardeners via email, recruited gardeners in person at the Master Gardeners' spring seedling sale, and gave paper surveys to members of La Mesa Verde and Valley Verde. This study complied with Santa Clara University's Institutional Review Board (IRB) Protocol (Protocol ID: 15-04-671) for the protection of human subjects and all survey respondents gave their consent to participate.

Surveys included both closed- and open-ended questions. Closed-ended questions assessed the impacts of participation, while open-ended questions gave respondents an opportunity to describe their local food system experiences in more depth.

Limitations

Because of the limitations of our sampling strategy, the home and community gardeners included in our study are not representative of all gardeners in Santa Clara County. By using email to recruit community gardeners, our sample is biased toward gardeners who are fluent English speakers and have reliable online access. As a result, immigrant and lower-income gardeners are likely underrepresented among our respondents relative to their presence within the community gardening population as a whole. By relying on gardening groups to reach home gardeners, the demographic profile of home gardeners in the study may be a better reflection of group membership than of home gardeners in the county. Master Gardeners tend to be older, college-educated adults (e.g., Tarkle et al., 2017). Members of La Mesa Verde and Valley Verde are more likely to be lower-income and immigrants. (A more detailed demographic profile can be found in Diekmann et al., 2020.) While there are limits to this way of sampling home gardeners, it does provide a cross-section of gardeners that cuts across gradients of experience, income, and race.

The same concern of representativeness also applies to the farmers' market shoppers. Our purposive sampling strategy of selecting three farmers' markets (of the eight total) in low-income neighborhoods may have skewed the demographics of our sample of farmers' market shoppers. We believe that the oversampling of this demographic provides insight into the impact that farmers' markets have in communities that may not traditionally be represented in the literature and provides a more representative cross-section of the Santa Clara County's diverse population.

MEASURES

Independent Variables

Type of Local Food System Activity

We coded the surveys by type of local food system activity: garden, farmers' market, and CSA. Garden surveys were further separated into community gardener or home gardener. If gardeners indicated that they gardened both at home and in a community garden, they were counted as community gardeners.

Production vs. Direct Marketing

We created a variable that grouped types of local food system activity into production (community gardening and home gardening) and direct marketing (CSAs and farmers' markets).

DEPENDENT VARIABLES

Motivations

We asked survey respondents to select reasons that best describe why they participated in a specific type of production or direct marketing. Options included saving money, relaxation, spending time outdoors, having fresh fruits and vegetables, getting produce not available in the store, knowing where food comes from, spending time with families and friends, learning from others, teaching children. Possible motivations were adapted from other studies that have examined reasons for participating in urban agriculture, such as food attributes, household economics, physical and mental health, connections to nature and culture, education, and interpersonal relationships (e.g., Armstrong, 2000; National Gardening Association, 2014; Taylor and Lovell, 2014). Direct market shoppers could select a few additional options specific to the market experience–knowing farmers personally, supporting local agriculture, convenience, and community atmosphere–that were adapted from previous studies of direct markets in California (e.g., Perez et al., 2003; Galt et al., 2017). Finally, an "other" option allowed respondents to indicate any reasons for participating that were not already provided.

Outcomes

Nutrition

To gauge the nutritional contributions of the types of local food system engagement, survey respondents were asked questions about changes to their eating habits and preferences. Participants responded to the following six statements: "Since I started [gardening/shopping at a farmers' market/joined a CSA program] I eat more fruits and vegetables that are organically grown; I eat different types of vegetables depending on what is in season; I enjoy trying new fruits and vegetables; I eat more than one kind of vegetable each day; I eat more fruits and vegetables; I encourage my family to eat more fruits and vegetables" with response options ranging from Strongly Disagree (=1) to Strongly Agree (=5) on a 5-point Likert-scale. A reliability analysis showed that the items were related (Cronbach's alpha=0.89); thus a scale score was created by taking the averages of the items for each participant.

Social Connection

To assess how local food system participation affected socializing and social relationships, survey respondents answered the following question: "Has [gardening/shopping at a farmers' market/participating in a CSA program] affected your relationships with other people? Please indicate to what extent you agree or disagree with the following statements: I have met new people; I have met a community leader; I have met people from different backgrounds; I look forward to socializing and interacting with other people; I feel a stronger sense of belonging in the community." Response options ranged from

Strongly Disagree (=1) to Strongly Agree (=5) on a 5-point Likert-scale. The five items were combined to create an average score (Cronbach's alpha=0.873).

Food and Agricultural Knowledge

To assess what respondents had learned since they began participating in a particular type of local food system activity, we asked participants to indicate the extent to which they agreed with the following statements: "I have learned more about healthy eating; I have learned more about how food is grown; I have learned more about sustainable agriculture; I have learned more about policies and food systems that affect the food we eat; and I have learned more about the local environment, including things such as soil, insects, or plants." Response options ranged from Strongly Disagree (=1) to Strongly Agree (=5) on a 5-point Likert-scale. A scale score was created from the five items (Cronbach's alpha=0.883).

Civic Engagement

To assess participation in their communities, we asked respondents to indicate whether or not they had participated in a particular civic/political activity: "Since you started [gardening/shopping at a farmers' market/joined a CSA program], "Have you done any [activity]?" Activities included volunteering, working on a community project, signing a petition (including online), attending a public meeting, writing a letter to a legislator or policy maker, organizing an event, class, or project; attending a class, workshop, or lecture (see Obach and Tobin, 2014). Responses were dichotomous (yes=1/no=0), and a summary score was created to compute the total number of activities participants engaged in for a total possible score of 7.

Produce Proportion by Season

To assess the contributions of each type of local food system activity to food access, participants responded to the question: "What portion of the produce that your family eats comes from the [farmers' market/CSA/garden]? Please select the closest amount for each season." Four seasons were listed–Spring (April-June), Summer (July-September), Fall (October-December), and Winter (January-March)–and the following response options were available for each season: none, very little, 25, 50, 75%, all.

Sociodemographics

We assessed standard sociodemographics including gender; age; race/ethnicity; employment status; household income; and education. We grouped household income by $50,000 increments (<$50 K, $50 K–$99 K, $100 K–$150 K, >$150 K). Households earning <$50,000 annually in the San Francisco Bay Area are considered very low-income (Galt et al., 2017). Households earning from $50,000 to $99,000 are above the federal poverty level for a family of four, but are still earning less than the median income for Santa Clara County as well as the minimum income necessary to cover basic expenses for a family of four.

Analytic Strategy

We used descriptive statistics to characterize the sample across each type of local food system activity. A chi-square test was run for each demographic variable across the four types. For motivations, we used descriptive statistics to characterize reasons for participating. Open-ended responses provided in response to the "other" option for motivations were categorized thematically. For outcomes, we conducted two sets of analyses: the first, using the type of local food system activity; and the second, production vs. direct marketing. To assess differences between types in the four outcome areas of nutrition, social connection, food and agricultural knowledge, and civic engagement, we used one-way ANOVA's to compare mean scores for the scales or summary score for each domain area across the four types of local food system activity. To assess differences between production and direct marketing in the four outcome areas of nutrition, social connection, food and agricultural knowledge, and civic engagement, we used independent sample *t*-tests to compare mean scores for the scales or summary score for each domain area across the two groups. To assess the proportion of produce each type of local food system activity provides to participants, we generated descriptive statistics. Analyses were conducted using SPSS 25.

RESULTS

Local Food System Participants

Between April and October 2015, 160 home gardeners, 264 community gardeners, 242 farmers' market patrons, and 208 CSA members completed the survey. There were statistically significant differences between the four types of local food system activity participants based on income level, race/ethnicity, employment status, and educational attainment (**Table 1**). Home gardeners and farmers' market shoppers were roughly evenly distributed between the four income brackets, with just over 25% having annual household incomes of <$50,000 and just over 25% having annual household incomes >$150,000. CSA members were generally high-income earners, with nearly 60% of CSA members reporting a household income >$150,000 annually and only 5% reporting a household income of <$50,0000. Gardens had a higher percentage of retired participants, 32% and 33%, respectively, than the direct markets. Among farmers' market shoppers and CSA members, 71% were working and approximately 15% were retired. In keeping with the greater percentage of retired gardeners, gardeners also had a higher median age than direct market participants. Respondents were overwhelmingly female, ranging from 90% of CSA members to 61% of community gardeners.

The population of Santa Clara County is roughly one-third Asian, one-third Latinx, and one-third white. The demographics of farmers' market shoppers most closely resembled that of the county as a whole: 30% of farmers' market patrons were Asian, 16% were Latinx, and 47% were white. Home gardeners were also diverse, although less so than the county as a whole: 14% were Asian, 23% were Latinx, and 58% were white. With approximately 75% of community gardeners and CSA members identifying as white, these local food system types were less racially diverse than home gardens and farmers' markets. The portion of participants born outside of the US was similar for the four local food system types (20–28%). Across all types,

TABLE 1 | Demographics of home gardeners, community gardeners, farmers' market shoppers, and CSA members.

	Home garden ($n = 160$)	Community garden ($n = 264$)	Farmers' market ($n = 242$)	CSA ($n = 280$)	*p*-value
Education					$p = 0.0004$
High school or less	9%	1%	8%	3%	
Some college	12%	9%	12%	5%	
College degree	43%	42%	41%	42%	
Graduate degree	36%	49%	40%	50%	
Income					$p < 0.0001$
<$50 K	29%	17%	27%	5%	
$50 K–$99 K	24%	29%	23%	17%	
$100 K–$150 K	21%	16%	22%	20%	
>$150 K	27%	38%	28%	58%	
Employment					$p < 0.0001$
Working	48%	59%	71%	71%	
Unemployed	16%	6%	12%	15%	
Retired	32%	33%	15%	14%	
Disabled	4%	2%	2%	0%	
Race/ethnicity					$p < 0.0001$
Asian	14%	13%	30%	9%	
Latino	23%	8%	16%	10%	
White	58%	74%	47%	76%	
All others	6%	5%	7%	5%	
Foreign-born	25%	21%	28%	20%	$p = 0.159$
Home ownership	79%	79%	66%	82%	$p = 0.005$
% renting	20%	19%	30%	17%	
Age (median)	55	58.5	50	48	
Gender (% Female)	83%	61%	66%	90%	$p < 0.0001$
Household size (mean)	3	2.4	2.9	3.2	

educational attainment was high. Thirty-six percent of home gardeners had a graduate or professional degree, compared to 40% of farmers' market shoppers, 49% of community gardeners, and 50% of CSA members.

Survey takers reported their participation in multiple local food system activities (**Table 2**). Shopping at a farmers' market was the most commonly reported other local food activity (roughly two-thirds of gardeners and CSA respondents indicated that they shopped at a farmers' market). Gardening at home was also a common activity, with approximately 60% of farmers' market patrons and CSA members reporting that they gardened at home and 66% of community gardeners reporting that they also had a garden at home. Belonging to a CSA program and community garden were much less common, with about 10% of survey takers indicating they were CSA members, and 5% or less reporting that they gardened at a community garden. Other common activities were composting and food preservation (e.g., canning, freezing, and/or drying). However, within these categories there were significant differences: while about half of gardeners and CSA members composted, only 29% of farmers' market shoppers did. Farmers' market shoppers were also significantly less likely to preserve food: just 50% reported putting away food compared to 64% of CSA members and roughly 70% of gardeners.

Motivations

Table 3 shows reasons for participating in localized urban food systems. All local food system participants were motivated: (1) To have fresh fruits and vegetables and (2) To know where their food comes from and how it is grown. Open-ended responses confirmed their enthusiasm for the freshness and flavor of both home-grown produce and produce purchased from small farmers. Representative comments from gardeners include, "Food is fresh, organic, and delicious!" and "garden grown veggies taste better than even Farmer's Market produce." CSA members and farmers' market shoppers also touted the quality of the produce they received, writing "CSA food is much fresher and tastier than any store bought food" and "because the produce has a really good taste." Farmers' market shoppers (47% of open-ended responses), CSA members (22% of open-ended responses), and gardeners (8% of open-ended responses) used the other option to express a preference for organically produced food. Additionally, 35% of CSA members who provided an open-ended response indicated that they enjoyed being exposed to new fruits and vegetables in their CSA shares. As CSA members wrote, "there is some adventure in this as well. Unknown food arrives, then I figure out what I might do with it" and it is "Fun to get surprised by something new."

A greater percentage of CSA members were motivated by a desire to support local agriculture (95%) than farmers' market shoppers (69%). Representative comments from CSA members about why they participate include "to support organic farmers and reduce the amount of pesticides my family and I ingest" and to "support small businesses and buy local and seasonal." A greater percentage of home gardeners (43%) than participants in other local food system types cite saving money as a motivation. Community gardens had the largest percentage of participants (44%) interested in learning from others. Teaching, personal satisfaction, and sharing with others also emerged as an important theme in gardeners' open-ended responses. Typical responses to why they garden were "there is something just very gratifying about growing a significant portion of the food that I eat" and "to share high quality, organic (heirloom when possible) produce with the community and friends." CSA members (5%) were least motivated by spending with family and friends.

Outcomes Across Four Types of Localized Urban Food Systems

We computed mean scores for the scales from the outcome areas of nutrition, social interaction, and knowledge, and from the summary score for civic engagement for each food system activity (see **Table 4**). For nutrition, CSA respondents reported generally strong agreement with statements about dietary intake

TABLE 2 | Other local food activities that urban agriculture participants engage in.

Activity	Home gardeners	Community gardeners	Farmers' market shoppers	CSA members	*p*-value
Shop at a farmers' market	68%	72%	–	65%	$p = 0.258$
Participate in a CSA	11%	11%	10%	–	$p = 0.812$
Garden at home	–	66%	59%	62%	$p = 0.124$
Garden in a community garden	–	–	5%	2%	$p = 0.221$
Shop at a farm stand	24%	26%	35%	25%	$p = 0.045$
Volunteer at community farm	4%	3%	4%	5%	$p = 0.873$
Compost	58%	55%	29%	44%	$p < 0.0001$
Raise chickens	11%	8%	6%	7%	$p = 0.391$
Grow native plants	52%	22%	27%	36%	$p < 0.0001$
Forage	4%	7%	5%	4%	$p = 0.496$
Can, freeze, or dry	68%	71%	50%	64%	$p < 0.0001$

TABLE 3 | Participants' reasons for gardening, shopping at farmers' markets, or belonging to a CSA.

Motivation	Home gardeners	Community gardeners	Farmers' market shoppers	CSA members	*p*-value
Have fresh fruits and vegetables	91%	89%	88%	90%	$p = 0.810$
Know where my food comes from and how it is grown	63%	67%	50%	87%	$p < 0.0001$
Save money	43%	25%	25%	21%	$p < 0.0001$
Get produce that I can't buy in the store	40%	36%	34%	31%	$p = 0.362$
Teach my children	34%	24%	17%	22%	$p = 0.001$
Learn from others	31%	44%	17%	14%	$p < 0.0001$
Spend time with family and friends	20%	24%	28%	5%	$p < 0.0001$

and changes in eating habits (mean = 4.20, SD = 0.92), followed by home gardeners (mean = 4.15, SD = 0.93), farmers' markets shoppers (mean = 3.97, SD = 1.07), and community gardeners (mean = 3.95, SD = 0.97). With regard to social interaction, community gardener respondents reported the strongest agreement with statements about interacting with different kinds of people and meeting new people (mean = 3.83, SD = 0.77), followed by home gardeners (mean = 3.67, SD = 1.04), farmers' market patrons (mean = 3.44, SD = 1), and CSA members (mean = 2.56, SD = 1.01). The greatest knowledge gains were seen among home gardeners (mean = 4.12, SD = 0.84) and the lowest by farmers' market patrons (mean = 3.42, SD = 1.05). For civic engagement, community gardeners reported participating in the most civic engagement activities [mean=3.44 (out of 7), SD = 2.15], while farmers market patrons participated in the fewest (mean = 1.82, SD = 2.04).

One-way ANOVA's showed that all of these differences between the four types of local food system activity across the four outcome areas were statistically significant at the $p < 0.05$ level. *Post-hoc* tests (Tukey) were conducted, given that the ANOVA results were significant. For the nutrition outcome, a comparison between community gardeners and CSA members showed significance ($p = 0.036$). For knowledge, significant results were shown for community gardeners and home gardeners ($p = 0.033$), home gardeners and farmers' market shoppers, and for home gardeners and CSA members. For social interaction, comparisons between home gardeners and CSA members, farmers' market shoppers and community gardeners, community gardeners and CSA members, farmers' market patrons and CSA members were all significant. For civic engagement, significant differences were seen for farmers market shoppers vs. home gardeners, CSA members and home gardeners, community gardeners and farmers' market shoppers, and community gardeners and CSA members.

In **Table 5**, we also compared the outcomes between production and direct marketing. There are no significant differences in means for nutrition between production (mean = 4.02, SD = 0.96) and direct marketing activities (mean = 4.08, SD = 1.01). There are significant results ($p < 0.0001$) for all the other scales from the outcome areas of knowledge, social interaction, and the summary score for civic engagement. Producers had higher scores than those participating in direct marketing activities for knowledge, social interaction, and civic engagement.

Portion of Food Acquired From Each Type of Local Food System Activity by Season

The various types of local food system activity differed in the quantity of fresh produce provided and the consistency with which it was available. In general, farmers' markets and CSAs supplied greater portions of the produce respondents consumed more consistently throughout the year (**Figure 1**). For instance, CSA members typically obtained 75% (median) of their produce from their CSA share in spring and summer, and 50% (median) in fall and winter. Farmers' markets provided 50% (median) of

TABLE 4 | One-way ANOVAs comparing outcomes across four types of UA.

	Home gardeners Mean (SD)	Community gardeners Mean (SD)	Farmers' markets Mean (SD)	CSAs Mean (SD)	*p*-value
Nutrition	4.15 (0.93)	3.95 (0.97)	3.97 (1.07)	4.20 (0.92)	$p = 0.016$
Knowledge	4.12 (0.84)	3.85 (0.91)	3.42 (1.05)	3.62 (1.00)	$p < 0.0001$
Social interaction	3.67 (1.04)	3.83 (0.77)	3.44 (1.00)	2.56 (1.01)	$p < 0.0001$
Civic engagement	3.43 (2.18)	3.44 (2.15)	1.82 (2.04)	2.26 (2.19)	$p < 0.0001$

TABLE 5 | *T*-tests comparing outcomes between production vs. direct marketing.

	Direct production Mean (SD)	Direct marketing Mean (SD)	*p*-value
Nutrition	4.02 (0.96)	4.08 (1.01)	0.441
Knowledge	3.96 (0.89)	3.51 (1.03)	$p < 0.0001$
social interaction	3.77 (0.89)	3.03 (1.09)	$p < 0.0001$
Civic engagement	3.44 (2.16)	2.03 (2.12)	$p < 0.0001$

the produce participants consumed in spring, summer, and fall, and 25% (median) in winter. Garden contributions were more seasonal on average, producing 50% (median) of the produce gardeners consumed in summer, 10% (median) in winter, and 25% (median) in spring and fall.

DISCUSSION

Results from this study confirm that urban agriculture and direct markets have multiple functions, which contribute to a variety of outcomes associated with localized urban food systems, including food access, food and agriculture education, community building, and civic engagement. Furthermore, different types of local production and direct marketing have distinct impacts on participants. In general, types of production had a greater impact on participants' self-reported food and agricultural knowledge, social interaction, and civic engagement than direct marketing activities.

Food Access and Nutrition

For participants in all four types of local urban food activity food and nutrition were a central motivation for and outcome of participation. For approximately 90% of all survey respondents having fresh produce was a reason for taking part in gardening or direct markets. Gardeners in this study and elsewhere prize the quality–including freshness and taste–of the produce they grow (Pourias et al., 2016; Porter, 2018; Diekmann et al., 2020). Similarly, produce quality and freshness are important food attributes for direct market shoppers (e.g., Brehm and Eisenhauer, 2008; Thilmany et al., 2008). Consistent with the larger scale of production on urban, peri-urban, and rural farms than urban gardens (Opitz et al., 2016) and the structure of direct markets where multiple farmers can sell or aggregate their product, farmers' markets and CSAs supplied survey respondents with a greater share of produce throughout the year than gardens. While a few gardeners were able to provide for most of their produce needs, for most gardeners, garden output was strongly seasonal (e.g., Vitiello and Wolf-Powers, 2014; Pourias et al., 2016). Although direct markets generally supplied more produce than urban gardens, survey respondents reported very similar impacts on dietary intake and food choices across all types. Moreover, nutrition was the highest scoring of the four scaled dependent variables, with mean scores ranging from an average of 4.2 for CSA members to 3.95 for community gardeners. Looking at the individual elements of the scaled scores, a majority of participants reported an increase in quantity of produce consumed, dietary diversity, and encouraging family members to eat more produce. In open-ended survey responses, CSA members in particular described eating a greater variety of produce, eating more seasonally, and consuming greater quantities of produce. As one CSA member wrote, "Our CSA effortlessly puts me on a schedule of buying fresh veggies regularly. We eat more veggies this way." Although food production may be a means to other social ends, these survey results are a reminder that food and agriculture remain central to efforts to encourage broader social and environmental change by localizing urban food systems.

Food and Agricultural Knowledge

Local food system initiatives often strive to overcome the alienation from food production associated with the global food system by reconnecting consumers to food production and restoring knowledge about food and agricultural traditions. Among urban food producers, a focus on education is common. In the San Francisco Bay Area, for instance, Siegner et al. (2019) found that 40% of urban agriculture operations identified primarily as educational farms or gardens and nearly all had some educational offerings. Our survey asked respondents about changes in their knowledge of food production, local environment, healthy eating, and food systems and policies since they began participating in local food production or direct markets. Reported knowledge gains were greatest among home gardeners. The statistically significant difference in knowledge gain between gardeners and direct market shoppers speaks to the physical and social space of gardens that facilitates learning through active, sustained engagement with the natural world and other people (Macias, 2008; Litt et al., 2011). Gardening requires ongoing interaction with the natural world in a way that shopping at a farmers' market or picking up a CSA box does not. Gardeners build experiential knowledge of the natural world and put it into practice as they manage their gardens in response to local conditions. Gardens also provide multiple pathways for teaching and learning–among gardeners, across

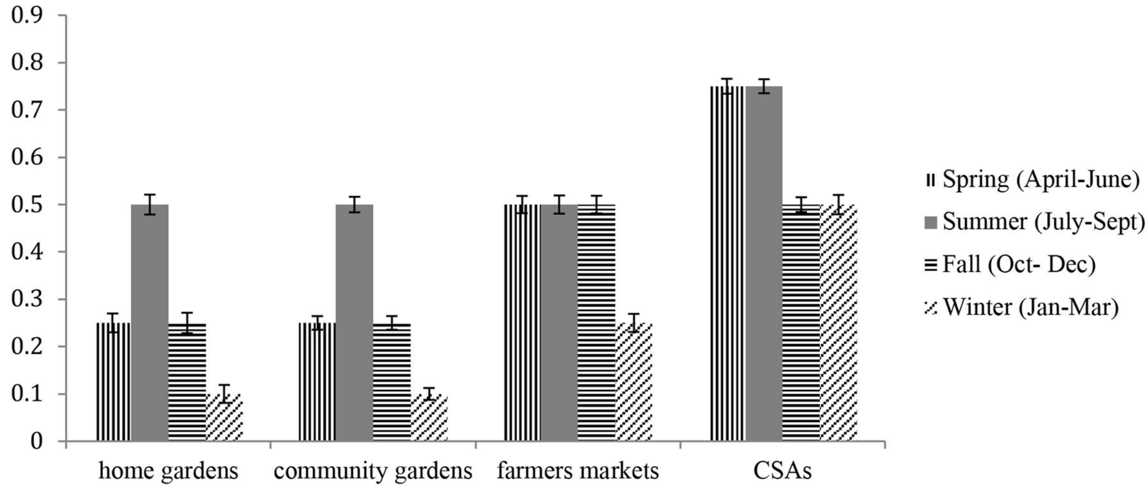

FIGURE 1 | Percent of produce (median) consumed that comes from local food system activity. Error bars show standard error.

generations, and with members of the public who pass by gardens in public or semi-public spaces (Macias, 2008; Porter, 2018). Somewhat surprisingly, knowledge was the only impact area in which there was a significant difference between home and community gardeners. This difference may be due to the educational opportunities offered by local gardening programs, whose members were heavily represented in our sample as a result of our strategy for reaching home gardeners.

Among direct markets participants, CSA members reported learning more than farmers' market shoppers. These findings suggest that the information CSA farmers provide to their members is effective in increasing knowledge about local agriculture. In open-ended survey responses, CSA members mentioned how much they enjoyed learning about the way their food is farmed and receiving recipes for using produce in weekly newsletters. In addition, for some CSA members, receiving an unfamiliar fruit or vegetable was an opportunity to learn how to prepare something new. Looking across the four types of local production and marketing, these results indicate that organizations can play an important role in supporting and offering educational opportunities. In spaces without intentional educational opportunities, such as the farmers' markets included in our study, learning is less likely to happen. Elsewhere farmers' markets may include cooking demonstrations or booths where shoppers can learn about gardening.

Social Interaction

The greatest differences in impact among the four different types of local food system participation were for measures of social interaction and civic engagement. The mean score for social connection was greatest among community gardeners (3.83), followed by home gardeners (3.67) and farmers' market shoppers (3.44), and lastly by CSA members (2.56). These results support the idea that community gardens create a space where community ties can be created and strengthened through cooperation, socializing, and social support (Glover, 2004; Kingsley and Townsend, 2006; Litt et al., 2011). As Taylor and Lovell (2014, p. 295) outline, gardens foster the development of social networks and social capital in three main ways. First, by providing a setting for social activities, gardens facilitate social interaction with other gardeners as well as friends and family (Pourias et al., 2016; Poulsen et al., 2017). As one community gardener stated, "my garden plot gets me out of my home and into nature and a community of like-minded people." Although home gardens may offer fewer opportunities to engage with other gardeners who are not part of the same household, they otherwise enable opportunities similar to those provided by community gardeners for social connection with family, friends, and neighbors, even sometimes becoming the gathering place for household social events (WinklerPrins and de Souza, 2005). Second, sharing food, germplasm, knowledge, and labor is another mechanism for building social relationships in the garden. It is common for gardeners to emphasize sharing (Pourias et al., 2016; Porter, 2018). The act of sharing reinforces a network of interaction and support among gardeners and others in their social orbit (WinklerPrins and de Souza, 2005; Taylor and Lovell, 2014). Finally, gardeners develop their social networks by engaging non-gardeners who either are interested in learning more or who are important sources of support (e.g., providing needed resources like compost). Some home gardeners who garden in their front yards report that they enjoy interacting with their neighbors and have the opportunity to model certain nutritional and environmental practices. It is possible that direct market settings offer fewer of these avenues for social interaction, particularly sharing food and engaging with non-participants, helping to explain their lower scores in social interaction.

Recognizing that social networks are not unidimensional (e.g., Alaimo et al., 2010), our questionnaire asked about horizontal linkages with people who are not like survey respondents in terms of their social identity or socio-demographic characteristics

["I have met people from different backgrounds"] and vertical linkages across gradients of power or authority ["I have met a community leader"]. Following the pattern for the mean social scores, a greater percentage of gardeners agreed with these statements than CSA members. These types of network connections may be especially helpful for taking action in the community. Consequently, gardeners may be especially well-positioned for civic engagement as an outgrowth of the learning and connecting that happens in the garden.

Social connection is the only impact category where a statistically significant difference between direct market types emerged: farmers' market shoppers had a significantly higher mean score for social interaction than did CSA members. The structure of these two markets offers some explanation for the difference. Farmers' markets are a site of regular social gathering (Macias, 2008), where people come to shop, but also to mingle, listen to music, and get food to eat. CSA members may pick up their farm share at a drop-off site where they might rarely encounter another member or they may have home delivery, completely removing the opportunity for social contact. Who is present in these spaces also affects the types of social interactions that take place. Given the relative homogeneity of CSA members in our study—primarily white, upper income, and well-educated—it is not surprising that they were also least likely to report meeting people from different backgrounds. Furthermore, as CSA models have shifted over time from membership to subscription models, where consumers pay less upfront and share less of the risk, some of the community-oriented goals of the original model have been harder to achieve (Center for Agroecology Sustainable Food Systems, 2015; Galt et al., 2016). While the high percentage of CSA members who say they belong to a CSA to support local agriculture suggests that the commitment to some of the ideals of CSA (e.g., farm viability, environmentally sustainable agricultural practices) remain, community building among members themselves or between members and farmers is less evident. Brehm and Eisenhauer (2008) concluded that CSA members do not see socializing or building social connections as either a motivation for or an outcome of participating in a CSA. Research by Galt et al. (2016) on CSAs in California has found that the demands placed on farmers by increased competition in the CSA space has also undermined some socially embedded practices–such as holding events for members, socializing at the pick-up point, and writing newsletters–and consequently, some of the social bond between farmers and members.

Civic and Community Engagement

Impacts on civic engagement had the lowest mean scores of all the functions examined in this study. Nevertheless, there were still large and significant differences between gardeners (mean score 3.44, on a scale of 0–7) and direct market shoppers (mean score 2.03). To some extent, these results support Obach and Tobin's (2014) findings that civic engagement is positively associated with a greater degree of social embeddedness, although a much larger percentage of farmers' market shoppers and CSA members in their study in New York reported participating in community and political activities than did respondents to our survey. In the literature, gardens in particular are framed as spaces of resistance and empowerment (e.g., Taylor and Lovell, 2014). One manifestation of this is the long-standing tradition of urban gardening as a constructive response to conditions of repression. Gardening for survival, self-reliance, resistance, and self-determination has been a part of urban Black communities for generations (White, 2018; Reese, 2019). In these instances, gardeners may be motivated to garden as part of a larger process of community resilience, healing, and liberation. Approximately 12 percent of gardeners in our study belonged to garden programs that promote community activism around food justice, community resilience, and self-sufficiency. Community gardens are also associated with activism as gardeners have had to organize to defend their garden sites from development (Schmelzkopf, 1995; Ernwein, 2014). Barron (2017) has outlined two other forms of agency through which gardeners seek to improve the city or the food system. First, gardeners as food producers exert greater control over their food choices and express some of their environmental and social values for the food system as a whole. Second, gardeners as citizens, see their role in the food system not just as that of a consumer but as someone who exercises their rights and responsibilities to create a better food system by engaging in political processes.

By combining new social relationships and heightened awareness of social and environmental issues, gardens may create a context for spurring collective action (Porter, 2018). Interestingly, in our case study, these attributes were somewhat split between the two types of direct marketing: farmers' markets had a higher mean score for social interaction than CSAs, and CSAs had a higher mean score for food and agricultural knowledge than farmers' markets. While direct markets do not have the same association with activism as gardens, for some direct market shoppers, participating in an alternative market may be a civic act in and of itself. As Galt et al. (2019) theorized, "CSA people" are willing to subordinate their personal preferences to support a more environmentally and socially beneficial system of farming. However, deLind (2002) has leveled a larger critique that the civic aspect of local agriculture has been overshadowed, and consequently underdeveloped, by the focus on developing markets and entrepreneurship. To realize the civic aspect of local food system activities will require "the development of collective activities that prioritize public interests" (Poulsen et al., 2017, p. 137). The generally low mean scores for participants in all four types of local production and marketing suggest that more organizational support may be needed to activate these spaces as venues for civic engagement and community mobilization. The reckoning with American racial injustice in summer 2020 sees more direct market farms in the San Francisco Bay Area (the larger region in which our case study is situated) publicly grappling with historic and ongoing racism. An interesting subject for future research could be to examine if and how the public acknowledgment and calls to action taking place at this moment will lead to sustained civic action by these farms and their customers.

Various types of local urban food systems provide a spatial, cultural, and political framework for food production and consumption activities (Reese, 2019). The potential impacts of these food system alternatives reflect the interplay of the individual and collective agency of the actors involved, organizational structures, local context, and larger-scale processes that structure city life and the food system. Though we separated different impacts in our analysis, it is important to note that participants do not experience the various functions of urban food system activities as separate. For example, one community gardener on a fixed income commented that her garden allowed her to have access to many more vegetables than she could otherwise afford and that she loved the social aspect of gardening and sharing with her neighbors. She described her gardening experience as being a like a spiderweb, with "benefits stretching out in different directions like fingers." The distinct outcomes of local urban food system activities call our attention to their different social relations and temporal and spatial configurations, which have the potential to contribute to particular social, economic and environmental outcomes. For instance, farmers' markets may be less likely to engender civic engagement than gardens, partly because of their ephemeral nature. Similarly, the temporality of farmers' markets, which are open only for a few hours at weekly intervals, may limit participants' ability to develop deep relationships with farmers or other shoppers. In contrast, as spaces of production with little or no restriction on hours for members, community gardens offer more opportunities for prolonged contact and more sustained exchanges. Gardeners may share knowledge and experiences around a mutually valued activity (gardening) or work together in a more structured environment to manage the collective aspects of the garden.

Future Research

While not explicitly tested in our survey, the results of this study suggest that gardening networks or programs like La Mesa Verde, Valley Verde, and the Master Garden Program play an important role in realizing the potential benefits of gardening because they offer program-based opportunities for education, social networking, and civic engagement. Porter (2018) notes that community-based organizations' (CBOs) support for gardens is likely to be particularly important for social connections and social change and for facilitating participation by people who need additional resources or support to garden. She writes, "The broad set of benefits in culture and spirit, people and relationships, and healing and transformation reported here, appear to be entwined with and emerging from CBOs' strategies for supporting gardening and gardeners.... These CBOs extensively use organizing strategies to achieve transformational goals with their communities" (2018, p. 198). Future research should examine which strategies employed by CBOs, farmers' market associations and other organizations support particular outcomes of local food system activities.

It is well-established that the environmental, cultural, and economic costs and benefits of the food system and food system alternatives are not equally distributed (Ammons et al., 2018). Similarly, we do not expect that the impacts of urban agriculture and direct markets benefit all people equally. An extensive literature documents disparities in access to urban agriculture, farmers' markets, and CSAs (e.g., Reynolds, 2015; Galt et al., 2017; Horst et al., 2017). In this case study, farmers' markets participants and home gardeners were the most racially and economically diverse; though we acknowledge that our purposive sampling strategy of selecting three farmers' markets in low-income neighborhoods to include in the study may have skewed the results in this direction. The literature also demonstrates the ways in which urban agriculture and alternative food have been coded as white cultural spaces (e.g., Slocum, 2007; Guthman, 2008; Alkon and McCullen, 2011). In addition, to understanding how various functions of localized urban food systems differ between type, it is important to understand how they differ in which participants are engaged and which benefit, taking into consideration race and ethnicity, income, culture, and language.

CONCLUSION

Our findings in Santa Clara County, California expand on previous work on the multifunctionality of urban agriculture to show that community gardens, home gardens, farmers' markets, and CSAs each have a distinct set of impacts on participants' lives. The creation of these alternative food system spaces creates multiple possibilities for change, so the impacts reported here are not fixed but rather a snapshot of a particular place at a particular moment in time (Allen et al., 2003). Engaging with the various impacts of local food system activities is one way to look at the intersection of food projects and their local context. Similarly, a focus on functions can help to reconcile debates about whether these activities uphold the status quo or promote change (see McClintock, 2014) by focusing on their functions in a specific context. Yet explorations of how various functions relate to one another are relatively rare. Observing various types of local food system activity in relationship to one another helps to situate these efforts in the broader context of food system change. In many urban regions, for example, networks of policymakers and community-based organizations are investing in urban food systems to create a healthier food landscape. A better understanding of which types of local urban food system activity, actors, and strategies deliver the desired results could help to inform these planning processes. Finally, urban gardens and direct markets are an important source of food for a large number of urban residents, but they are equally important as sites of education, social connection, and food justice (Siegner et al., 2018; Valley and Wittman, 2018). While pounds per square foot is a tangible metric, a better set of tools and evaluation processes could also help urban food system organizations to communicate the value that their multifunctionality provides to cities and their residents.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

Study procedures involving human participants were reviewed and approved by Santa Clara University Human Subjects

Committee. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

LD and LG developed and conceptualized the study together. CT and LD conducted the data analysis. All authors contributed to writing and revising the article. All authors contributed to the article and approved the submitted version.

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Facilitating Spaces of Urban Agroecology: A Learning Framework for Community-University Partnerships

Jennifer A. Nicklay[1]*, *K. Valentine Cadieux*[2], *Mary A. Rogers*[3], *Nicolas A. Jelinski*[1], *Kat LaBine*[1] *and Gaston E. Small*[4]

[1] *Department of Soil, Water, and Climate, University of Minnesota – Twin Cities, St. Paul, MN, United States,* [2] *Environmental Studies, Hamline University, St. Paul, MN, United States,* [3] *Department of Horticultural Science, University of Minnesota – Twin Cities, St. Paul, MN, United States,* [4] *Biology Department, University of St. Thomas, Saint Paul, MN, United States*

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Johann G. Zaller, University of Natural Resources and Life Sciences Vienna, Austria

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***Correspondence:**
Jennifer A. Nicklay
nick0135@umn.edu

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At the local scale in Minneapolis/St. Paul (MSP), MN, urban farms, community gardens, and home gardens support diverse individual and community goals, including food access and sovereignty, recreation and outdoor activity, youth education, and racial, economic, and environmental justice. Collaborations between urban growers, policymakers, scholars, and communities that leverage urban farms and gardens as sites of ecological, social, and political transformation represent spaces of urban agroecology. Participatory research can play a vital role in urban agroecology by facilitating integration of science, movement, and practice, but frameworks to accomplish this are still emerging. This paper, therefore, proposes a "learning framework" for urban agroecology research that has emerged from our community-university partnership. We—a group of growers, community partners, and researchers—have worked with each other for 5 years through multiple projects that broadly focused on the socio-ecological drivers and impacts of urban farms and gardens in MSP. In fall 2019, we conducted our first formal evaluation of the participatory processes implemented in our current project with the objectives to (1) identify processes that facilitated or were barriers to authentic collaboration and (2) understand the role of relationships in the participatory processes. Qualitative surveys and interviews were developed and conducted with researchers, partners, and students. Analysis revealed that urban agroecology research provided a space for shared learning, which was facilitated through co-creation of research, embodied processes, and relationships with people, cohorts, and place. As part of our partnership agreements, we as researchers wrote this article—in close consultation with partners—to share this framework in the hopes that it will serve as a model for other research collaborations working within complex urban agroecological systems.

Keywords: urban agriculture, participatory research, sustainable agriculture, community gardens, urban farms, food justice, community-engaged learning

INTRODUCTION

Urban growers, organizers, and policy makers in Minneapolis/St. Paul (MSP), MN, view urban food growing initiatives as an important strategy to support diverse goals such as food access, intergenerational learning, racial/environmental justice, climate adaptation and mitigation, stormwater management, community development, and food justice (Recknagel et al., 2016). These goals are pursued through farms, community gardens, and home gardens that utilize diverse growing practices such as raised beds, containers, high tunnels, aquaponics, integration of perennials, and other diversified farming practices (Recknagel et al., 2016). The number of farms and gardens in MSP has increased steadily over the past decade, from 166 community gardens in 2009 to over 600 in 2016 (Prather, 2016).

These increases are the result of significant grower, policymaker, neighborhood, researcher, school, and community efforts to improve support and funding for urban farms and gardens at the city, county, and state levels (Lang, 2014; Recknagel et al., 2016; Department of Community Planning Economic Development, 2018; Bress, 2019). As these diverse advocacy efforts and their documentation suggest, urban growing initiatives arose from collaborations between growers, supporters, and scholars. Collaborations imagine and enact new ways of being in relationship with individuals, communities, and the environment through urban food production, thus joining global movements for food sovereignty and justice (Penniman, 2018). We—a group of growers, community partners, and researchers—have collaborated with each other for 5 years on a multi-site program of participatory urban agroecological field research, and this article reports on a mid-process evaluation of our participatory processes. *This article specifically addresses the need for learning frameworks that help such collaborations adaptively share knowledge, cultivate relationships, and engage in collective action toward systemic transformation.*

Urban Agriculture and Urban Agroecology

The "radical, transformative potential of urban food production spaces" is not adequately addressed within the current urban agriculture paradigm (Siegner et al., 2020). Definitions of urban agriculture often focus on yield and productivity, perpetuating productivism, which prioritizes maximizing yield over other potential benefits or externalities. Consequently, this focus on productivity limits our imagination for the wide variety of co-benefits provided by urban farms and gardens (Siegner et al., 2020). A focus on yield alone arises from reductionist/positivist research paradigms, which form the foundation of many natural (and social) science disciplines (WinklerPrins, 2017; Bowness et al., 2021). Reductionism seeks to break down systems into discrete, ever smaller component parts, and positivism is grounded in the idea that "solving" these component parts will "solve" the systemic problems. Framed by calls to feed the world's growing population, these paradigms result in a focus on maximizing yield as the solution to hunger, which fundamentally doesn't address how inequitable food access (among other challenges) are the result of historic and contemporary systems of oppression (Cadieux and Slocum, 2015). In urban areas specifically, such systems include racist planning policies such as limited land access/tenure, financial barriers, pollution and soil contamination, development pressure, and gentrification (Greenberg-Bell, 2019). Thus, a productivist definition of urban agriculture fails to *locate challenges within the systems that create them* and instead attributes problems to *individuals and neighborhoods*.

Research, which is itself embedded in social and political relationships, is not alone in perpetuating such narratives; as Pudup (2008) wrote, non-profit and local governments often:

> deliberately organize gardens to achieve a desired transformation of individuals in place of collective resistance and/or mobilization.... Linking all such efforts is the promise that direct contact with nature, through gardening, will transform people who are otherwise poor and socially and culturally marginalized.... In other words, gardening is a personal and not a social process in contemporary garden projects (1230).

In other words, research and action paradigms that rely on metrics like yield per acre, vegetables per neighborhood, or production potential reproduce the idea of individual responsibility to solve systemic challenges—which is an especially dangerous narrative when working with communities experiencing marginalization due to race, class, immigration status, sexuality, etc. Thus, we echo Siegner et al. (2020) in arguing that this productivist focus on yield and individuality fundamentally obscures the complex (and usually more-than-monetary) socio-ecological goals, practices, and impacts of urban food production.

Urban agroecology represents an alternative research and action paradigm that "clearly positions itself in ecological, social, and political terms" (Tornaghi and Hoekstra, 2017). As opposed to reductionism, urban agroecology encompasses complex systems and relationships to explore questions of governance, resource availability, education, ecological relationships, policy, and justice; this breadth provides space to explore the diverse outcomes and goals of urban food production (Fernandez et al., 2015). Through this systemic approach (Meadows, 2008), urban agroecology builds on broader agroecological traditions, which seek to "transform food and agriculture systems, addressing the root causes of problems" (FAO, 2018).

While there are many definitions of agroecology, the label is used to encapsulate efforts that focus on *ecological* relationships, sustainable farming *practices*, and food sovereignty, land access, and other socio-political *movements* (Holt-Giménez, 2011; Rosset and Martínez-Torres, 2012; Levkoe et al., 2019). Wezel et al. (2009) proposed that these threads of agroecology were grounded in different traditions, while more recent scholarship has focused on the potential power to transform agrifood systems when they are interwoven (Montenegro de Wit, 2014; Fernandez et al., 2015; FAO, 2018). Despite the potential, however, agroecological science often struggles to integrate with movement and practice, in part because balancing the expectations of broader scientific rigor, reductionism, and knowledge creation runs counter to the expectations for dispersed power, socio-political engagement, and systemic focus of movements and practice (Montenegro de Wit and Iles, 2016).

Enacting Urban Agroecology Through Participatory Research

Participatory research approaches are often positioned as important strategies to integrate agroecological science with movements and practitioner knowledge (e.g., Stassart et al., 2005; Montenegro de Wit, 2014; FAO, 2018). In contrast to positivist scientific research in which scholars drive research, participatory action research (PAR) requires shared power/ownership so growers and communities can meaningfully participate throughout the research process, including generating questions, designing and implementing methods, analyzing and creating meaning from data, and sharing results (Méndez et al., 2017). The goal of shared ownership is both to ensure that all partners benefit from the research and that knowledge is shared across institutional and cultural boundaries (FAO, 2018). PAR relies on iterative cycles of reflection, research, and action to ensure that shared ownership and benefits remain relevant to participating growers, scholars, and communities (Méndez et al., 2017). Méndez et al. (2015) argue PAR is necessary to "include or amplify those voices that have been traditionally excluded from the research process." Finally, it is necessary to acknowledge that this complex, negotiated process takes time and commitment to nurture long-term collaborative relationships grounded in humility, trust, and accountability (Méndez et al., 2017). Taken together, PAR in agroecology reimagines *who* generates knowledge, *how* it is generated, and, ultimately, *what* is considered knowledge (Montenegro de Wit and Iles, 2016; Méndez et al., 2017).

Thus, participatory approaches developed in rural agroecology provide a valuable foundation for urban agroecology. Multiple partnerships and sites are now refining these approaches for urban agroecology; researchers in the Bay Area (Montenegro de Wit, 2014; Altieri and Nicholls, 2018) and Central Coast (Egerer et al., 2018) of California, Portland (McClintock et al., 2016), and Chicago (Taylor and Lovell, 2015) are just a few examples. This disbursed network across many cities and regions means that it is vital to share and report back as we build participatory approaches for urban agroecology (and contribute, more broadly, to community engaged scholarship).

Over the past 5 years, we—a group of researchers, growers, community organizers, and students in MSP—have also implemented participatory practices for urban agroecology research. MSP provides a particularly salient case right now for contemporary researchers in this field, with intense scrutiny of racial equity, differential resource access and outcomes in health and wealth, and unusually broad public discussions of the relevance of urban food production for meeting community economic development and other needs, from hyper-local to state scales. In addition to PAR, we've drawn inspiration from a strong local infrastructure for community-based participatory research (CBPR), such as long-term public health collaborations (Gust and Jordan, 2010; Jordan and Gust, 2010; SoLaHmo Partnership for Health and Wellness and University of Minnesota Program in Health Disparities Research Advisory Board, 2017), the University of Minnesota Center for Urban and Regional Affairs research model (Anderson, n.d), and food systems collaborations (Miller, 2012; Goellner, 2013; Ramer et al., 2016; Charles, 2018).

While PAR and CBPR are similar, these CBPR programs have a stronger focus on racial equity, reparative practice, and linking research outcomes with organizing for change. Most models also explicitly call for research that builds on community strengths (Israel et al., 2008; SoLaHmo Partnership for Health and Wellness and University of Minnesota Program in Health Disparities Research Advisory Board, 2017), which reflects calls in MSP for research that is grounded in community assets (McKnight Foundation, 2011). More recently, community organizing literature has articulated this call as working from a lens of abundance—the idea that we, together (growers, organizers, researchers, policymakers, artists, and others), already have the necessary skills and resources to actualize transformative visions (brown, 2017). Participatory research frameworks that integrate agroecological science, participatory process, reparative practice, and collective action are still being developed. Thus, through our participatory urban agroecology research program, we seek to create such a framework. PAR in rural and urban agroecology, CBPR, and our mentors in community organizing have shaped the overall goals of our community-university partnership to (1) integrate grower knowledge and experiences throughout the research process and (2) deepen relationships between community and university partners in order to support community-led transformation of urban food systems.

It is necessary, however, to create space to evaluate whether the *intentions* of our goals align with *implementation* and *impact*. As Arnold and Siegner (2021) write, idealizing "community-academia relationships creates an environment where UAE [urban agroecology] researchers can fail to assess processes and outcomes, creating space for negative externalities in the form of extracted knowledge and labor from at-risk communities." Thus, in Fall 2019, we undertook a participatory evaluation process to identify strengths and opportunities for improvement in our program. Our objectives were to:

- determine to what degree participatory research processes facilitated authentic collaboration between researchers and community partners, and
- understand the role of relationships between researchers, partners, and students in those processes and how relationships were formed.

The results of qualitative surveys and interviews conducted with researchers, community partners, and students illuminated that a unique role of urban agroecology research programs is to facilitate shared learning, which is seen as a key part of collective, transformative action. In other words, the broader purpose of principles like iteration, shared power, mutual benefits, and relationships were to support learning communities, which requires a framework beyond participatory principles alone. We use the themes identified in our responses to propose a "learning framework" for community-university partnerships to facilitate spaces of urban agroecology, which we hope will be a valuable tool for other researchers and communities.

URBAN AGROECOLOGY RESEARCH IN MINNEAPOLIS/ST. PAUL

In Fall 2019, we conducted this evaluation of our community-university research participatory processes at the midpoint of a broader program exploring how management practices used in urban farms and gardens impact a holistic set of ecosystem services, including food production, water quality, soil health, biodiversity, and socio-cultural benefits (Nicklay et al., 2019). We trace the origins of our partnership to 2015, when two projects—one researcher-initiated, the other community-initiated—converged to explore the co-benefits of urban food production. In this section, we provide an overview of how participatory processes evolved in our partnerships.

The researcher-initiated project (**Figure 1**) grew out of a food systems summit sponsored by the University of Minnesota, where Mary Rogers (a co-author of this paper) proposed that an ecosystem service framework could make the social, cultural, and environmental impacts of urban food production legible for a wide variety of stakeholders (Camps-Calvet et al., 2016). Project activities focused both on building relationships and exploring how growers, community organizers, researchers, extension educators, and policymakers conceptualized the multiple benefits and challenges of urban food production. This project largely focused on "pre-flection" —conversations with communities before research starts (Méndez et al., 2017). However, many of the engagement activities, such as a public art installation where residents could bring soil for lead testing, also represented concrete actions to address community-identified needs.

At the same time, a local farm advocacy non-profit approached Nic Jelinski and the Jelinski lab researcher Kat LaBine (both co-authors of this paper) to conduct a pilot study investigating urban food production as a potential green infrastructure strategy; this research need was identified by the non-profit through listening sessions with over 50 growers. The non-profit mediated all communications between the researchers and growers, which helped initiate connections to establish on-farm field plots. However, this also placed a large labor burden on that non-profit, limited relationship building between researchers and growers, and resulted in misunderstandings regarding data collection requirements and logistics as the season progressed. While collaborators identified these communication concerns, growers still felt the study activities fulfilled their research needs.

Though initiated separately, the researcher- and community-initiated projects involved many of the same practitioners, organizations, and researchers (**Figure 1**), who together marked the end of both projects by hosting the Twin Cities Urban Agriculture Research Workshop in October 2016. About 70 growers, organizers, policy makers, and researchers attended the workshop to share knowledge and facilitate reflection on the projects' activities through presentations, breakout sessions, and networking time (Frank et al., 2017). There was a great deal of energy around the pilot study results from the community-initiated project, so five researchers and three community partners decided to continue the community-university partnership. New partners, who connected with the project through engagement activities, also joined; for example, Jennifer (the lead author of this paper) attended the Workshop as a community garden coordinator and later joined as a graduate student researcher.

Together, this group designed a 3 year, on-farm project to explore how urban food production practices impact a holistic set of ecosystem services; the group also helped inform a 5 year off-farm study led by Gaston "Chip" Small (a co-author on this paper), which had more space and time to explore additional management practices. The goals of these projects were to integrate grower knowledge with on- and off-farm research to create tools/guidance for growers implementing management practices and policy resources for local non-profits and governments. During this moment of transition and project design, researchers and partners also reflected on the 2016 projects and identified necessary changes to participatory processes.

To create a structure that supported shared power, we shifted from what Quick and Feldman (2011) describe as high participation to high inclusion. While the engagement activities in the researcher-initiated project created space for *a large number of participants*, the smaller group in the community-initiated project facilitated *greater inclusion of partners* in the decision-making process. Importantly, researchers and partners remain accountable to the large network of organizations and practitioners who shaped this work because we often check-in with those wider networks at meetings, events, and through personal communication.

This structural shift was paired with new internal communication processes, including a yearly "All Hands" meeting for all project researchers and partners to participate in planning, methods design, and analysis. This structure would also provide ongoing space to identify and integrate relevant benefits for all partners. To create a strong foundation for mutual benefits, financial compensation for community partners was increased and researchers committed to hiring undergraduate research assistants to train in community-engaged scholarship—and plan for about ¼ of undergraduate time to support partner operations via contributed labor.

To facilitate stronger relationships, we built on strategies developed in the researcher-led project, where direct communication between researchers and growers, conversation groups, and participation in community events had created strong relationships. Though participants acknowledged the logistical benefit of a communication mediator (such as the non-profit in the community-initiated project), it precluded the relationship building necessary to build trust between participants in different roles.

These processes have guided our work over the last 3 years, but continual reflection and evaluation are necessary to ensure that processes are effective, relevant, and inclusive. Thus, in Fall 2019, we undertook a participatory evaluation to determine how these processes had facilitated or impeded genuine collaboration in our community-university urban agroecology partnership. The goal of this evaluation was to identify strengths and opportunities for growth that could be built on during the 2020 field season and used as a foundation for future projects.

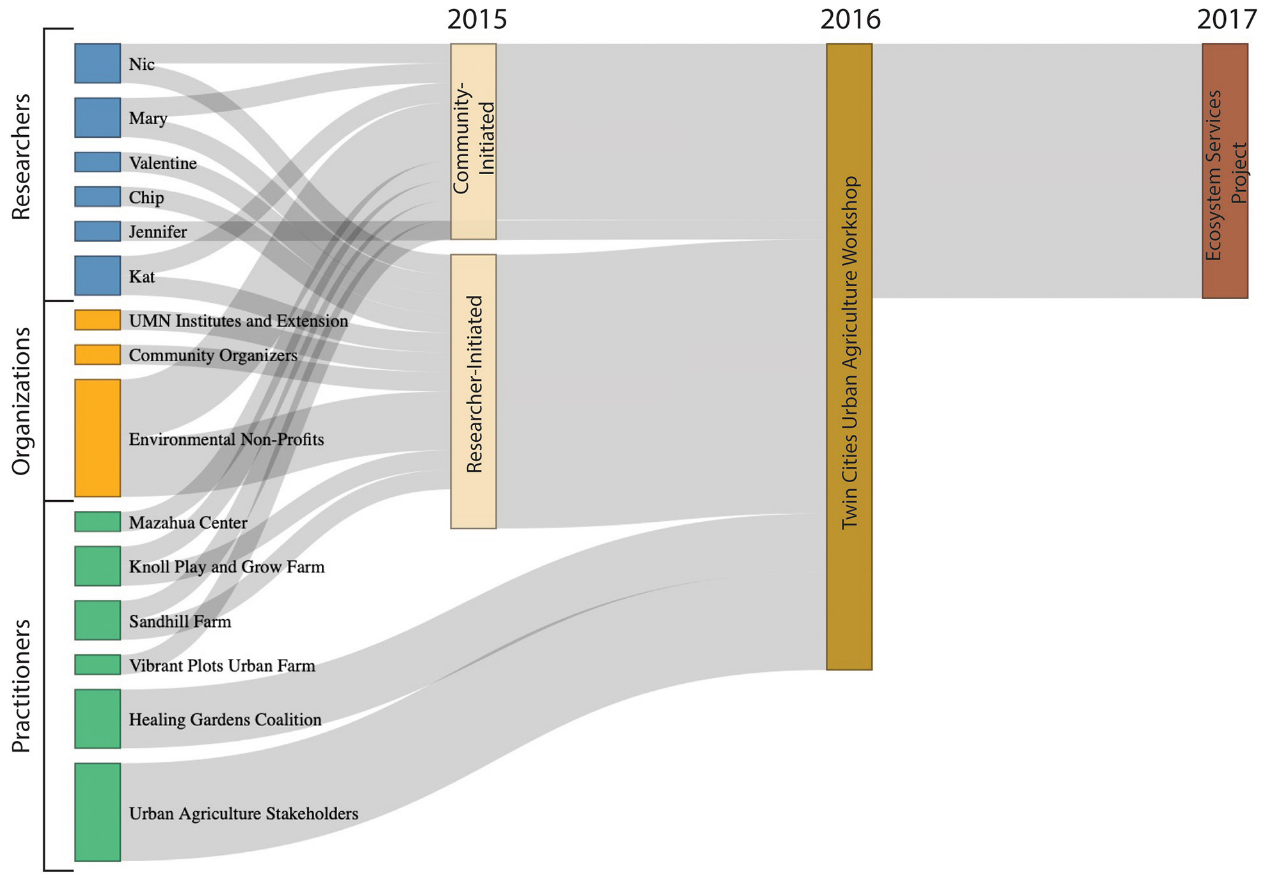

FIGURE 1 | MSP Urban Agroecology Community-University Partnership Development. The progression of our research program from the initial conversations and pilot studies in 2015 to the start of the current projects in 2017. At the University of Minnesota Convergence Colloquium on Sustainable Foods in 2015, a group of 20 researchers, organizers, and practitioners connected and pursued a 1 year, researcher-initiated project to host conversations and engagement activities around the ecosystem services of urban farms and gardens. At the same time, a community-initiated project convened three researchers, several non-profits, and four growers to do an on-farm pilot study exploring the potential for urban food production as a green infrastructure strategy. The projects converged by collaboratively hosting the Urban Agriculture Research Workshop, which was attended by over 70 urban growers, organizers, policymakers, and researchers. Some attending this workshop would eventually join the ecosystem services project. After the workshop, some partners from the community- and researcher-initiated projects left to pursue other priorities or other participatory projects, and a smaller group continued working together for the current ecosystem services research.

METHODS

At the end of 2019, we developed and administered an open-ended survey to evaluate our participatory processes, understand relationships within those processes, and articulate the community-university research framework emerging from this work. Researchers led question development, drawing on evaluation examples from prior participatory and community engagement scholarship, both locally (Gust and Jordan, 2006; Union of Concerned Scientists, 2015; Frank et al., 2017; Livstrom et al., 2018) and nationally (Pain et al., 2011). All partners and students were invited to review/edit the draft questions and create additional ones if an important area was overlooked. Ultimately, fifteen question surveys were developed for researchers, community partners, and students (**Table 1**). Respondents were asked to choose their main role, though many hold multiple roles in the wider urban agroecology network. Ten questions were the same across all roles; these questions explored relationship building, learning, and the benefits/challenges of community-university partnerships. The remaining five questions were role-specific, focusing on how individuals in different roles experienced shared power and mutual benefit processes. The survey was considered "exempt" by the Hamline University Institutional Review Board.

The survey was distributed to all current members of the urban agroecology community-university research program. Six researchers, seven community partners, and eight students completed the survey (**Table 2**)—a 91% response rate. The survey was administered online to researchers and students using Qualtrics^{xm}. Community partners could choose the survey delivery format: two individuals completed the survey online, two in one-on-one interviews, and three as a focus group. Interviews and the focus group were audio recorded for transcription. While multiple delivery methods can complicate analysis, providing community partners with the agency to choose how to conduct this evaluation was one way the researchers demonstrated respect for their time and experiences.

TABLE 1 | Evaluation Survey Questions.

Everyone		
Describe our collaborative urban agriculture project in 2–3 sentences.		
What are/were your goals for participating in this project?		
What is/was your role in this collaborative project? *Community Partner, Researcher, Student*		
Who are the other collaborators you interacted with most for this project? *This could include people who are researchers, students, and/or community members. If you've interacted a lot with more than one person, feel free to include multiple names!*		
What experiences, practices, or processes helped you build and maintain relationships with those collaborators?		
Community partners	**Researchers**	**Students**
What processes and/or products have been useful to you? *Some examples of processes could be emails, in-person conversations, yearly meetings, etc. Some examples of products could be nutrient test results, signing letters of support, or other actions*	What is community-engaged research to you? Why is it important?	What is your major and current year in school?
Have researchers and/or students shown up with your community in meaningful ways? Yes/No If Yes: Please share what that looked or felt like when researcher and/or students showed up with your community If No: Please share your vision for how researchers and/or student could meaningfully show up with your community in the future	What are the benefits and challenges of community-engaged research?	When did you work with this collaborative project? Please include start and end dates (month/year), if applicable
How have you participated in decision making? *This could include things like helping with the original grant, deciding where to locate the plots, etc.*	In what ways does your institution support this work? What could your institution do to better support your community-engaged work? *For example, consideration in P&T, capacity to use research funding for teaching releases, student support, administrative support, funds, recognition, etc.*	Prior to working on this project, did you have experience with service learning or community-engaged work? Yes/No If Yes: Please briefly describe your prior service learning or community-engaged work experiences
What communication strategies have you found most valuable? Is there anything you wish could be done differently?	How does community-engaged research contribute to your scholarship, teaching, or service responsibilities?	How did your participation in the collaborative urban agriculture project shape your understanding of community-engaged research?
When have you felt heard/seen? When have you felt dismissed/uncomfortable?	How does community-engaged research contribute to your mental health, well-being, or sense of purpose?	How does community-engaged research contribute to your undergraduate experience?
Everyone		
What is the value of approaching urban agriculture research through community-engaged research, from your perspective? *In answering this question, some things to keep in mind are: what values are embedded, lived, and communicated in this collaboration? what are the benefits and challenges of partnering with academic institutions? what are the benefits and challenges of partnering with other growers/organizations?*		
How has your understanding of urban agriculture changed as a result of this collaborative project?		
What other things have you discovered, learned, or experienced that you want to share? *We welcome any and all responses, and we are particularly interested in how urban agriculture and ecosystem functions can reinforce or address systems of power and privilege/racism/etc.*		
When we wrap this iteration of our collaborative work in Fall 2020, what are some things we should consider in the project evaluation and reflection?		
Who are the individuals, organizations, or communities that should be invited into this work in the future?		

Fifteen-question surveys were developed for partners, researchers, and students. Questions are listed in the same order they were presented to participants. Ten questions were the same across all roles (labeled as "everyone"). The remaining five questions were role-specific. Text in italics that follows questions is explanatory information that was provided to participants.

Inductive coding was used to analyze responses (Christians and Carey, 1989; Lofland et al., 2006). Codes and emergent themes were then compared to existing codebooks, field notes, and participant observations created by Valentine[1] based on her long-term work in the Twin Cities (Cadieux et al., 2013); coding schemes were used to identify key community-university research framework components in the analysis phase. Survey results and the "learning framework" were shared with all research group members at the "All Hands" annual project meeting in early 2020, and their feedback was used to refine the framework and analysis. Researchers conducted evaluation analysis alongside and in communication with

[1]While using titles and last names are conventional in most academic writing, we use first names throughout this paper to reflect how our group interacts with each other.

TABLE 2 | Fall 2019 Evaluation Respondents.

Names	Identities	Organization	Description
COMMUNITY PARTNERS			
Fannie*	Female, Black	Knoll Play and Grow Farm* St. Paul	Farmer. Knoll Farm is a non-profit farm located in neighborhoods with Hmong, East African, and Black communities. They focus on youth education and community building; produce is sold at markets and taken to the weekly neighborhood food shelf
Lily*	Female, White, community elder	Healing Gardens Coalition* St. Paul	Lily and Joshua are co-organizers of the Coalition, and Benny is the coordinator for a community garden in the Coalition. The Coalition has member gardens throughout a predominantly Black neighborhood. The Coalition sees connection with land as a way to heal intergenerational trauma and growing food as a way to heal physical health while building community wealth
Joshua*	Male, Black, community elder		
Benny*	Male, Black, community elder		
Pepe*	Male, White	Mazahua Center* Minneapolis	Pepe is the Food Systems Manager and Amanda is the Farmer. Mazahua is a non-profit located in one of the most diverse neighborhoods in Minnesota, with particularly large Indigenous and Central/South American immigrant communities. Their urban agriculture program focuses on food production, youth education, intergenerational learning/healing, and land access. Food supports their community food shelf and kitchen
Amanda*	Female, White		
Caitlin*	Female, White	Sandhill Farm* Minneapolis	Farmer. Sandhill Farm is a for-profit business that farms several vacant lots and former parking lots. They primarily sell at farmers markets and through a Community Supported Agriculture program
RESEARCHERS			
Jennifer Nicklay	Female, White, Queer	University of Minnesota	Non-faculty researcher: graduate student. Focus: agroecology, political ecology, and soil science
K. Valentine Cadieux	Female, White, Mixed ancestry	Hamline University	Faculty researcher. Focus: geography, political ecology, food systems, and sustainability
Mary Rogers	Female, White	University of Minnesota	Faculty researcher. Focus: entomology, plant science, and horticulture
Nic Jelinski	Male, White, Hispanic	University of Minnesota	Faculty researcher. Focus: soil science and urban systems
Kat LaBine	Female, White, Dakota	University of Minnesota	Non-faculty researcher: Jelinski Lab Manager. Focus: soil science
Chip Small	Male, White	University of St. Thomas	Faculty researcher. Focus: nutrient cycling and hydrology
UNDERGRADUATE STUDENTS			
Karl	Male, White, Cis/heterosexual	University of St. Thomas	May 2018–present. Biology major.
Matt	Male, White	University of Minnesota	May 2018–May 2019. Environmental Science, Policy, and Management major
Naomy	Female, Latina	University of Puerto Rico	June–August 2018. Sustainable Agriculture major
Tulsi	Female, Asian, Queer	Macalester College	June–August 2018. Knoll Farm Intern in 2019. Environmental Studies major, Food, Agriculture, and Society concentration
Dania	Female, Mexican-American	University of Minnesota	May–December 2019. Environmental Justice Studies and Landscape Design/Planning major
Madison	Female, White	University of St. Thomas	May–August 2019. Biology major
Tanner	Male, White, Queer	University of Minnesota	May 2019–March 2020. Former Sandhill Farm intern. Global Studies B.A. (2013), returning to complete requirements for plant science graduate program
Yashira	Female, Hispanic	University of Puerto Rico	June–August 2019. Sustainable agriculture major

At the request of respondents, individual/organization names have been changed for all community partners (marked with an asterisk); most partners chose their own pseudonyms. Student last names have also been omitted. Participant identities were chosen by each individual in relation to ongoing discussions and topics in the survey responses.

partners throughout the writing process, though partners chose not to be listed as authors.

All statistical and diagrammatic analyses were performed in R (version 3.5.2, R Core Team, 2018). The project development visualization (**Figure 1**) was constructed using the networkD3 package and network diagrams to visualize relationships (**Figure 5**) were constructed using the iGraph package.

RESULTS

The objectives of our Fall 2019 participatory evaluation were to determine to what degree the participatory processes in our urban agroecology research program facilitated authentic collaboration and the role of relationships between researchers, partners, and students in those processes. Inductive coding identified four broad themes in the evaluation responses (**Figure 2**). *Participatory processes* and *relationships*, the main foci of our objectives, represented "how" we work together and "who" is in relationship with each other. In addition to these themes, respondents highlighted that *shared learning* was "why" they participated in a community-university partnership and named the ways in which the *social and environmental systems* in which we work impacts "what" we do in the other themes. These themes—and their relationship to who, how, why, and what—build on previous research on urban food justice movements in MSP conducted by Cadieux et al. (2013). Findings for each of these four themes are discussed in this section. We then synthesize trends across themes in the next section to articulate the approach that has emerged from our partnership and propose a framework for future urban agroecology research that facilitates transformative learning.

Participatory Processes

Shared Power

Many partners affirmed that they felt their expertise and knowledge were valued throughout the research process; for example, Caitlin, a farmer with Sandhill Farm, said, "I feel like the entire project was set up based on our consent and insight" (**Figure 3**). Responses identified that weekly informal meetings between non-faculty researchers, partners, and students during the summer; yearly "All-Hands" Meetings with all program members; and regular email, text, and phone conversations during the rest of the year were all important strategies for shared decision making. Researchers, in turn, expressed commitment to "co-develop" and "co-own" research with partners, including generating objectives, choosing methods, and analyzing and making meaning from the data. Students' observations supported the importance of shared decision making; for example, Matt, who worked with us for a full year, said, "What I learned through this work alongside community partners is that a collaborative approach is absolutely crucial for strong and respectful relationships that are intended to benefit all parties involved."

Reciprocity and Mutual Benefits

Shared decision making helped identify relevant benefits for group members. Partners highlighted the benefit of ongoing capacity building, especially soil testing and interpretation that they used to inform farm management practices and address soil contamination concerns. Three partners also highlighted that financial resources, such as stipends, were so vital that they should be expanded. Fannie, a Black female farmer for Knoll Farm, shared,

> There have been bits and pieces of conversations that I've heard about how the U has all this funding and … nonprofit organizations have none, and then Nic has mentioned several times creating ways to partner and collaborate and share, let's not call it funding, let's say resources. So, I've just become more aware of how you guys...are, and could be, a really valuable resource to all us nonprofits or community organizations.

This quote highlights two important community perceptions of the University of Minnesota: that it has significant financial resources and that communities whose residents identify as Black, Indigenous, or People of Color (BIPOC) have been systematically excluded from receiving financial support from them. As undergraduate student Karl articulated, our partnership must "reconcile with academic exploitation of some communities we work with," past and ongoing.

While financial compensation is irreplaceable, non-monetary resources can also be important benefits. Partners highlighted that shared labor was a valuable benefit; undergraduate research assistants are paid to work with each of the partners for a full day every week of the growing season. Students identified this time as a benefit as well. Dania, an undergraduate student who had been involved in urban garden and farm organizing prior to joining our project, expressed, "I had some connection to each of these partners before this project but not much understanding—now, I know more about each project and their efforts, and I appreciate this."

Students also highlighted that participatory research allowed them to integrate their work, relationships, and values. Dania and Tulsi—both of whom are women of color—shared that they hadn't been interested in research before finding a project that reflected their values. Tulsi expanded on this, sharing the impact on her career goals:

> Seeing my own values prioritized gives me more hope for the future of academic research. . . . I want to see a shift toward more interdisciplinary research that calls for input from academics of different backgrounds, community members... more voices at the table. I want to continue to explore where these bridges are being built.

Researchers expressed that academia can feel very dehumanizing, but their participatory work restores that humanity. Chip, a hydrologist/biologist at the University of St. Thomas, shared "I was intentional about shifting my research into issues of relevance to our community" because of the sense of purpose it provided.

Challenges of Inclusive Participatory Processes

The participatory processes in our urban agroecology research program, though, were not without challenges. As Nic stated, "university-community collaborations and community engaged-work is always a challenge because it is by nature asymmetrical." These asymmetries are visible in many ways, including funding allocation discussed previously, perceived legitimacy of different knowledge (discussed in more depth in the Social and Environmental Systems section), and as Fannie named, in the identities of those in different roles:

> there's this inclusivity problem within agriculture, in general, so of course, it's going to happen with agriculture at the academic level. So, it's kind of like, okay, these are the scientists, or the people with the knowledge, and they often times look a certain way. And then here are the farm workers, or the laborers, and they often times look a very—certain way, yeah...So it's just like, there's those unspoken conversations can be had.

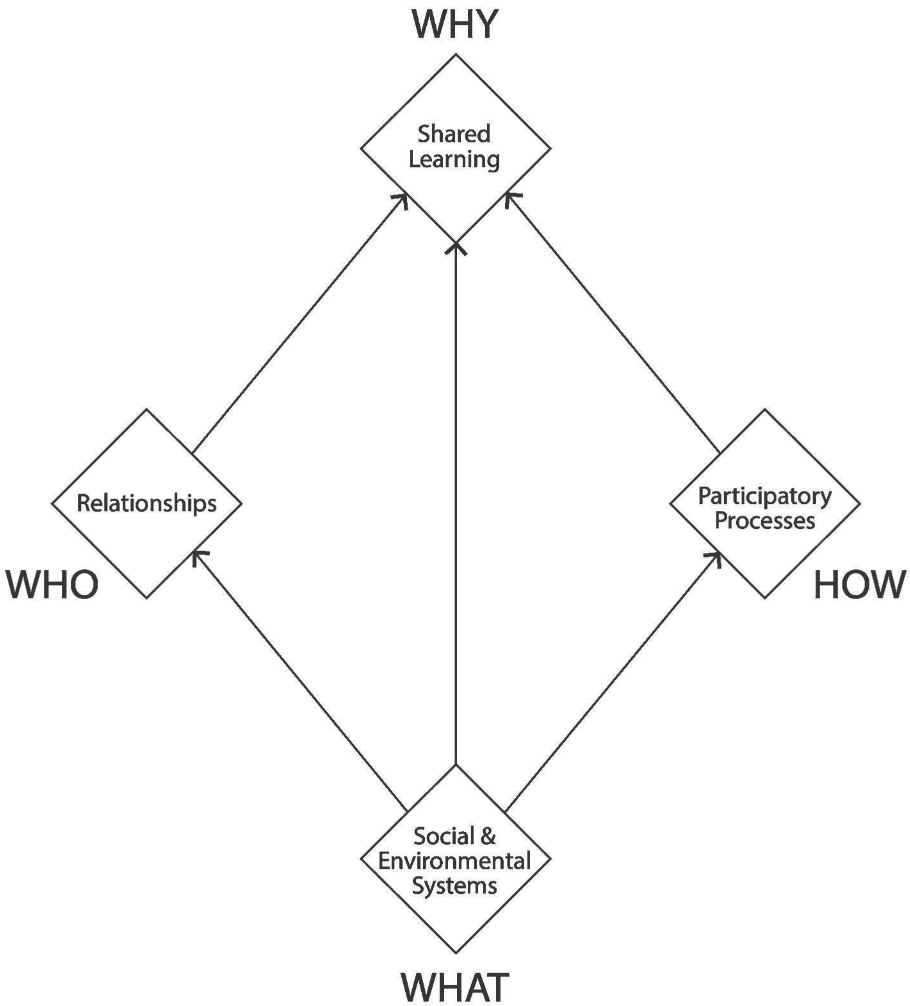

FIGURE 2 | Visualization of coded themes from evaluation responses. Inductive coding elucidated four main themes from the surveys: social and environmental systems, relationships, participatory processes, and shared learning. The content of these themes corresponded to "what," "who," "how," and "why" themes in code books previously developed by Cadieux et al. (2013).

Most researchers are white in this project, and though concerted efforts are made to create a generative space for students (and non-faculty researchers) with identities that are marginalized in science (and society more broadly), the asymmetrical power of universities and communities is still felt and present—even in the bodies of those participating. Kat shared it is often challenging to balance her identities with her role as part of the University; "some days the work may be hard because my brain has to think in many ways and I have to remember my representation." As a Dakota woman who is white-presenting, Kat has to exert mental and emotional energy to balance the privilege/power of her role in the University with the ways in which her Dakota identity is not seen (or dismissed) by academia and the communities in which we work. Thus, we see ways in which participatory research still grapples with institutionalized racism/colonialism.

Several partner responses, in critiquing the survey's reliance on the term "collaboration," also invited our group into a more nuanced understanding of project members' roles and responsibilities during different stages of the research. While partners helped design the on-farm study, research processes during this study were not always flexible enough to incorporate new directions they took. For example, while collards were chosen as the research crop through shared decision making (**Figure 3**), the meaning of collards has shifted for partners from a crop that would provide food in their communities to a broader symbol. Sandhill Farm has used the insect damage on some of the research collards to spark conversations with their CSA members around why eating "ugly produce" is good for the environment. For the Coalition, which is based in a vibrant Black neighborhood that has experienced repeated institutionalized wealth theft, the collards have transformed into a conversation about building community wealth. Without a space to rearticulate project goals,

FIGURE 3 | Co-developing research methods—Origins of "The Collard Crew." Photo credit: Stacy Nordstrom. Pictured (from left to right): Tanner, Kat, Dania, and Madison. Researchers and partners often referenced that an important example of the participatory research process was how we chose the crop for the current ecosystem services project. The pilot study had grown kale—but no one was very excited about having that much kale for 3 years. Over the winter prior to the first field season for this project, Jennifer had one-on-one conversations with each grower about what crops worked best for their goals and, during the yearly "All-Hands" Meeting with all partners and researchers, we used consensus decision making to ultimately choose collard greens. This choice not only better reflects neighborhood and community preferences but also represents a significant research gap; despite the importance of collard greens to Black communities, especially diaspora communities formed during the Great Migration, there is limited representation of this crop in scientific research. Finally, growers expressed appreciation that researchers asked for their expertise in how to harvest, wash, and package the greens to meet their specific sale/distribution needs.

the research process has not been agile enough to incorporate support for these important partner interests.

One reason for this limited adaptability may be that partners who were involved at the beginning of the project (Fall 2017) felt more integrated into the participatory processes than those who joined later, which meant their goals were not integrated effectively. While the *organizations* involved in our group have been consistent since 2016, the *specific people* have changed frequently (**Figure 4**). At the time of the evaluation in Fall 2019, two new growers had joined: Benny and Fannie. Benny, a coordinator for a community garden within the Coalition, joined in May 2018 when he agreed to host research plots, and Fannie joined in February 2019 when she was hired as the farmer for Knoll Farm. They had very different partnership experiences based on *how* they joined the project.

Connecting with the larger group of researchers and partners upon joining the program corresponded with stronger partnerships. Benny did not meet most project researchers or partners until spring 2020, and he felt disconnected from the project because researchers largely coordinated activities with the wider Coalition. As a result, Benny expressed *frustration*, saying "you're getting the space and there's nothing that allows us to reap the benefits other than your research at the end." Conversely, Fannie attended the All-Hands Meeting within 2 weeks of starting her position and noted the value of benefits like stipends, student labor, and outreach activities. While she felt there was room for improvement regarding her power in decision making, she was *excited* about the prospect of designing partnership goals, research questions, and community connections. Thus, the relationships with other research program members served as a vital support for participatory processes.

Relationships

Our evaluation found that relationships grounded in trust were a necessary foundation for enacting participatory processes. As Nic articulated:

> Community-engaged research to me really can be boiled down to one major core. Do researchers have strong interpersonal relationships with community members that go beyond interactions in the context of a project? Do we know each other, do we trust each other, do we eat together, just to listen and be people together? If so, then I think that goes a long way to sustainable community-engaged research.

To better understand relationships between researchers, partners, and students, we conducted a preliminary network analysis (**Figure 5**) based on relationships named by each respondent. This highlighted both the importance of individuals as key connectors and gaps in the relationship networks, while contextualizing relationship-building strategies and opportunities.

Several researchers served as key connectors. Nic, the principal investigator, is an important connector between

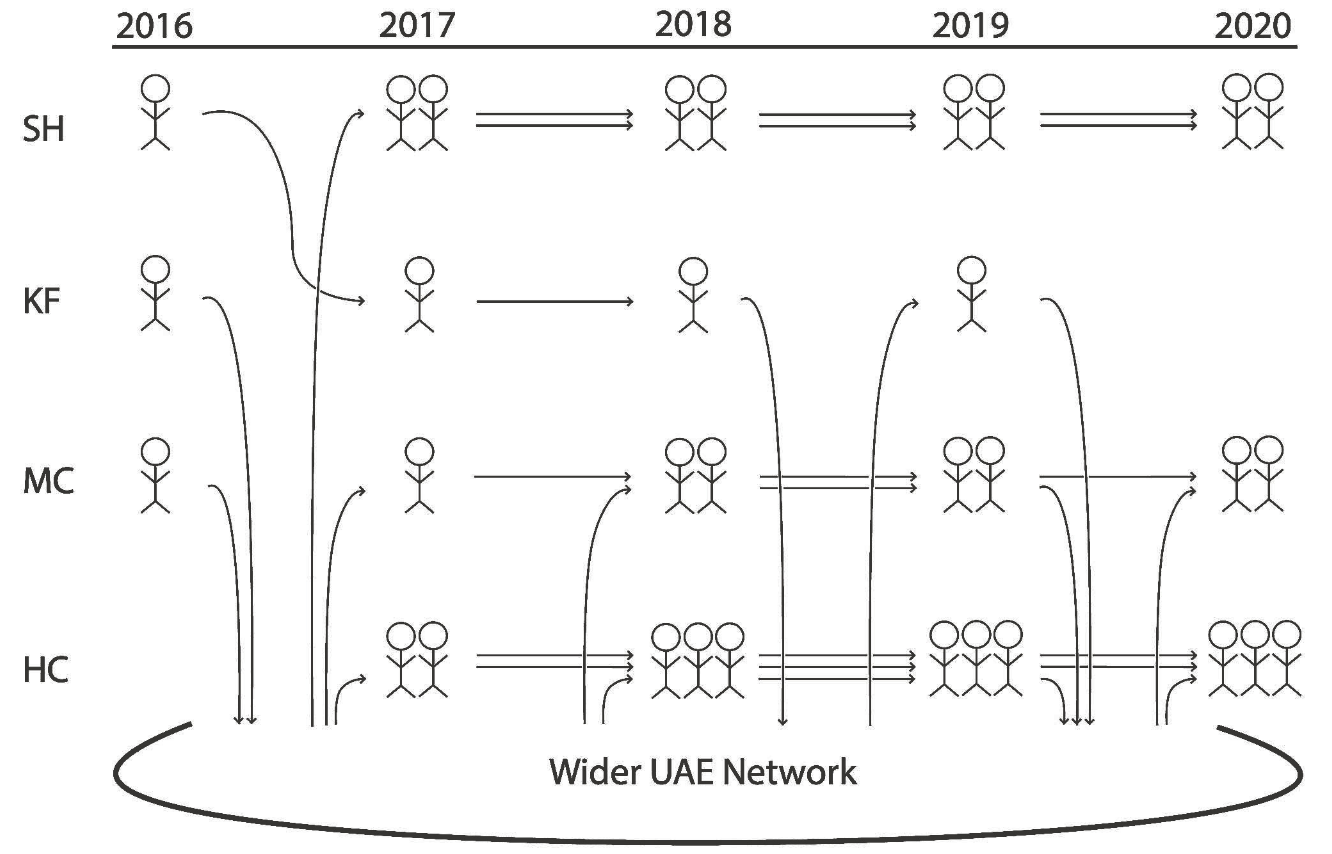

FIGURE 4 | Community Partner Transitions. This figure depicts some of the transitions our current partners have experienced. We show growers/coordinators joining from and leaving to the wider urban agroecology (UAE) network because, like the many additional partners from the 2016 projects, we as researchers and community partners retain connections and communication with former project members. Between 2016 and 2017, we see that each partner experienced a grower transition or newly joined as a partner, in the case of the Healing Garden Coalition (HC); this season also marked the end of the 2016 community- and researcher-initiated projects and the start of the current ecosystem services exploration in late 2017. The farmers at Sandhill Farm (SH) have remained the same during the current project, but the farmer at Knoll Farm (KF) has changed nearly every year. Growers and coordinators have transitioned in and out of both Mazahua Center (MC) and HC, but continuity and institutional memory has largely been maintained because at least one individual at each organization has remained. Finally, it's important to note that during spring 2020—concurrent with the COVID-19 pandemic—three of our four partners experienced significant transitions.

the faculty researchers and community partners. Non-faculty researchers—Kat and Jennifer—are clearly at the center of the network, though, with connections to every researcher, partner, and student. This reflects Kat and Jennifer's role in mediating shared decision making; they checked in with partners every week during the field season and maintained regular communication during the winter. Holding space for so many relationships, however, can also be a challenge; as Jennifer shared, while

> I love what I do everyday – literally – I feel like I'm somehow failing at something most days. Some of that comes from trying to put in the time necessary to do community engaged work.... [especially] figuring out how to build relationships in different ways with different community partners.

Despite Jennifer's concerns, most partners described close relationships with Jennifer, Kat, and Nic. For example, Amanda, the farmer at Mazahua Center, reflected that "Their positive and fun energy is always so amazing to be around," and Caitlin shared that their support "helped me open up to feeling confident about grant writing and asking for funding for a big project!"

However, partners also expressed that they generally didn't know the other researchers or partners (**Figure 5A**). Several partners noted that the existing communication strategies were mediated by the researchers, but they wanted a space or more regular meetings to communicate, build relationships, and share experiences with other growers and to connect with researchers. Other than the yearly "All Hands" meeting, there were no formal opportunities for partners to interact with each other within the project, and other researchers were often only able to attend occasional community events. For example, Mary, a horticultural researcher, noted that she has "multiple responsibilities in the summer months (teaching, research, administrative) and it is very difficult to be regularly present at the research sites. I try to come at least once." The network analysis demonstrates that the All-Hands meeting and community event participation were not enough to

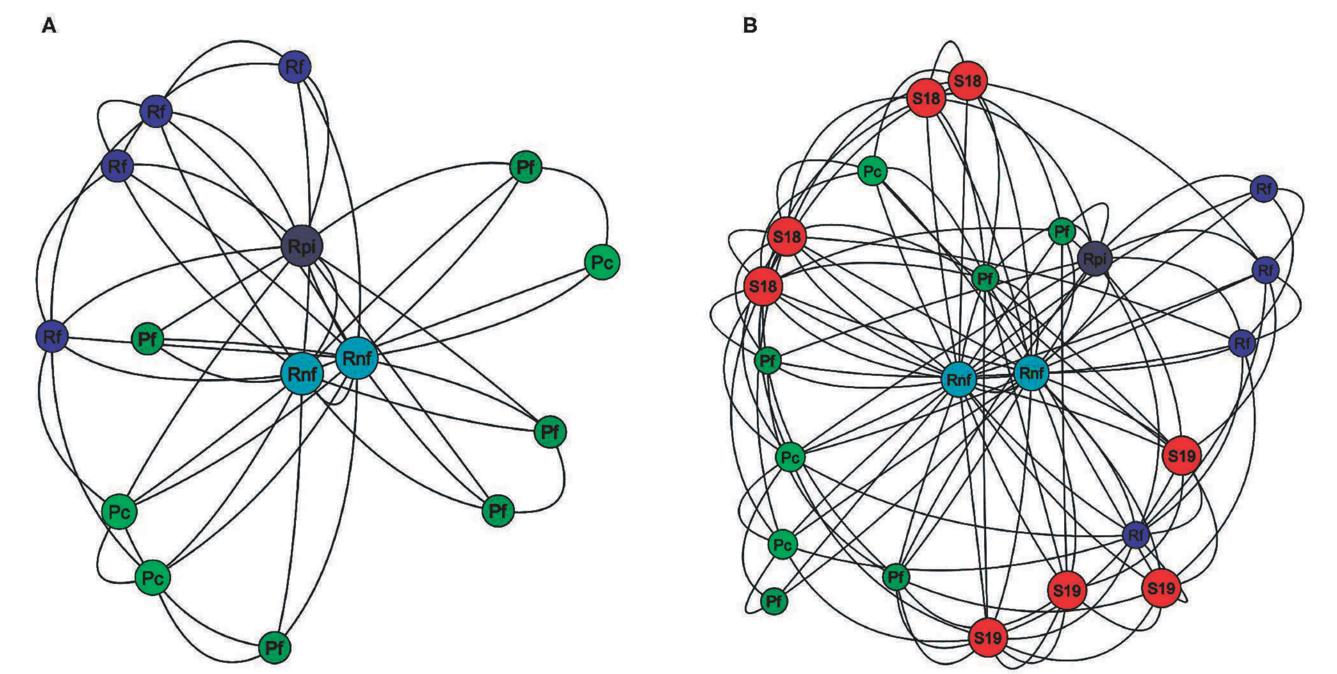

FIGURE 5 | Network analysis. All participants were asked the people with whom they interacted with most during the current project. **(A)** Researchers and partners only. Non-faculty researchers (light blue, R_{nf}) Kat and Jennifer represent central nodes in the network with connections to all program participants. Faculty researchers (dark blue, R_f) have formed a cluster, with Nic, the principal investigator (dark blue, R_{pi}) connecting them to partners. Partner farmers (dark green, P_f) and coordinators (light green, P_c) cluster close to others from their organization but are not connected to other partners. **(B)** Researchers, partners, and students. Students (orange) are pivotal in creating interconnections between participants in different roles. Students also form clusters based on the year they were employed-–2018 (S18) or 2019 (S19).

build strong relationships between researchers and individual partners, but responses highlight that they did help integrate researchers into communities more broadly. As Caitlin shared, "We see each other at community meals, fundraising events, educational events and such. They are definitely a part of the community!"

Students, who spent a significant amount of time with community partners each summer, demonstrated some of the ways that regular interactions helped build interconnected relationships (**Figure 5B**). Each week, students spent a full day embedded with a partner, in addition to attending community meetings and events, and students and partners both identified that eating and working in the field together were important relationship-building activities. As Pepe, the Food Systems Manager at Mazahua Center, commented, "it's always nice when other people are on their hands and knees weeding and harvesting, and you have that shared labor of love." However, the limited tenure of most students with the project (sometimes as little as 2 months) did pose challenges. Some community partners expressed that they "need a seating chart" to keep up with the students, while others regretted that they didn't get to say goodbye and share their appreciation with students before they left. Some students also expressed that their relationships felt unresolved because their community involvement suddenly ceased when they left the project or transitioned to fall lab work; others did not experience this because they decided to continue as community volunteers past their period of employment.

Shared Learning

While our evaluation objectives were to understand participatory processes and relationship development in facilitating collaboration, the responses also highlighted why program members valued this type of research: the opportunity for shared learning. Reciprocity created space to learn from each other. Pepe shared that inviting researchers and students to the daily free community lunch was an act of reciprocity for the research activities; "I love seeing everyone up there even when I wasn't a part of it, that Mazahua Center could give something back to y'all. That's really important to me; reciprocity is important." Across roles, project members also described the importance of humility; as undergraduate student Madison articulated, "keeping an open mind and being respectful are necessary to learn from others." Joshua, a co-coordinator for the Coalition, built on this, noting that he appreciated interacting with students because of:

> their presence and their presence to stretch. For me, when I use the term stretch is to stretch to listen at meetings and be willing to share. I think about a couple of [community] meetings, I would call one of them out and it's like a deer in the headlights, but then

> they would speak. And for me it's good learning, so they became good teachers.

Together, reciprocity and humility allowed our partnership to value the strengths and skills project members contributed to learn from each other.

Building on the previous discussion of benefits, one reason growers partnered with the university was to learn how research findings could inform their practices. Partners were excited about data and results—such as soil nutrient and temperature data—and unanimously voiced that, as Caitlin exclaimed, they "want to explore the ecological benefits of urban agriculture!" Researchers and partners were unsure, though, how best to integrate our complex data sets with grower knowledge and translate both into applicable tools and resources for farm management and policy advocacy. As Valentine—a food systems geographer and political ecologist—summarizes, "nutrient budgeting and other heuristics that seem like they could be so worthwhile in showing where urban ag fits into the landscape in an Ian McHarg-ian[2] way may actually be too complicated to be worth the effort." This was further complicated, Valentine articulated, by researchers trying to avoid imposing scientific ways of knowing on communities: "I think it partly might be that we...are a little too sensitive about taking up community time. So that when people are like, 'No we don't want to talk about the research results now,' [we respond,] Okay, we won't." Conversations during the evaluation, though, highlighted that partners valued researchers' skills and were invested in the project's scientific results.

Researchers also expressed that they were constantly learning from partners'. Kat noted, "There is no one way to do things...there are so many differences in each farm." Nic, similarly, shared, "the innovation that is the most fun, and the site and community specificity of urban agriculture...I have learned how much I really need to keep my eyes and ears open to continue learning." Furthermore, undergraduate students who joined our project wanted to learn how to interweave research and community. Dania, for example, wanted to "learn about how this research model collaborates with community partners to create reciprocal relationships," and Tanner explained that he learned "making connections with partners, attending events, and community engagement are just as much a part of this project as the data collection and analysis," which has inspired him to pursue participatory research in his graduate program.

In addition to learning between roles, group members also learn from others in the same role. These connections are seen in the network analysis (**Figure 5B**), where there are clear clusters for researchers and for students (in their respective field seasons)—which indicates the development of cohorts. Researchers noted that some of their longest professional relationships are with other researchers in this group, and we saw students each year support each other within and outside the project. Many partners and researchers wanted to strengthen these cohorts, especially among students. Hamline and the University of St. Thomas both have students working directly with this project, Bethel University has a strong partnership with our St. Paul partners, and several farms have summer student interns. Fannie, who mentored and managed Knoll Farm interns, wanted to begin the season with an intensive political agroecology education course and to take them on field trips throughout the season but hadn't had time to implement this yet. The evaluation helped us identify this as a future goal for our partnership.

Partners were also interested in having the opportunity to learn from each other, but there were limited connections between partners, as previously discussed in the Relationships section. Joshua expected to learn a lot more about the Minneapolis partners, and Pepe (one of those Minneapolis partners) said,

> I would love to see the other sites...I don't even know where, who, where are they at? I want to connect with the other people. We got the time and space, we're like involved in this research too. And by involved, I mean we're in it.

The opportunity to learn from other growers and organizers was considered a huge potential benefit, and partners named that they wanted to share skills (like soil building strategies), knowledge about grant funding, and experiences implementing programs. They also wanted to discuss larger socio-ecological topics, such as starting reparations, honoring elder knowledge, and the sacredness/love that's in their garden spaces. As Lily, a Coalition co-coordinator, noted, connections with other growers "expands the consciousness of what's going on in the field, the urban field."

Social and Environmental Systems

Finally, the processes, relationships, and learning highlighted were all, ultimately, interwoven with the urban field—the broader environmental and socio-political systems. Survey responses articulated that urban gardens and farms arose as an act of "innovation and creation on the land" to address unanswered community needs. It makes community care networks visible alongside institutional support; Pepe shared, "when we connect community members to community gardens, they don't visit the food shelf during growing months.... We see them start *donating* to the food shelf because they're growing from a place of abundance." These acts of creation were often done "as an act of resistance to institutional racism."

All partners shared that increasing gentrification and displacement are particularly important examples of institutional racism and are impacting their ability to secure long-term land access. For example, the Coalition's neighborhood experienced severe displacement as a result of freeway construction in the 1950's and ongoing "urban renewal." Benny noted that:

> a lot of our [church] members were, well, relocated off that strip.... And now the majority of our membership is living outside that

[2]Ian McHarg is an important figure in the history of community land use planning, known primarily through his 1969 book *Design With Nature*. McHarg's "ecology-first" perspective for planning shaped the early history of the Metropolitan Council, the regional planning body for the Twin Cities Metropolitan Area (Adkins et al., 2018). Thus, there is a precedent for an ecosystem-level approach to land use planning in our area.

> 2-mile radius. When you think of gardening, you have to have a real intent or a love for gardening if you live 2+ or even 3+ miles away.

Each partner also highlighted that when communities are *displaced from* a place, they are often *displaced to* more polluted areas as a result of racist housing and lending policies. Pepe explained that, "When a government entity finds polluted land, who do we put there? It's people of color and Natives, it's new immigrants and refugees, right? I mean, for me, that's the reason this area is one of the most diverse places in the entire state." Environmental injustices impacted our partners in many ways, including soil arsenic and lead contamination, proximity to active foundries and industry, and lots where buildings were folded into the soil during construction or redevelopment.

Some viewed partnering with the university as one strategy to build capacity in addressing these challenges. Caitlin noted that many of her potential customers think urban food is polluted, but "I just name drop the research project and the soil testing that's been available and then their opinion changes in favor of urban farming." Mazahua Center also noted that the community-university partnership helped them access financial resources and decision-making spaces because funders and policymakers took their work more seriously. It's important to note that the partners leveraging research in this way are both white; partners who are Black shared that they grappled with the perceived legitimacy of scientific research over the knowledge of farmers, elders, youth, women, and others with marginalized identities. The following exchange between two organizers (Joshua and Lily) and the community garden coordinator (Benny) during the Coalition focus group highlights this dynamic:

> Joshua: I don't like this part, that it's going to take research to validate good stuff; I'd rather for validation come from an elder or from somebody who does it already.
>
> Benny: You ARE an elder.
>
> Joshua: I'd rather it be validated by ME saying it.
>
> Lily: It is too bad that our elders don't have more influence and credibility. Because I was thinking that it really does legitimize urban farming and gardening when the university starts to study that, and that's just how our society looks at stuff.

Fannie affirmed this sentiment in saying "I think while university knowledge is much more valued in our society in general, it's important to have a program that can acknowledge both, a space for both." Therefore, it was clear from our responses that while leveraging university power could be valuable, this needed to be done in conjunction with dismantling perceptions of legitimacy perpetuated in U.S. institutions as part of systemic racism and colonialization. Ultimately, these commitments need to guide the research outcomes; as Caitlin expressed, "I want to use the data to steer urban agriculture in the most sustainable direction, and I also hope that the data can help urban ag become an integral part of our city!"

FACILITATING SPACES OF TRANSFORMATIVE LEARNING THROUGH URBAN AGROECOLOGY RESEARCH

Assessing Intent and Impact

When we embarked on this evaluation in Fall 2019, we sought to understand to what degree our participatory research processes facilitated authentic community-university collaboration and learning and the role of relationships in those processes. Our results illuminated and made visible that a framework—a way of being in community with each other—had emerged through our current practice (**Figure 2**): that community-university partnerships supported shared learning through relationships and participatory processes grounded in specific socio-ecological systems. We use "emerged" here in the spirit of systems theory (Meadows, 2008), adaptive cycling (Holling, 2005), and movement building principles (brown, 2017), all of which describe how properties and systems emerge from complex interactions between people, communities, institutions, and the more-than-human world. This emergent framework also revealed valuable nuance to our overall program goal of supporting community-led transformation in urban food systems: that shared learning was seen as necessary to achieve transformation.

Shared learning was a main reason all project members participated in urban agroecology research. Pepe expressed it best, sharing that other growers had knowledge that:

> I don't have from growing up on a farm, that Amanda doesn't have with her master's degree, sorry Nic, but with his PhD...you know a lot about one specific thing. But isn't that the beautiful concept...it's all of us working together to have the best results.

Understood in the context of the overall conversations—which focused on community benefits—our results support a belief in collective power articulated by Méndez et al. (2017) and echo recent scholarship that defines agroecology learning as "transformative in politics and practice. . . .as a strategy of social movement mobilization" for socio-ecological action (Anderson et al., 2019). This articulation of shared learning added important nuance to our understanding of the *intention* of urban agroecology research. Going into the evaluation, we focused on its role supporting community-led transformation of urban food systems, but it became clear from our results that the unique contribution of urban agroecology research in relation to community-led efforts was to *facilitate spaces of transformative learning*.

With a more nuanced understanding of the contribution of urban agroecology research, our results also highlighted ways in which the *implementation* of our research was both effectively facilitating and confounding the emergence of transformative shared learning. Our focus on relationships between individuals led to sharing *knowledge and skills*, a CBPR principle (Israel et al., 2008; Gust and Jordan, 2010); while this sometimes facilitated *individual* transformation, such as in Caitlin having confidence to write a large grant proposal for her farm or in student career decisions, it often failed to build the relationships required for the *collective* learning necessary for systemic transformation (Anderson et al., 2019). Our language to describe participatory processes also held vestiges of individualism. While researcher responses—and broader scholarship (Gust and Jordan, 2010; Méndez et al., 2017)—used "co-ownership" to describe community participation in the research process, partner responses continually redirected conversations toward community wealth and the tangible community benefits, such as the collard harvest or screening for heavy metals in soil. In these interactions, we saw broader trends of communities articulating stewardship and responsibility in ways that transcend ownership—because individual wealth and ownership models support existing systems of oppression and racism (Geisler and Daneker, 2000; Voller, 2018). Through this tension, it became clear that "co-creation" better rhetorically encompassed the intersection between agroecology principles (FAO, 2018) and communities centering collective interdependence (brown, 2017).

There were many disconnects between relationships and co-creation (participatory processes), which we can see visualized in the lack of direct connection between them in **Figure 2**. We lacked a regular space to share stories with and learn from each other about ourselves, the research, growing practices, program strategies, community histories, and more. As a result, there were missing relationships between researchers and growers and among growers, which prevented fully realizing the shared learning we saw in student and researcher cohorts. Without space to welcome new partners into relationships and co-creation, we missed opportunities to integrate their skills and goals into decision making. Therefore, our results demonstrated the need for a revised framework to connect relationships and co-creation to facilitate the emergence of transformative learning and socio-ecological change so that our impact matches our intent in future research.

A Proposed "Learning Framework" for Urban Agroecology Research

Recommendations about the larger research process that emerged from this evaluation are centered around the need for "embodied spaces" *through* which relationships and co-creation are connected to facilitate the emergence of transformative learning toward socio-ecological change (**Figure 6**). Having a "through" category builds on the previous framework developed by Cadieux et al. (2013), which contained an uncategorized theme describing tensions between rhetoric (intent) and action (impact) across organizations of differing political power. We see the main role of "embodied spaces" as a way to engage with similar tensions between learning about "what is" and to imagine and create "what can be" (Dendoncker et al., 2018), both in our research partnership and at larger socio-ecological scales. "Embodied spaces" —or the seeds of them—already existed in our partnerships through the All-Hands meeting; shared meals and work with partners, non-faculty researchers, and students; and co-leading tours of our study areas during community events (**Figure 7**). For "embodied spaces" to facilitate transformative learning, our results highlighted the importance of including embodied learning experiences and sharing rituals/ceremonies.

Embodied learning experiences seek to break down the boundaries between mind and body. In our results, student experiences sharing meals and working together in the field with partners showed us that physically being present in a space was important. Partner discussion of what they wanted to share with visitors highlighted how sharing practical/technical knowledge was as important as sharing goals for community change, including critical conversations of socio-political influences and impacts. Through these conversations, as Lily said, "you get to know people really in a deeper way." This type of learning values multiple types of knowledge, which Pepe, Fannie, and the Coalition all particularly highlighted. This operates from a fundamentally different perspective than the dominant model of extension agriculture education, in which knowledge transfers one way—from the university to growers (Warner, 2008).

Agroecology, as a field, already values this integration; horizontal learning is a central tenet of the transformative agroecology learning framework developed by Anderson et al. (2019). Much of these horizontal learning models have been deeply informed by Friere's (2000) popular education pedagogy. Many grower-led organizations pursue practical and political education through peer-to-peer networks; for example, activist Holly Baker, in describing a People's Agroecology Process "encounter" —a gathering for growers to share knowledge—said, "One beautiful part of the experience was that we made sure there was a mix of time for political dialogue and sharing technical skills. . . .Rather than only talking, when you use your body and physical energy, you just get to know people in a different way" (e.g., Black Dirt Farm Collective, 2020). This language closely mirrors our responses.

Within an "embodied space," sharing ceremonies/rituals enhances embodied learning by creating a space of heightened meaning. We all exist in space all the time, but because spaces are products of interactions and relationships from small to global scales, people experience these spaces differently based on their identities and histories (Massey, 2005). Ceremonies and rituals help us share those experiences with each other; Dr. Shawn Wilson writes "the purpose of any ceremony is to build stronger relationships or bridge the distance between aspects of our cosmos and ourselves" (Wilson, 2009, p. 11). For example, the Coalition opens and ends meetings by having participants share the "one word" they are bringing to and taking with them from the experience, and ritualizes other elements of a circle dialogue process. This mirrors the People's Agroecology Process, which uses theater, art, poetry, and more into the beginning and end of their encounters (Black Dirt Farm Collective, 2020). Ceremonies/rituals can also mark transitions and the passage of time, such as the yearly Greens Cookoff that celebrates the collective wealth and resilience of St. Paul's Black community by sharing the collard harvest.

Researchers enact practices and processes (ceremonies) to bring attention to information and create spaces/times dedicated to community meaning making, even if these are often abstract and inaccessible to most people (Wilson, 2009). Gathering our project participants in "All Hands meetings," for example, marks

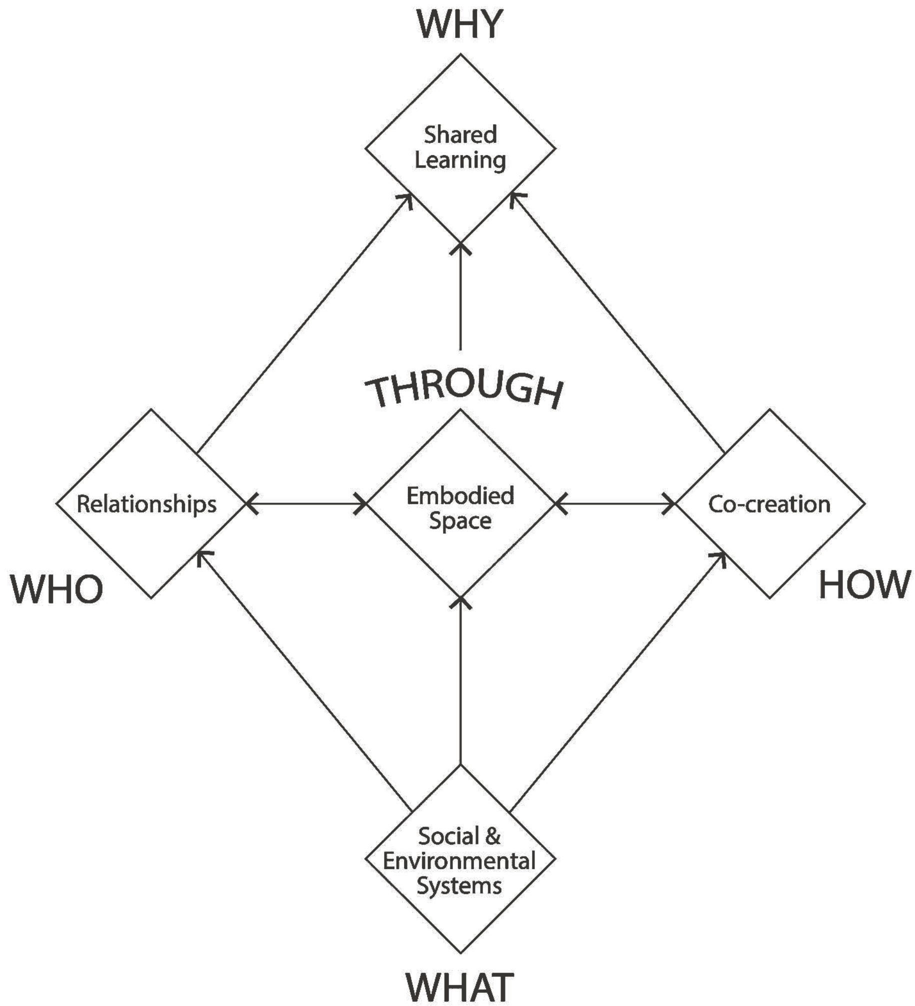

FIGURE 6 | "Learning Framework" for urban agroecology research. Building on themes that emerged from our evaluation (**Figure 2**), we propose that "embodied space''—consisting of embodied learning experiences and shared rituals/ceremonies—is necessary to connect relationships to co-creation of projects and processes. Through embodied space, interactions are facilitated that result in the emergence of transformative learning toward changing social and environmental systems.

the passage of time and ritualizes the sharing of data (**Figure 8**). This space has become more effective as researchers, students, and community partners learn from each other how to inhabit (or at least visit) the performative spaces of collected data, shared analysis, and recommendation building. The evaluation helped us more explicitly understand the similarities and differences in our story sharing habits. The recommendations for "embodied space" in our results shaped our 2020 meeting, and we integrated shared meals, talks, Q&A periods, celebrations, field trips, facilitated exercises, and unstructured time together to open and hold space for all members to explore and communicate what seems important in the project.

When we discuss experiences and ceremonies held in "embodied space" within our project group, we often, more simply, call them "gatherings." Our responses revealed that integrating more frequent and intentional embodied gatherings would facilitate (1) building relationships with cohorts and place, which required (2) enacting reparative ecologies in our partnership to (3) support diverse co-creation participation structures (**Figure 9**). Together, relationships, co-creation, and embodied spaces create interactions from which transformative learning and socio-ecological change emerges—as we discuss more below.

Expanding and Deepening Relationships: Cohorts and Place

While "people-to-people" power (**Figure 10A**), as Lily calls relationships, are the foundation of our work, the network analysis and responses broadened our understanding of relationships to also include cohorts (**Figure 10B**) and relationships to place (**Figure 10C**). This represents a significant expansion from PAR and CBPR research, one which focuses on traits of relationships, and is inspired by the centrality of relationships in BIPOC organizing (Wilson, 2009; Ramer et al.,

FIGURE 7 | Farm and garden tours as embodied spaces. Joshua (far right) giving a tour of the Coalition's community garden where we have our study plots to the Urban Food System Symposium attendees in August 2018. Undergraduate students were also there to share about the project and answer questions about the plots (from the far left—Karl, Tulsi, and Matt). Embodied learning allowed attendees to physically experience the space of a garden, see how the history of this neighborhood is physically inscribed on the area, and feel the interactions between collaborating groups. Doing so through the ritual/ceremony of a farm tour—so ubiquitous for those working in agriculture—makes these embodied learning experiences legible across different roles, since this circle included urban and rural extension educators, students, researchers, and activists from across the country.

FIGURE 8 | All-Hands meeting as an embodied space. Photo credit: Stacy Nordstrom. Coming together as a full group at the yearly All-Hands meeting is a ceremony/ritual that helps us mark the start of another year, and in 2020, we used results from the evaluation to add more aspects of embodied learning experiences. Here, partners from the Coalition, Knoll Farm, and Sandhill Farm, plus researchers Jennifer (second from left) and Chip (far right), are working through the meaning-making process for the relationship network analysis. Creating physical things to interact with (like the printout and pens) as well as using small groups and circle process are one way that sharing ceremonies/rituals in embodied learning experiences are helping us understand how others share stories and create meaning from symbols.

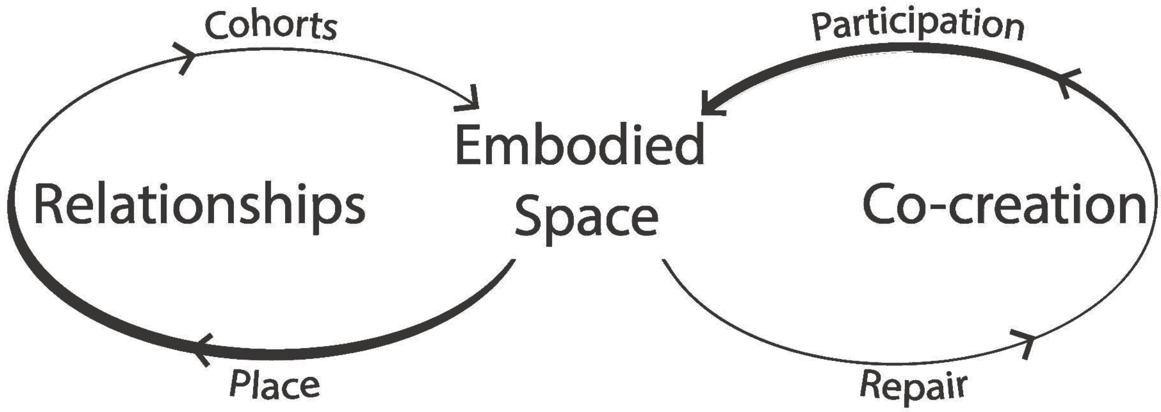

FIGURE 9 | Key Impacts of Embodied Space. Embodied space facilitates the development of cohort relationships, which creates the foundation for diverse participation structures for co-creation. In order to welcome people into these co-creation processes, ceremonies/rituals in embodied space heighten attention to role and responsibility transitions. The development of community-driven co-creative structures continues the process of repairing white supremacy and colonialism in research structures and relationships with socio-ecological systems. Repairing relationships and structures allows partnership members to contribute to generative, co-created embodied spaces (avoiding re-traumatization). Finally, the development of cohorts, co-creation structures, and reparative ecologies within the partnership comes back to relationships to place through collective work in "embodied spaces;" however, because of the work done in the rest of the cycle, our relationships to place have now changed and the cycle begins again.

2016; brown, 2017; Charles, 2018; Penniman, 2018). Supporting the embodied space of gathering especially facilitates building relationships with cohorts and place.

Cohorts are groups of peers in agroecology "with whom to process learning, address issues, be vulnerable, and be inspired," as articulated in the agroecology graduate education pedagogy being developed by students and faculty at the University of Minnesota (Nicklay et al., 2017; Wauters et al., 2019). Building on responses that articulated goals for strengthening student cohorts, cohorts for growers and researchers would provide an important support network to engage in embodied learning experiences, which in turn would cultivate the trust, humility, and respect necessary to be in relationship and work with each other. Grower cohorts, as Fernandez et al. (2015) writes, are "the backbone of the agroecology movement globally" because centering knowledge sharing and regenerative practices/perspectives decenters and creates alternatives to extractive systems (Varghese and Hansen-Kuh, 2013). There are many existing examples of cohorts in grower-led initiatives, such as "base groups" within encounters in the People's Agroecology Process (Black Dirt Farm Collective, 2020). Cohorts including researchers and growers are less common—likely due to complications caused by asymmetrical power relations—but were recently proposed as "wisdom councils" in the transformative agroecology learning framework Anderson et al. (2019) developed based on their work in Europe.

For multi-role cohorts to thrive, ceremonies/rituals are necessary in order to make symbols used by researchers, partners, and students legible across roles. As Kat says:

> both sides have to put themselves in a place of possible discomfort to learn from the process. Whether it's learning the scientific process and understanding the terms, or learning how to communicate that information in a way that anyone can understand. Neither of the sides have it 'easy', we have to work together to understand each other.

Ceremonies and rituals—such as the yearly All-Hands meeting—create space to hold that tension and discomfort to translate between different knowledge cultures, discourses, and fundamental understandings of what is valuable in urban food production. For example, growers, researchers, and students might share their rituals around recording information. Farm plans, lab notebooks, and R code may at first glance seem very different, but these rituals start a work period (whether that's a season or day) and help us process information in our respective roles. Sharing ceremonies/rituals requires coordination, extra explanation, and offers good cheer and solidarity that helps participants suspend habitual disinvestment in others' detailed symbolic lifeworlds, and engage in cultural boundary crossing and learning.

Through cohorts engaging in learning experiences and ceremonies/rituals at farms, gardens, community centers, labs, parks, and other sites that are important to partnership members, gatherings also build relationships to place. We use "place," to encompass the farms/gardens, food systems, environmental dynamics, histories, communities, wider socio-political forces, and embodied lived experiences that all interact to create our social and environmental contexts (Tornaghi, 2014; Solin, 2015). Place—and relationships to place—are complex, representing deep connections to land and community. Our results showed that using gatherings (including field research days and walking tours, in addition to regular field work or informal time together) to connect to place allowed students and researchers to engage with complexity in a way that is usually difficult within academia. For example, when Pepe invited researchers and students to community lunch, it was a way to welcome us into the wider community, into some of the central social relationships that

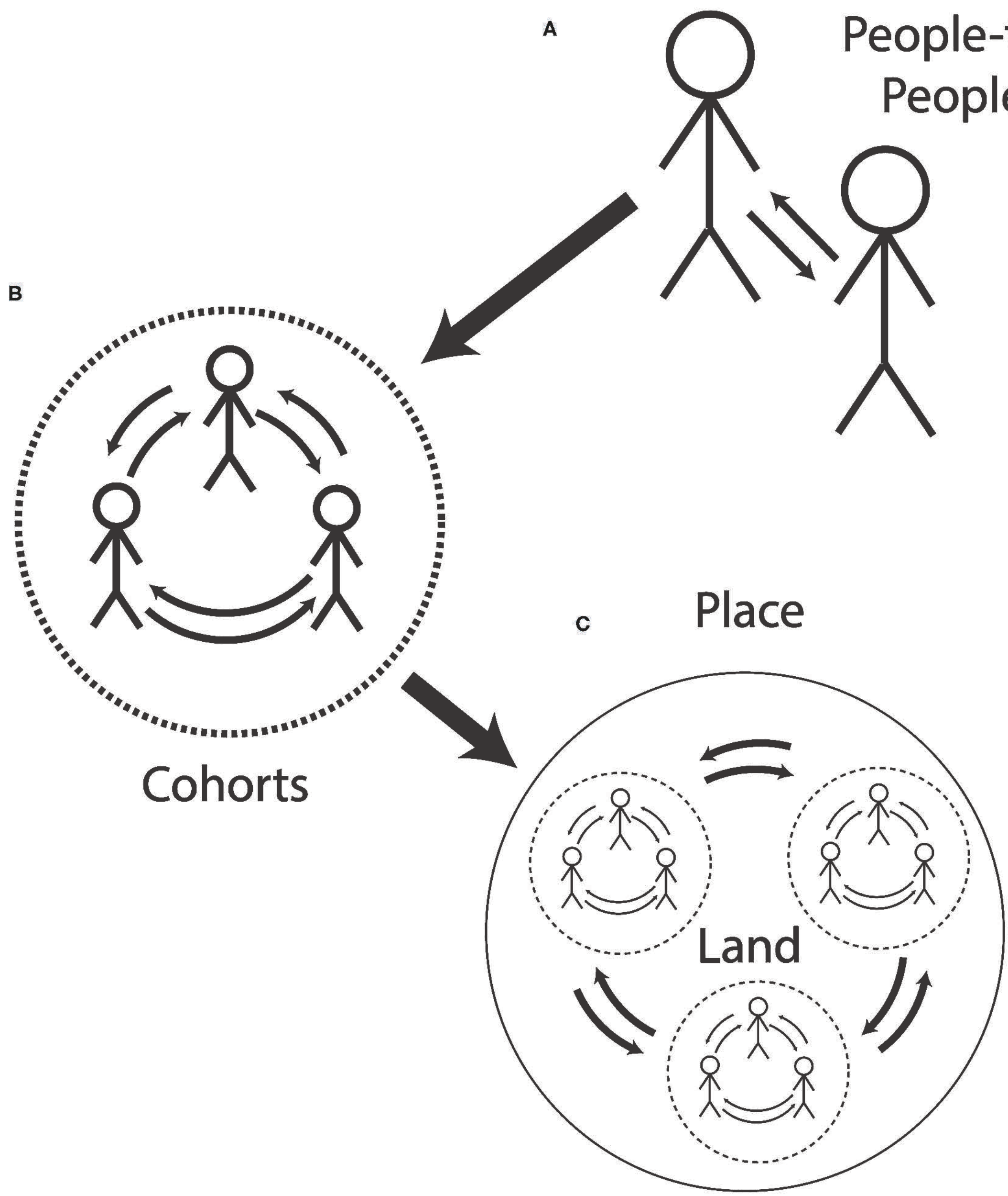

FIGURE 10 | Relationships between people and place. Through the "learning framework," relationships form **(A)** between individuals, **(B)** within groups (cohorts), and **(C)** with place.

are integrated with the reciprocal socio-ecological stewardship Mazahua Center facilitates. Madison reflected that, over the course of embodied experiences throughout the summer, "I learned about environmental racism and how sometimes minorities do not have the option to live more sustainably. In order to combat climate change, we need to also combat racism and inequality." Therefore, the relationship to place cultivated in gatherings that attended to embodiment in space facilitates research—and learning communities more generally—that holds, witnesses, and documents complexity, rather than attempt to control it or direct it toward extractive "development" (Checker, 2011).

Repair Ecologies

Gatherings, called "lighthouses" by Montenegro de Wit (2014), have the opportunity to create space for embodied learning where cohorts come together as coequals. Creating a space that removes barriers to participation and supports coequal gathering, within a research partnership, however, requires repairing relationships of harm, violence, and extraction implicit in our current land, food, and academic systems (see Lee and Ahtone, 2020 for one example). As we saw in the results, asymmetrical power relations are just as present in participatory research and manifest in the identity of participants in different roles, differing experiences relating to intersectional identities, funding allocation, and the perceived legitimacy of different types of knowledge. However, while it can sometimes feel, like Nic said, that these asymmetrical power relations "by nature," they are created, supported, and perpetuated through systems and institutions—such as the "feed the world" narratives that arose out of productivist development paradigms (Bowness et al., 2021). One of our most important areas for work—especially as researchers—is to deconstruct and repair the systems that cause them. PAR and CBPR scholarship acknowledge this but propose few tangible strategies to deconstruct colonialism and white supremacy beyond participatory processes themselves, which ultimately serves to "re-inscribe white, patriarchal systems of power and privilege" (Bradley and Herrera, 2016). Our results indicate that participatory processes alone are not enough to reconcile and repair individual relationships, cohorts, community-university research programs, or larger scale socio-ecological systems.

Embodied learning experiences structured around repair, however, do provide an opportunity to enact decolonization and anti-racism. Repair is described as a two-pronged approach to critically engage with socio-ecological crises toward building community capacity (Cadieux et al., 2019), which builds on the previously described political and practical learning done through embodied spaces. While analyzing responses, partners highlighted that this dual approach of critique and healing is rooted in a long tradition of community driven efforts in MSP, as discussed in Cadieux et al. (2019), where

> highly networked groups of farmers, gardeners, and academic-activist organizers working in the Twin cities have facilitated the emergence of reparative agroecologies.…These efforts have built community action and resistance on the margins of capitalist development and state governance. Simultaneously, they have made demands on state, finance, and non-profit actors for redistributive programs and reparations-based land and financial access (654).

We saw this dual organizing approach in partner discussions of leveraging scientific knowledge and legitimacy in our responses, and it is important that embodied learning experiences focus on how practices can be applied "on the margins" and how to demand that existing systems change.

This includes demanding that white researchers and students practice their own healing and repair work as they awaken to contemporary coloniality (both systemically and within their own bodies) so they can participate in embodied spaces without retraumatizing people with marginalized identities (Menakem, 2017). In our results, researchers were overly cautious about imposing scientific norms and narratives on communities because of the ways in which science has often been used to reinforce existing systems of power and oppression. This meant that researchers deprioritized sharing information about our scientific work, which resulted in a missed opportunity because partners valued that knowledge! Therefore, it's clear that we need to pair deconstructing whiteness in research, which has been a consistent thread throughout our project's iterations (Frank et al., 2017), by pursuing individual and collective repair in order to participate in this work as co-equals.

As Mary observed, "We haven't built in enough from the racial/social equity piece, but I view this as an opportunity and have ideas on how we might address it as we grow." Jennifer highlighted that facilitating a multi-racial program—especially as a white woman—required a significant amount of training and internal reflection:

> I don't know how I would do this work without all the social justice, anti-racism, and decolonization work and training I have done for the past 10+ years. The learning curve would have been so much steeper not only in connecting with community partners, but also in sufficiently supporting students in navigating these complex situations.

This is especially work for researchers to do as a cohort, because individual healing requires support and shifting institutional structures requires collective healing (Menakem, 2017). Partners mentioned inviting and supporting researchers, as well as students, into their work in significant part because of the potential role their research could play, in turn, in supporting communities to heal from structural traumas (such as the manifestations of environmental racism discussed in the Social and Environmental Systems section) through co-creating embodied ways of being with urban agroecologies. Inflecting embodied learning spaces with this possibility also includes creating labs, departments, institutes, and universities that are generative and inclusive, rather than dehumanizing. This will build on the value-based culture identified in our results by students with marginalized identities and is one step to addressing the lack of BIPOC representation among researchers.

Researchers and students, once doing the internal healing work, can then contribute to embodied learning spaces in a reparative way by reimagining the kinds of data and knowledge our research frameworks support. In the Introduction, we discussed that Urban Agroecology has space for systemic, asset- and strength-based research approaches. Ceremonies and rituals in embodied space help us understand the important symbols others use to represent the benefits of urban farms and gardens. This, in turn, supports embodied learning experiences because understanding important symbols across roles helps us examine negotiations over what justifications and evidence are being used to support access to and governance of land for food cultivation. It also helps integrate complex researcher and grower narratives to inform management practices, a significant challenge to sharing knowledge identified across roles in our results. In our project, many of the metrics of ecosystem services have been selected because, through farm tours with growers and organizers (a regular ritual every field season), we noticed the continual refrain that "soil health is community health." By focusing on this value, among others, we were able to avoid re-traumatizing communities negatively impacted by scarcity and deficit narratives that arise from reductionist science and instead create a reparative research approach that focused on community values and strengths (Cadieux et al., 2019).

Diverse Co-creation Participation Structures

Repair is focused on "negotiative collaboration, mutual recognition, and consent" (Cadieux et al., 2019, p. 654), which, in combination with interconnected networks developed in cohorts, would promote horizontal learning and leadership structures (and also alleviate the pressure non-faculty researchers feel as the central relationship nodes). Valentine shared that her hope that

> Our approach would help enable the researchers to get solidly behind some community goals – recognizing that these goals might themselves be emergent and dynamic. However, I am wondering whether there's a process the community partners might LEAD at this stage (like an action planning process) that helps re-articulate these goals going forward.

Reparative co-creation asks us to imagine the full range of ways communities can lead research and outcomes within a horizontal learning structure. Participatory research is often portrayed as a spectrum, with activities ranging from outreach to community-based action (Ellison and Eatman, 2008) and relationship types ranging from manipulative to collaborative to participant controlled (Arnstein, 1969; Bacon et al., 2005). To avoid harmful or extractive research, the implicit goal in much participatory research is to aim for *the most* community participation in the research possible, though research processes that aren't grounded in repair often can't achieve participant control (Arnstein, 1969; Post et al., 2016). However, this centers the *research* activities themselves rather than strategically thinking about how different skills and activities can contribute to the overall goals of the community-university partnership and the wider community.

Within our project, one way we're already experimenting with different roles for community led research is through on- and off-farm projects. In the on-farm project, the relationship between growers/organizers and researchers is best described as a collaborative partnership because they were involved in decision making and implementation throughout the research process (Bacon et al., 2005). However, the relationship between community partners and researchers for the complementary off-farm research conducted by Chip is consultative. This doesn't mean either type of relationship is better or worse; in fact, both are necessary for communities to drive research agendas in order to use the full research tool-kit—applied, basic, legal, policy, social, and more. This welcomes more researchers into community-centered programs by making space to value the unique skills of community partners and also the participation of researchers who may not be organizing their current work around CBPR/PAR.

Embodied learning in cohorts sets the stage for developing the relationships necessary to support diverse co-creation approaches and make the products/outcomes visible to all involved through the collective work activities. Regular return to embodied learning experiences would facilitate activities that continually make changing goals, strengths, and needs visible, which would help community-university partnerships navigate the spectrum of co-creation options. Without these, it is easy to fall into old models of "helicopter research." For example, in the absence of planned meals or field work, Benny observed that, "There wasn't a lot of conversation...it seems as though you're focused on the task that you're there to do." Dania named discomfort in this situation, sharing "it felt strange to just extract data and leave a space." However, other times when we offered help, it was sometimes rebuffed (usually when we hadn't built broad enough relationships with a community partner for them to trust our competence at providing help without requiring more supervision than they had capacity for). Using embodied experiences to solidify roles and needs with each partner can help better communicate expectations and capacities.

Ceremony/ritual helps mark transitions as people change roles and responsibilities, which becomes especially important if there are multiple co-creation paths operating at one time. In addition to the partner transitions (**Figure 4**), students transition between roles; Tanner and Dania were involved in community urban agriculture programs before joining the project, and Tulsi transitioned from student researcher to Knoll Farm intern. In 2020, as a result of COVID-19, Knoll Farm took a year off from farm production, so Fannie transitioned to join the research team. Ceremony marking changing roles would allow us to indicate to group members that they are taking on new responsibilities. We see how the formal scaffolding of welcoming someone into a role, or a project, creates the excuse to repeat content and build social relationships that might otherwise be felt as repetitive or hard to justify asking collaborators to spend time on. Adding practices to create, maintain, and end relationships ensures that all group members—no matter how long they are part of the project—are integrated into cohorts and co-creation processes.

Scaling Out: Facilitating Multi-Scalar Transformation

Through this learning framework, we aspire to a community-university urban agroecology research program that invites researchers, partners, and students (and others!) into a liberatory community where everyone is transformed. Embodied space continually "calls us in" to recommit to transformative learning and drives iteration through relationships, repair, and dynamic co-creation. These iterations build new structures and innovations within the research program, which, as adaptive cycles posits, become the seeds for multi-scalar, systemic transformation (Holling, 2005). This transformation process is represented in similar ways across many fields: adaptive cycling in ecology (Holling, 2005), local spiritual leaders use an infinity loop to represent inward and outward transformation (Sit, 2020), and many Black community organizers use fractals to show patterns repeating from small to large scale (brown, 2017). In this spirit, **Figure 11** represents a more dynamic representation of the learning framework in which we can imagine the vertical

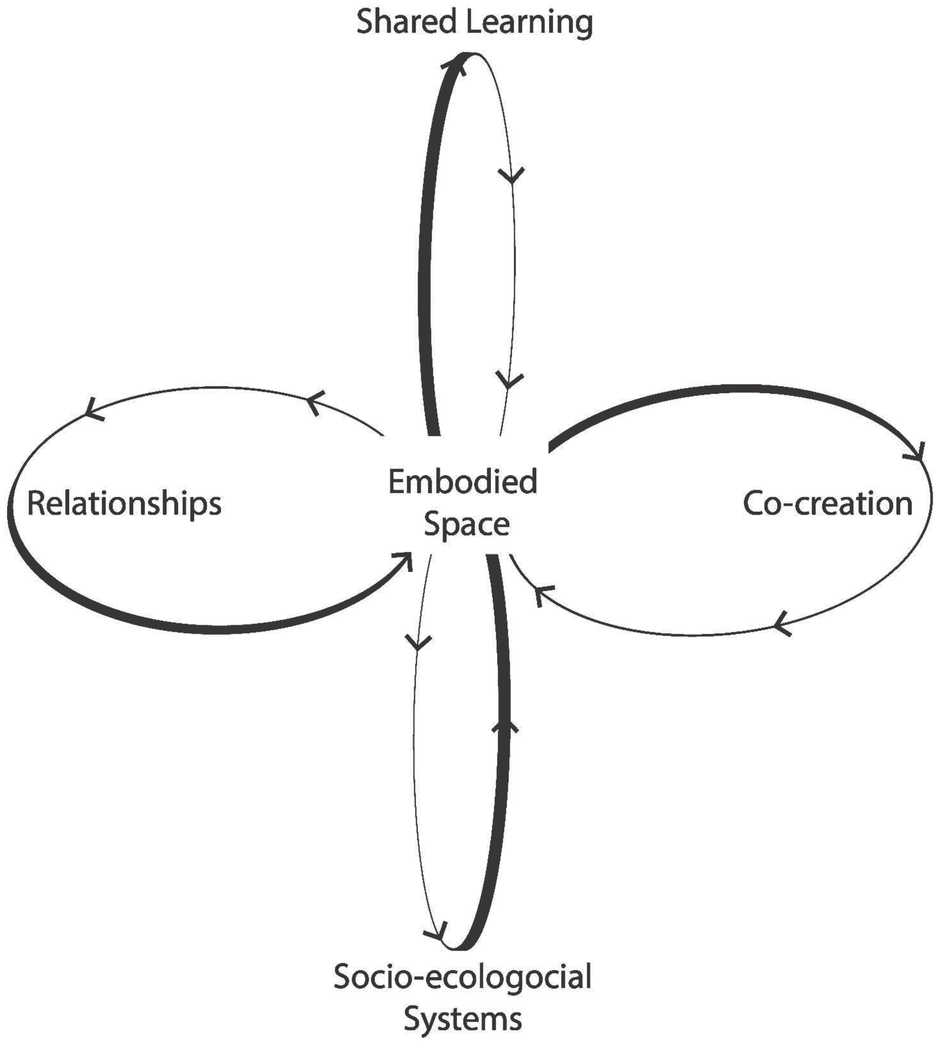

FIGURE 11 | Urban agroecology as a dynamic research framework. The vertical transformative learning cycle moves along the horizontal process loop as embodied spaces facilitate the emergence of transformative learning.

"transformative learning" cycle moving dynamically along the horizontal "process" loop.

There are several avenues for further research, as well, both locally and across many urban agroecology research sites. This evaluation (and the subsequent learning framework) did not gather information about relationships between members of our partnership and external individuals, institutes, and places. We did not have conversations with *former* partners, which could provide valuable context and also provide an excellent opportunity to update people on the project's activities (and invite them into the partnership again if it matches their goals and interests). Finally, COVID-19 complicates physical gatherings, and we haven't fully explored what embodied spaces look like in this context, for small group gatherings or for virtual embodied spaces. Our research in general, and these questions specifically, are drawing from calls by community partners—locally and in other cities (Drake, 2015, p. 274–76)—for researchers to be embedded in the communities in which they're working while also continually interrogating whether the goals of our program are having the intended impact to repair structural inequities (Barthel et al., 2013, 2015).

In sharing how this learning framework emerged from our work, we hope to provide tools and inspiration for other community-university urban agroecology research partnerships. It has already deeply informed our work so far in 2020, from the implementation of the yearly All Hands meeting to our response to the COVID-19 pandemic and the Uprising for Black Lives that was initiated by the murder of George Floyd in Minneapolis. Through uncertainty, rage, grief, fear, and determination, this framework kept us focused on being in relationship with each other as we provided urgent support to each other and determined which parts of our ongoing research projects could be let go and which parts were important for long-term community goals. Our framework was developed in a specific context, but the systems of disinvestment and repair which we are facing are not unique to our area. The U.S., generally, is reckoning with ongoing systemic racism, and around the world, there are inequities and movements for justice being embodied in spaces of urban food production—and researchers are part of these spaces. Applying the framework in other areas, then, requires attention to the ways in which those differences will impact our work. Our world is in a moment of rapid transformation, which means that the seeds and structures we put in place now may expand beyond our individual efforts and, collectively, have impacts we have not yet imagined.

CONCLUSION

Urban food production in MSP is often pursued as one way to transform ecological, social, and political systems by mobilizing "egalitarian grassroots solidarity and new forms of dispersed power" (Cadieux et al., 2019, p. 645), thereby contributing to the emerging realization of urban agroecology. This paper has engaged with the tension around how researchers can be in community with growers, organizers, policymakers, and residents to support systemic transformation through urban agroecology research. Within this context, it is necessary to reimagine how we do research; to that end, we've proposed a learning framework for community-university urban agroecology partnerships based on our experiences as a 5 year community university partnership and the themes that emerged from a participatory evaluation we conducted in Fall 2019.

Urban agroecology research represents a unique space to come together as co-equals and use a process of transformative learning to facilitate being in relationship with "what is" in our environmental and socio-cultural systems to imagine and create "what can be." In order for learning to transform everyone involved, relationships to people, cohorts, and place are integrated into co-creation processes through "embodied spaces." Within these spaces, community-university partnerships share embodied learning experiences and ceremonies/rituals that repairs our internal structures so we can, in turn, transform larger scale socio-ecological systems through community-driven actions. As Dania said in her evaluation:

> From my experience, urban agriculture has always been driven by community efforts and ultimately many urban agricultural projects are community-based. If we are to do research on urban agriculture, especially in efforts to support these communities, then we must be actively working and collaborating with community partners. These are the people who are doing the work, therefore the research needs to recognize that.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Hamline University Institutional Review Board. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

JN, MR, and KC led development of the survey and led data analysis, with support from NJ. JN created the online survey, conducted one-on-one interviews, and managed the data. JN and KC conducted the focus group. Writing was led by JN, MR, and KC, with support from NJ, KL, and GS. All authors and community partners participated in designing, implementing, and revising the partnership processes upon which this paper is based. All authors collectively conceived the idea for the evaluation survey. All authors, community partners, and undergraduate research assistants reviewed the instrument.

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and Ahtone, 2020). The land was ceded in the Treaties of 1837 and 1851, but when the U.S. later abrogated those treaties, the land was not returned to the Dakhóta, as is legally required when treaties are revoked (Case, 2018). We also acknowledge that the University of Minnesota received financial support in 1856 from William Aiken Jr., who enslaved more than 700 people; this money was gained through forced labor (Lehman, 2019). We offer these acknowledgments as one way to recognize relationships between the University, land, and communities, and more importantly, as our commitment to ongoing actions within and outside our research that support reconciliation and repair.

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Features and Functions of Multifunctional Urban Agriculture in the Global North: A Review

Francesco Orsini, Giuseppina Pennisi, Nicola Michelon, Alberto Minelli, Giovanni Bazzocchi, Esther Sanyé-Mengual and Giorgio Gianquinto*

DISTAL – Department of Agricultural and Food Sciences, Alma Mater Studiorum – Bologna University, Bologna, Italy

In recent years, urban agriculture (UA) projects have bloomed throughout the world, finding large applications also in the developed economies of the so-called Global North. As compared to projects in developing countries, where research has mainly targeted the contribution to food security, UA in the Global North has a stronger multifunctional connotation, and results in multiple combinations of farming purposes and business models pursued. The present review paper explores the contribution and role that UA plays in cities from the Global North, defining its functionalities toward ecosystem services (ES) provisioning and analyzing the factors that hinders and promote its regional diffusion and uptake. The manuscript integrates a description of UA growing systems, as well opportunities for crop diversification in the urban environment, and a comprehensive classification of UA business models. The distinctive features in terms of business models, farming purposes and farm size are then applied over an inventory of 470 UA projects in the Global North, allowing for a characterization and comparative analysis of distribution frequency of the different project typologies.

Keywords: urban horticulture, green infrastructure (GI), vertical farm, rooftop agriculture, ecosystem service, ecology, business models, circular cities

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Institut de Ciència i Tecnologia
Ambientals (ICTA), Spain

****Correspondence:***
Francesco Orsini
f.orsini@unibo.it

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INTRODUCTION

First, it was hunting for food and caves to live in. Then, settled agriculture came, in the form of horticulture, primarily practiced by women, to complement the game that men brought home (Hansen et al., 2015). Homes that were built to provide shelter to the family, with horticulture that along the ages would become the first formal organization of nature, following strictly defined structural patterns. While geometry naturally occurs within ecological systems, human mind requires regular forms; therefore, gardens were created following geometrical patterns already in ancient Egypt. Integration of agriculture within the anthropic landscape also emerged in Babylon's hanging gardens (**Figure 1**) or in the so-called *sacred lands* devoted to food production in Greek cities in the classical era (Isager and Skydsgaard, 2013). In *Roman* gardens, exotic species could be found, as emerged in the buried gardens of Pompeii. The practice of plant cultivation in villages and towns further became established in the middle ages in the form of *hortus,* where applications of relationships, dimensions and figures evolved from the Pythagoreans (Steenbergen and Reh, 2003). The *hortus* pattern recurred through gardens that complete the village's general geometry and feed the local community. They were often placed between the town defensive walls, enabling food security in times of wars. Horticulture also developed in monasteries where food production and processing were established under the Rule of Saint Benedict (Aben and de Wit, 1999). *Arabic*

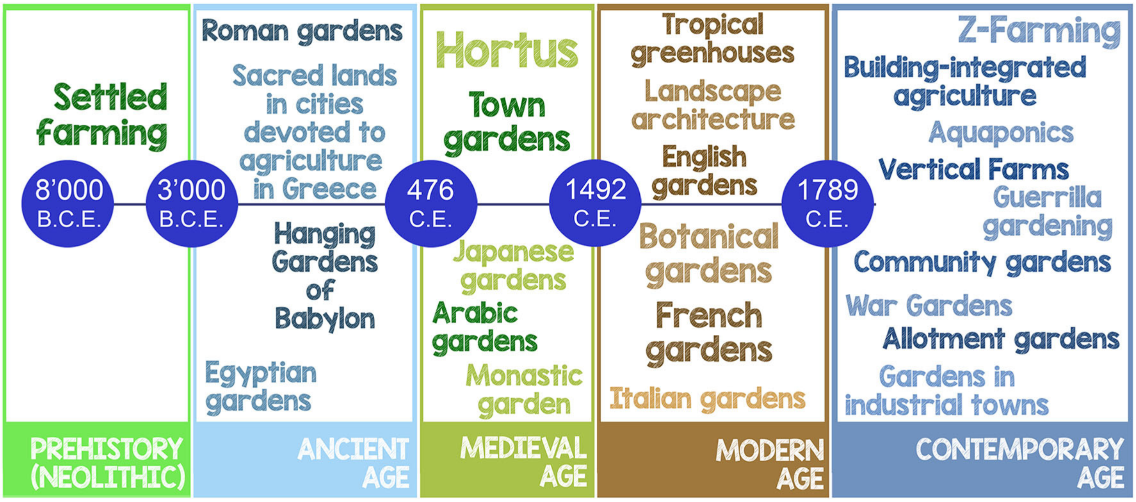

FIGURE 1 | Timeline of relevant keywords along the history of Urban Agriculture.

gardens combined beauty and sensorial experiences, building on the beneficial effects that plants can bring to humans (**Figure 1**).

In the modern age, and along the Renaissance, whole farms were conceived following the *hortus* design, until the Romanticism and toward the time of affirmed urbanism, where a re-unification of the rural-urban continuum occurred. Exotic plant species were grown in tropical glasshouses in private villas of the wealthier or in urban botanical parks. English, Italian and French gardening schools were born, paving the way for modern landscape architecture principles. In the contemporary age, and from the industrial revolution, gardens were found within the fringes of industrial towns, contributing to the food security of the migrant workers (Partalidou and Anthopoulou, 2017). Allotment gardens were established and became formally recognized. During the world conflicts of the twentieth century, war or "victory" gardens were promoted by governments to feed the urban population, while starting from the post-war period, urban horticulture has become a social structure, an economically fundamental element, a source of ecosystem services (ES) for sustainable cities (Keshavarz and Bell, 2016). It assumed the form of political activism, as for the case of community gardens and guerrilla gardening initiatives. In these same years, however, the rapid economic growth of cities was associated with a general decentralization of functions (e.g., with agriculture being moved out from the city, where it was assumed to be healthier thanks to the lower air pollution), and the increased urbanization resulted in severe fragmentation of urban and peri-urban farmed plots (Mok et al., 2014). Nevertheless, from the beginning of the twenty first century, the rapid evolution of agricultural technologies has brought new forms of plant cultivation, allowing for multiple productions and circularity (e.g., in aquaponics systems), but also through the creation of common metabolisms in urban buildings, as for the growing examples of vertical farming and rooftop agriculture projects (**Figure 1**) (La Rosa et al., 2014).

While fresh horticultural goods represent its main products, urban farming today also explores new crops and novel food products and services. A set of innovative business models takes form, and a plethora of experiences emerge at global level. Meanwhile, a clear differentiation emerges between urban agriculture (UA) specifically aimed at tackling food insecurity and the forms it may take when occurring in wealthier world regions, where the associated ES may even become more relevant than food production *per se*, at least until the SARS-CoV-2 outbreak (Lal, 2020). Indeed, while the role and functions of UA in developing countries have been addressed in several review papers (Bryld, 2003; de Bon et al., 2010; de Zeeuw et al., 2011; Gallaher et al., 2013; Orsini et al., 2013; Hamilton et al., 2014; Poulsen et al., 2015), a more limited body of literature (e.g., Mok et al., 2014; Lin et al., 2015) considered to date the role and forms it may play within stronger economies of the so-called Global North (e.g., UN classified "developed countries, United Nations, 2020).

In the coming sections, this review paper brings together a comprehensive state of the art of all the above-listed features of agriculture in cities in the Global North, including a classification and inventory of urban farming projects. While the research does not target the comparative analysis of UA in the Global North vs. Global South, it actually builds on data from Global North in order to answer the following research questions:

1) *Which are the main ES of UA in the Global North?*
2) *Which factors affect the development and diffusion of UA projects?*
3) *Which are the most represented farming systems for UA in the Global North?*
4) *What is the average farm size in UA projects?*
5) *How can business models in UA be classified and which business models are more common in the different regions of the Global North?*

6) *Which are the most relevant farming purposes of UA?*

In order to answer the research questions, the research methodology combined an extensive literature review on ES provided, functions, enabling factors, cropping system typologies and associated business models observed in UA projects in the Global North, altogether with the implementation and classification of a database of regional case studies. The literature review was performed using scientific journal databases, including Google Scholar® and SCOPUS®. Search strings were compiled by integrating selected keywords including "urban farming," "urban and periurban agriculture AND/OR horticulture," "urban food security," "urban food safety," "horticultural therapy," "multifunctional agriculture," "ecosystem services," "social function," "urban regeneration," "urban planning," "urban land," "vacant land," "eco-efficiency assessment," "life cycle assessment (LCA)," "social-life cycle assessment (S-LCA)," "social justice," "urban green infrastructures," "life cycle costing (LCC)," "urban ecology," "urban biodiversity," "food contaminants," "urban pollution," "urban heat island," "allotment gardens," "community gardens," "rooftop agriculture AND/OR farming AND/OR garden AND/OR greenhouse," "hydroponics," "plant factories with artificial lighting (PFAL)," "vertical farms," "urban beekeeping," "urban peasant," "business model," "farming purpose," "entrepreneurial urban agriculture." Within each combined search, selected articles from first 50 results for each keyword search were used for the study, altogether with snowball sampling (e.g., from references and citations included in already identified documents) additional articles already familiar to the authors and those suggested during the review process. The inventory of regional case studies in the Global North was implemented using internet search (through Google®), of selected keywords (including multiple combined searches for words "urban farming," "urban agriculture," "community supported agriculture," "vertical farm," "indoor farm," "rooftop garden," "community garden," "rooftop greenhouse," "allotment garden," "periurban farm," "solidarity buying group," "farmers market," "workshop"), eventually translated in national languages through online translators. Among identified projects, those with available information (e.g., online or responding to contact e-mails) were integrated in the study, accounting for a total of 470 projects, out of which, 417 declared their cultivated area (m^2). The results emerged from both the literature survey and the implemented case study database are discussed in the following sections. Classes for cultivated area were then created, diversifying projects based on area below 500 m^2, between 501 and 1,000 m^2, between 1,001 and 5,000 m^2, between 5,001 and 25,000 m^2, between 25,001 and 100,000 m^2 and those above 100,000 m^2 (10 ha). Contingency tables were used to analyze the relationships among class of projects dimension and business model typologies ($n = 447$), farming purposes ($n = 470$), city typology ($n = 470$), city density ($n = 470$), or city climate ($n = 470$). According to Magrefi et al. (2018), business models were classified in cost-reduction, differentiation, diversification, share economy, experience and experimental. Farming purposes were classified in commercial, image, innovation, social and educational and urban living quality (Thomaier et al., 2015). Cities were classified according to urban population in six categories (Dijkstra and Poelman, 2012): Small (S) for cities with a population ≤100,000 inhabitants; Medium (M) for cities with a population ranging 100,001 to 250,000 inhabitants; Large (L) for cities with a population ranging 250,001 to 500,000 inhabitants; Extra-large (XL) for cities with a population ranging 500,001 to 1,000,000 inhabitants; Megacity (XXL) for cities with a population ranging 1,000,001 to 5,000,000; (Global city) for cities with a population ≥ 5,000,0001 inhabitants. Cities were also classified according to city density in three categories (Saldivar-Sali, 2010): "LOW density" for cities with a population density ≤ 5,000 inhabitants km^{-2}; "MEDIUM" density for cities with a population density ranging 5,001 to 15,000 inhabitants km^{-2}; "HIGH density" for cities with a population density ≥ 15,001 inhabitants km^{-2}. Finally, city climate was classified according to Koppen's classification in tropical, temperate and continental.

Chi-square test was used to assess the null hypothesis (i.e., the independence of the two categorical descriptors) comparing observed and expected frequencies. When Chi-square test resulted significant, a standardized Pearson residuals analysis as a measure of the strength of the difference between observed and expected values was performed (Agresti, 2003). Standardized residuals are useful as they enhance the detection of the cells that mainly contribute to the value. Additionally, a Bonferroni adjustment was applied by dividing the significance level by the number of cells in the contingency table in order to compensate for potential type 1 family wide errors (Garcia-Perez and Nunez-Anton, 2003).

DEFINING URBAN AGRICULTURE (UA)

UA has been defined by the Food and Agriculture Organization of the United Nations as the "plant cultivation and animal rearing (including aquaculture) within cities and towns and in their immediate surroundings" (Drechsel and Kunze, 2001). While providing for both food and non-food products for household consumption as well as income generation, UA also includes all related activities (production and sale of agricultural inputs and processing and marketing of products) (Mougeot, 2000). Being a complementary activity to the dominant agricultural production taking place in the countryside, UA overall increases the efficiency of the food system. UA allows for producing several typologies of crops (cereals, roots and vegetables, fruits, herbs, ornamentals, trees) and livestock (poultry, rabbits, goats, sheep, cattle, pigs, guinea pigs, fish) or animal-based products (meat, eggs, milk). However, in most cases it is represented by horticultural crops (vegetables, aromatic and medicinal plants, flowers and ornamentals, fruit and wood trees) grown in small fields or gardens (Orsini et al., 2013). Within a recent debate on how to define UA in developed economies, definitions building on its main features were elaborated, including *where* it is conducted (spatial dimension), *what* it produces (functional dimension), *why* it takes place (motivational dimension), *where* its produce *is consumed* (market dimension), *how* it generates (origin dimension), or *by whom* it is performed (actor dimension) (Vejre et al., 2016). Furthermore, as within UA projects in the Global North, externalities and non-food products may take over the primary driver of farming, their classification may either rely on the adopted business strategy (Pölling et al., 2015) or the main farming purpose (Thomaier et al., 2015), as further detailed in the following sections.

ECOSYSTEM SERVICES (ES) ASSOCIATED WITH UA

As farming takes place closer to cities or even inside them, several differences from conventional agriculture arise, translating into both advantages and limitations (**Table 1**), whose perception among societal groups and initiatives may largely vary (Sanyé-Mengual et al., in review). It appears that, according to Sanyé-Mengual et al. (2019), in order to be viable among the three sustainability dimensions (social, economic and environmental) and overcome the constraints related to the urban environment, the development of UA needs to combine both social and technological innovations. As a result, urban farming must bring together the existing knowledge and advances from the traditional agricultural sector with a set of new skills, technologies, tools and strategies allowing to target a diversified set of ES, falling into four main categories (TEEB, 2010):

(a) *provisioning services*: services that describe the material or energy output from ecosystems, including food, raw materials, water and medicinal plants (Pourias et al., 2015).
(b) *regulating services*: services that ecosystems provide by acting as regulators (e.g., regulating the quality of air and soil, storing greenhouse gases, or providing flood and disease control, Camps-Calvet et al., 2016).
(c) *habitat services*: services that ecosystems provide by the maintenance of genetic biodiversity and offering habitat for species (Lin et al., 2015).
(d) *cultural services*: services which represent the non-material flow of benefits from ecosystems to humans, including recreation, mental and physic health, tourism, spiritual experiences, amenity or social inclusion (Camps-Calvet et al., 2016).

All of them are strictly connected with and contribute to the functionality and environmental sustainability of the city. Moreover, since UA experiences primarily target specific ES, a classification based on the *farming purpose* has been recently elaborated (Thomaier et al., 2015), which distinguishes UA projects in five main categories (image, commercial, urban living quality, innovation, or social-education).

Urban Food and Nutrition Security

Among *provisioning services* supplied by UA, the most acknowledged is associated with food production and supply. Indeed, while estimates for the potential UA contribution to food security (Orsini et al., 2013) and sovereignty (García-Sempere et al., 2019) are available for several cities in developing countries, a lower number of studies addressed the quantification of urban food production in cities from richer economies, where aims of UA are mainly associated with environmental and social functionalities. Nonetheless, food production potential of UA in the Global North has raised interest in response to economic crises (e.g., after 2007, Colasanti et al., 2012) or as a tool to mitigate the effects of food deserts on the health status of the poorest strata of the population (Meenar and Hoover, 2012; McClintock et al., 2013). The emergent phenomenon of new peasantry as a response to growing urban poverty has also lead to new forms of UA, where innovation takes place in both businesses and land-use models, as occurred for instance in Detroit, Michigan (USA) (Draus et al., 2014), Berlin (Germany) (Clausen, 2015) and Yokohama (Japan) (Ikejima, 2016). Accordingly, several studies targeted in the last couple of decades the quantification of potential food production of UA in cities of North America, Europe, Asia and Oceania (**Table 2**), although estimates most often built on scenarios rather than actually measured data.

Health

Horticulture is a discipline that has great therapeutic potential, and its role in human well-being was well-explained by Diane Relf in her "Human Issues in Horticulture," which examined "the other side of horticulture" (Relf, 1992). Since then, horticulture's therapeutic roles were increasingly studied and debated, and the definitions and methodologies that use horticulture as support in therapeutic processes of physical and/or mental rehabilitation were elaborated (Relf and Dorn, 1995; Burls, 2008). A distinction was made between *Horticultural Therapy* and *Therapeutic Horticulture*. *Horticultural Therapy* is defined as a process through which plants, gardening activities and the simple contact with nature are used as tools in therapy and rehabilitation programs conducted by a therapist. It is an active process in which horticulture is used as support for other rehabilitation interventions. *Therapeutic Horticulture* is instead defined as a process that uses plants and the relationship with them to create or improve people's physical, psychological and social well-being. It is a process in which the plant plays a central role but in which specific therapeutic objectives are not pursued (Shoemaker and Diehl, 2010).

The therapeutic role of horticulture is based on the general positive psychological and physiological actions promoted by all sensations and emotions that arise from contact with nature, especially in those contexts (e.g., a walk in a park, taking care of a vegetable garden, the presence and sight of plants and flowers) in which the relationship between man and nature does not have the character of a working commitment (Ulrich, 1984; Ulrich et al., 1991; Kaplan, 1995; Thwaites et al., 2005; Mattson, 2010). Although scientific evidence of the positive effects of gardening on blood pressure, body temperature, brain activity, immune system response and psychological sphere are only recent (Coleman and Mattson, 1995; Liu et al., 2004; Park et al., 2004; Sugimoto et al., 2006; Gonzalez et al., 2009; Park and Mattson, 2009; Kam and Siu, 2010), the intuitions about the beneficial effects of horticulture on human health are much older. More than 2,000 years ago the Chinese Taoists built gardens in the belief that the environment had beneficial effects on health.

TABLE 1 | PROs and CONs of Urban Agriculture.

Category	Experimental evidence	References
ADVANTAGES (PROs)		
Food security and ecosystem service provision	Contribute to the city food security	Orsini et al., 2014
	Improve food system sustainability, reduces food miles and post-harvest handling	Sanyé-Mengual et al., 2013; Pascale et al., 2015; Dimitri et al., 2016
	Landscape management	Donadieu, 2006
	Biodiversity promotion	Halaj et al., 2000; Colding et al., 2006; Andersson et al., 2007; Baker and Harris, 2007; Breuste et al., 2008; Loram et al., 2008; Matteson et al., 2008; Ricketts et al., 2008; Sperling and Lortie, 2010; Shrewsbury and Leather, 2012; Burkman and Gardiner, 2014; Lin et al., 2015; Pölling et al., 2016a; Bazzocchi et al., 2017; Lanner et al., 2019; Tresch et al., 2019; Bazzocchi, 2020
	Social inclusion	Armstrong, 2000; Saldivar-Tanaka and Krasny, 2004; Wakefield et al., 2007; Teig et al., 2009; Anguelovski, 2013; Taylor and Taylor Lovell, 2014; Camps-Calvet et al., 2015; Marchetti et al., 2015; Gasperi et al., 2016; Reynolds and Cohen, 2016; Calvet-Mir and March, 2017; Specht et al., 2017; Sanyé-Mengual et al., 2019
	Job creation and creation of business opportunities	Yang et al., 2010; Draus et al., 2014; Clausen, 2015; Ikejima, 2016; Pölling et al., 2016a
	Therapeutic and recreational activities	Coleman and Mattson, 1995; Liu et al., 2004; Park et al., 2004; Sugimoto et al., 2006; Gonzalez et al., 2009; Park and Mattson, 2009; Kam and Siu, 2010; Meneghello et al., 2016; Righetto et al., 2016
	Increase liveability and improves the value of nearby buildings	Vitiello and Wolf-Powers, 2014; Colle et al., 2017; Poulsen, 2017
Resource use efficiency	Use of rainwater or regenerated greywater for irrigation	Mok et al., 2014; Opher et al., 2018; Mason et al., 2019; Rufí-Salís et al., 2020
	Improved energy use efficiency	Nadal et al., 2017
	Use composted urban organic waste	Cofie et al., 2006; Dorr et al., 2017
Climatic resilience	Reduction of flood risk	Zasada, 2011
	Reduction of heat waves	Depietri et al., 2012; Dubbeling, 2014
	Improves air quality	Lin et al., 2015
Awareness creation	Engage citizens in the food system and linking them to local farmers	Sanyé-Mengual et al., 2019
	Improving dietary habits and health	Gerster-Bentaya, 2013
	Increasing awareness and providing educational and training opportunities	Magrefi et al., 2018
CONSTRAINTS (CONs)		
Land access	High land costs as compared to the generally limited profits associated with agricultural production	Cohen and Reynolds, 2015
	UA may ultimately foster gentrification and increased costs of living in the neighborhood	Anguelovski, 2015; Cohen and Reynolds, 2015; Reynolds and Cohen, 2016
	Extreme fragmentation results in small farmed plots and lower economy of scale	Mok et al., 2014
	Long term sustainability and investments may be compromised by the limited duration of space concession agreements	Tornaghi, 2017
Legal and policy framework	Land-use is mainly devoted to building purposes	Masson-Minock and Stockmann, 2010
	Agricultural production in cities is not regulated	Bell et al., 2016
	Food marketing schemes used in rural agriculture are not applicable	Opitz et al., 2016
	Taxation regimes are different from conventional agriculture	Heckler, 2012
	Absence of marketing infrastructure limits marketing to informal scheme (farmers market, solidarity buying groups	Brown and Miller, 2008
Water use	Inefficient water use due to limited knowledge	McDougall et al., 2019
	Competition for water availability may occur	Molle and Berkoff, 2009

(Continued)

TABLE 1 | Continued

Category	Experimental evidence	References
	Elevate use of tap water	Deelstra and Girardet, 2000
Health and safety	Risk associated with urban atmospheric and soil contamination	Mancarella et al., 2016, 2017
	Risk of mosquito outbreak	Winkler et al., 2010
	Limited farmer skills may result in overuse of pesticides	Ochoa et al., 2019

TABLE 2 | Estimated and potential contribution of UA to food security in world cities.

Continent	Country	City	Estimated contribution to food security	References
Asia	China	Shanghai	About 2,000,000 t year^{-1} of cereals, 100% of milk and 90% of eggs	Yi-Zhang and Zhangen, 2000
	Japan	Yokohama	UA could alleviate food insecurity of 25,000 local residents	Ikejima, 2016
Europe	France	Paris	Around 600 t year^{-1} are produced within 10 hectares of community gardens	Pourias et al., 2015
	Italy	Bologna	Up to 12,500 t year^{-1} of vegetables (77% of the city requirements) if the 82 ha of vacant rooftop spaces would be transformed in gardens	Orsini et al., 2014
	Spain	Barcelona	15% of the vegetables circulating in the wholesale vegetable market is locally produced	Paül and McKenzie, 2013
	Spain	Barcelona	Tomato production with rooftop greenhouses in the Zona Franca logistics park could satisfy from around 130,000 to 1,100,000 inhabitants (from short-term to long-term scenarios)	Sanyé-Mengual et al., 2015c
North America	Canada	Toronto	Up to 4,000 t year^{-1} from 65 ha of greened rooftops	Peck, 2003
	CA, USA	Oakland	UA produces 30% of the city food needs	McClintock et al., 2013
	MA, USA	Boston	UA implementation in Boston could satisfy from 10 to 75% of the USDA dietary guidelines of different groups of vegetables	Goldstein et al., 2017
	OH, USA	Cleveland	When devoting to UA urban vacant lots, industrial and commercial rooftops and limited up to 100% of the city requirements could be satisfied	Grewal and Grewal, 2012
	PA, USA	Philadelphia	About 8,500 t year^{-1} are donated from urban gardens to food cupboards	Meenar and Hoover, 2012
Oceania	Australia	Adelaide	Up to 98% of the cauliflowers consumed within the state are urban grown	Mok et al., 2014
	Australia	Melbourne	About 97% of the strawberry consumed are grown within the city	Mok et al., 2014
	Australia	Sydney	The city already produces 99% of the Asian Vegetable consumed and about 12% of the total agricultural production of the state. It may potentially cover up to 15% of the food requirements	Mok et al., 2014; McDougall et al., 2020

In Europe, therapeutic activities related to horticulture have been documented as beneficial already in the seventeenth century in Spanish psychiatric hospitals, whilst in America Benjamin Rush mentioned the practice of horticulture and gardening as a remedy for anxiety or phobic disorders or, more generally, against depression, in the eighteenth century (Smith, 1998). Nowadays, all over the world, horticulture is a consolidated and recognized practice for the treatment of a wide range of disorders in therapeutic programs. Furthermore, it is integrated in the aims and fields of activities of numerous associations such as the American Horticultural Therapy Association founded in 1973 (www.ahta.org), the Thrive founded in 1978 in England (www.thrive.org.uk), the Canadian Horticultural Therapy Association founded in 1987 (www.chta.ca), the Japanese Horticultural Therapy Society founded in 1996 (www.jhts.jp), the German Association for Horticulture and Therapy founded in 2001 (www.ggut.org), the Horticultural Therapy Swiss association established in 2004 (www.horticulturaltherapy.ch), and the Therapeutic Horticulture Australia (www.tha.org.au).

Social Inclusion and Justice

Within the sustainability rhetoric of UA (Tornaghi, 2014), social inclusion and justice have been commonly linked to UA initiatives. As a matter of fact, some initiatives have started as a reaction to urban policies, the marginality of neighborhoods or to economic crises (Anguelovski, 2013; Camps-Calvet et al., 2015; Gasperi et al., 2016; Reynolds and Cohen, 2016; Calvet-Mir and March, 2017). Accordingly, the regeneration of unused urban spaces and the creation of community networks to manage and access food production resources are seen as an opposition to the capitalistic framework of conventional food production (McClintock, 2010). Gardens can be a place where "collective efficacy" flourishes (Teig et al., 2009), where citizens can create community and empower themselves toward conflicts resolution and rights claiming. Such characteristics support the UA contribution to community improvement, including social inclusion and empowerment (Armstrong, 2000; Saldivar-Tanaka and Krasny, 2004; Wakefield et al., 2007; Teig et al., 2009; Taylor and Taylor Lovell, 2014; Camps-Calvet et al., 2015).

Notwithstanding the potential social benefits, society's impact mainly relies on the typology of initiative, as already reported for rooftop agriculture (Specht et al., 2017). Sanyé-Mengual et al. (2019) observed that socially innovative UA activities contributed to a larger diversity of social benefits than technologically-innovative ones. UA grassroots initiatives (e.g., community gardens, squatting gardening) commonly focus on enhancing social inclusion and justice, such as improving food access for low-income citizens, thereby creating socially inclusive spaces. On the contrary, within commercial initiatives, economic profit stands as main driver, while specific social aspects are usually sidelined (Poulsen, 2017).

Nonetheless, UA initiatives can also generate negative social impacts. Some bottom-up initiatives claiming social inclusion and justice have become places of injustice and exclusion, where elites can displace low-income and culturally-diverse citizens (Anguelovski, 2015). Access to UA programs can be imbalanced, accentuating social exclusion and injustice among the community instead of closing the gap between citizens with different economic and cultural backgrounds (Cohen and Reynolds, 2015; Reynolds and Cohen, 2016). On the other hand, when UA experiences are implemented by local governments in a purely top-down process without including the citizens through participatory approaches, ineffective and unsuccessful projects can appear, negatively affecting the local community (Gasperi et al., 2016). As an emerging new urban space typology, urban gardens can also ultimately contribute to urban green gentrification, as observed in Barcelona (Anguelovski et al., 2018).

Ecological Aspects

UA is strongly related to some *regulating* and *habitat* ES. Genetic agro-biodiversity is strictly linked to food security (Thrupp, 2000; Frison et al., 2011). In a survey on UA projects in 10 European countries (Pölling et al., 2016a), it was observed that about half of the considered cases promoted biodiversity preservation, by cultivating more than thirty crop types and varieties. Alternatively, limited biodiversity was only observed within intensive monocultural farms, including vine growers or greenhouses. UA also intrinsically foster biodiversity: more than 1,000 plant species were recorded in 267 private gardens in London (Loram et al., 2008) and 440 different species have been found in a single 400 m^2 allotment garden in Stockholm (Colding et al., 2006). Small and widely diversified urban crop systems also increase the vegetative complexity of the cities and can have positive effects on animal biodiversity, providing suitable habitats for the microbiological fauna (Tresch et al., 2019), invertebrates (Halaj et al., 2000; Sperling and Lortie, 2010), birds (Andersson et al., 2007), and mammals (Baker and Harris, 2007).

UA systems can have a relevant impact on the provision of arthropod mediated *regulating* ES, such as natural pest control and pollination (Shrewsbury and Leather, 2012; Lin et al., 2015; Bazzocchi, 2020). Allotment gardens often exhibit a rich abundance of flowering plants, supporting urban pollinators for long periods: at least a quarter of all known bee species in Vienna are hosted by communal gardens (Lanner et al., 2019) and 54 species (13% of the recorded New York State bee fauna) were found in few community gardens located in heavily developed neighborhoods in New York City (Matteson et al., 2008). Importance of increased floral resource availability and plant structural diversity of urban agro-systems has been demonstrated to maintain and promote presence of ladybugs (Bazzocchi et al., 2017), main agents of natural pest control.

In addition to habitat quality, habitat connectivity is a key factor. Some studies suggest that proximity to natural habitat can increase bees abundance and pollination success for a wide range of crop species (Ricketts et al., 2008). Agro-ecological corridors, exploiting a network of small, natural habitat fragments and cultivated patches across urban areas may affect the ability of beneficial insects (both pollinators and pest natural enemies) to persist in the urban landscape (Breuste et al., 2008; Burkman and Gardiner, 2014; Bazzocchi, 2020). On the other hand, potential disservices might come from UA and must be considered. Intensive UA, which can be characterized by pesticide application, extensive pruning, and frequent mowing, would presumably have a negative impact on biodiversity and ES. Moreover, not all biodiversity is necessarily "desired": some pests and pathogens are polyphagous and can benefit from vegetational diversification, and potentially dangerous mosquitos can proliferate due to the presence of stagnant water for irrigation (Winkler et al., 2010).

Economic and Environmental Sustainability

In recent years, research studies aimed at evaluating the environmental impact of UA initiatives have flourished, with a number of reference studies being released, with a main focus on Mediterranean Europe, including Spain (e.g., Sanyé-Mengual et al., 2015a) and Italy (e.g., Sanyé-Mengual et al., 2015b), also thanks to associated European (e.g., SustUrbanFoods, FewMeter, UrbanGreenTrain, and FoodE projects) and National (e.g., FertileCity project) fundings on the topic. Literature on impact assessment of UA systems often refer to innovative solutions and technologies, including aquaponics (e.g., Forchino et al., 2018), mushroom cultivation (Aubry and Daniel, 2017), rooftop farms and greenhouses (Sanyé-Mengual et al., 2015a,b; Grard et al., 2018; Sanjuan-Delmás et al., 2018), indoor and vertical farms (Liaros et al., 2016; Martin and Molin, 2019; Martin et al., 2019; Pennisi et al., 2019a,b), or resource use efficiency including energy (Nadal et al., 2017), organic waste (Dorr et al., 2017), or water (Opher et al., 2018). Nevertheless, applied studies on more traditional systems also exists, as for the case of urban gardens in Italy (Sanyé-Mengual et al., 2018a), USA (Algert et al., 2014) and Canada (CoDyre et al., 2015), or periurban commercial farms in The Netherlands (Benis and Ferrão, 2018). Besides evaluating existing strategies, some of these studies also indicate alternative management scenarios, including crop input and management, resource origin and management structures (Sanyé-Mengual et al., 2015b; Martin and Molin, 2019; Pennisi et al., 2019c). Nevertheless, each study's peculiarities and uniqueness (which relate to both the UA project itself and the specificities of the city where it takes place), often limit the possibility to drive general conclusions and implement widely applicable policy tools (Sanyé-Mengual et al., 2019). Indeed, by combining the available body of evidences, it emerges that environmental sustainability shall be specifically targeted by a series of actions, which can be summarized as follows:

- Cradle-To-Grave studies are very limited in number. Mostly, available literature concentrated to certain production stages and often excluded initial investments or infrastructural elements. More comprehensive research is needed to compare sustainability among urban and rural agriculture, with adequate emphasis on all stages associated with food production, transformation and distribution (Sanyé-Mengual et al., 2013). Such life cycle approach has been highlighted in the recently published Farm to Fork Strategy (EC, 2020).
- Available evidence is limited to specific case studies, often experimental or small-scale, and geographical areas, preventing the existing literature's capacity to draft conclusions on the actual contribution of UA in sustainability terms (Sanyé-Mengual et al., 2018c). Such aspect limits the capacity to define how UA can be framed in policy-making.
- The economic sphere and sustainability of newly born UA projects in the Global North still needs to be confirmed. Further studies should specifically target the identification of economic viability of innovative experiences, also through adequate valorisation of the ecosystem and environmental services they supply to the urban fabric (Sanyé-Mengual et al., 2018b). On the other hand, in order to elaborate viable strategies for UA in the Global North it becomes crucial that labor costs are included in the overall economic balance even when information are limited (Love et al., 2015) or associated costs could pose a risk on the financial viability of the experience (Algert et al., 2014).
- Cross sectorial studies are needed. Impact assessment needs to be comprehensive and shall not disregard any element within the three sustainability spheres (economic, environmental and social). Integrated tools—e.g., combining Life Cycle Analysis (LCA) with Life Cycle Costing (LCC) or Social Life Cycle Analysis (S-LCA)—are needed in order to compile a comprehensive and reliable vision on UA experiences. Economic analysis should also make use of financial tools including determination of Net Present Value (NPV), Internal Rate of Return (IRR) and Payback Period (PP). S-LCA may allow to better identify which variables—especially when economic figures associated to mere food production and marketing are non-sufficient to ensure viability—should also be accounted for in the evaluation of services provided by UA experiences (Sanyé-Mengual et al., 2018b).
- Environmental studies may provide functional tools to UA entrepreneurs and local policy makers through the creation of alternative scenarios (Martin and Molin, 2019). They allow to identify how local resources availability (including raw materials, energy or labor) may affect a certain project's sustainability, or how alternative management strategies may result in avoided impact. Overall, scenarios allow to widen the applicability of the study and offer adequate policy tools.

FACTORS THAT AFFECT DEVELOPMENT AND DIFFUSION OF UA

Growth and diffusion of UA may be hindered by factors that range from regulatory frameworks, access to land and its potential contamination, the local climatic conditions and resource availability. Each of these hindering factors will be targeted and discussed in the following sub-sections.

Laws and Regulations

Western World cities are densely populated and Europe is one of the most densely urbanized continents in the World, where, between 2012 and 2018, 539 km^2 of land is yearly transformed into housing, industries, roads or recreational uses (EEA, 2019). At the same time, the amount of green space per city dweller for many European cities remains below the minimum standard suggested by the World Health Organization (EEA, 2012). The percentage of green space in the cities of EU varies from 3 to 4 m^2 per person (Reggio Calabria, Italy) to more than 300 m^2 per person (e.g., Liège, Belgium, Oulu, Finland, and Valenciennes, France) (Fuller and Gaston, 2009). In this context, within the EU, strategies that aim at reusing and regenerating the so-called vacant land (Gasperi et al., 2016) have become key elements for territorial development and urban planning (EEA, 2015). They foster the sustainable use of the land by providing green habitats and peaceful places to promote respect for urban heritage (EC, 2010). These policies are geared toward a more sustainable and efficient use of resources, recognizing that land is a limited and declining resource, subject to competing pressures from urbanization, infrastructure, increased food, fiber and fuel production and supply of key ES (Gasperi et al., 2016).

While policies tend to promote green spaces and UA in the city carried out for ecological-environmental, aesthetic-recreational, and social-educational purposes (urban farming as a tool for social inclusion, intercultural dialogue and job creation such as in Bologna, Oslo, Barcelona or Paris), the same cannot be said for UA oriented toward food production. Apparently, while cross-sectoral innovation blooms, taking the form of new technologies (e.g., vertical farms, rooftop greenhouses), production and management models (e.g., community-based agriculture) or supply chain (e.g., solidarity buying groups, farmers markets), the integration of UA within the food system is slowed down by the lack of National and European policies and strategic frameworks (Fox-Kämper et al., 2018). Meanwhile, food consumption becomes accounted for as main driver of EU citizens' environmental impact (Sala et al., 2019), and, within the EU Green Deal, the improvement of the sustainability of the food system paves the way for the upcoming Farm to Fork strategy (EC, 2020), where UA may find appropriate ground for evolution.

Notwithstanding that more than 200 World Cities signed the Milan Food Policy Pact in 2015 (Filippini et al., 2019), a general and consistent uptake at global level is still lacking. A legislative and regulatory environment enabling to ease the establishment and management of small-scale and citizen-driven UA initiatives is needed, overarching the economic, environmental and social functions that sustainable food systems may play. Policies often underestimate the ES associated with multifunctional UA, overall resulting in a limited support to initiatives that in turn, as previously described, would provide climate change prevention and resilience, job creation and social inclusion. Furthermore, given that UA initiatives' long-term success is hindered by both the lack of training and the difficulties in formal community engagement (Ochoa et al., 2019), appropriate policies for awareness creation should be fostered. Accordingly, in recent years, some municipalities have integrated support policies for UA, as in the case of Paris (Colle et al., 2017) or Barcelona (Giacchè et al., 2016) as further described in the coming sections.

Land Access

Today, in developed countries about 20% of the global irrigated cropland is located in cities or within 20 km from the urban centers, where also 44% of the global rainfed agriculture occurs (Thebo et al., 2014). In urban settings, cropping intensity (expressing the amount of crops cultivated within a year in a specific plot) was also found to be higher in urban areas (1.48) (Thebo et al., 2014) than in rural areas (1.12) (Portmann et al., 2010), suggesting more intense rotations in the former, a phenomenon that has also been associated with higher population density (Ellis et al., 2013). In general, agricultural activities' success is correlated with the farm size (Hansson, 2007), given the reduced costs of production that can be achieved when economy of scale can take place (Bertoni and Cavicchioli, 2016). In cities, however, a major constraint limiting the development of UA projects is associated with land access, given that generally any other activity has a greater and faster return of investment (Wästfelt and Zhang, 2016), and the fact that UA still struggles to have a recognized economic role (Specht et al., 2016). Consistently, in USA, grassroot UA initiatives were shown to occur in districts with highest land value, a phenomenon that was linked with smaller plot size (Rogus and Dimitri, 2015) and therefore limited income perspectives (Centrone Stefani et al., 2018).

On the other hand, as cities grow, the phenomenon of urban sprawl is generally observed, with periurban areas characterized by dispersed, scarcely planned and low-density settings (Jaeger et al., 2010), where several unused or empty lots are usually found and named as *vacant lands* (Gasperi et al., 2016). In response to the economic and financial crisis started in 2007 (Heath, 2001), further voids in the urban fabric have emerged, including abandoned industrial districts, but also public buildings (e.g., dismissed army barracks, hospitals and schools) (Frumkin, 2003). In many cities, UA explores potential new uses for these *vacant lands* (Gasperi et al., 2016), by colonizing brownfields, empty rooftops or taking place within abandoned buildings. Municipal plans that foster urban regeneration through UA are also issued, providing land use rights to urban gardeners as for the case of the Green Thumb agency in New York (USA) (Smith and Kurtz, 2003), the Pla Buits in Barcelona (Spain) (Giacchè et al., 2016) or the Parisculteurs initiative in Paris (France) (Colle et al., 2017). Although UA projects are consequently sprouting in marginal urban lands, their long-term sustainability is posed at risk by factors that include small plot size (Ernwein, 2014), limited time concessions for land-use (Tornaghi, 2012), potential contamination risks (Vittori Antisari et al., 2015), space accessibility (Tornaghi, 2017) and distance from potential consumers (Ancion et al., 2019).

Environmental Contamination

When plants are grown within cities' highly anthropogenic environment, questions may arise on the potential contamination risks associated (Hursthouse and Leitão, 2016). While most commonly experienced contaminants are heavy metals or metalloids (B, As, Cd, Cr, Cu, Mo, Mn, Pb, Zn, Hg), a growing concern is also linked to specific localized components (e.g., selenium, or radioactive isotopes) and organic compounds (e.g., polycyclic aromatic hydrocarbons, poly-chloro-biphenyls, pesticides, dioxins and furans) (Megson et al., 2011; Mitchell et al., 2014). In the last couple of decades, the comprehension of how contamination originates and the possible strategies to tackle associated human health hazards was targeted by a relevant body of research activities (**Table 3**). It emerges that, within urban environments, contamination hazard generally varies according to the location where horticulture takes place, being higher in proximity of pollution sources (e.g., main roads, or within former industrial districts) (Hursthouse and Leitão, 2016) or as a consequence of the background geology of the site (Jean-Soro et al., 2014). Heavy metal deposition from nearby roads was however shown to decrease through distancing (e.g., by 25 m, Reinirkens, 1996), elevation (e.g., in rooftop gardens) or inclusion of vegetated barriers (Vittori Antisari et al., 2015). Conduction of accurate soil analyses and quantification of hazard risk (e.g., through application of contamination indexes) is generally recommended before starting the cultivation (Hough et al., 2004). Whenever contamination risk is confirmed, however, strategies may be set in place in order to limit the hazard, including integration of soil amendments or adoption of agronomic practices to reduce plant uptake of the contaminants (**Table 3**). Whenever UA takes place in potentially contaminated sites, the integration of peat or potting soil may also be an option to overtake contamination (Pennisi et al., 2016, 2017), although at the expenses of increased associated environmental impacts (Dahlin et al., 2019), which on a large-scale could pose at risk the overall sustainability of UA (Meharg, 2016). Alternatives to commercial/potting soils should therefore be considered, these including among others composted urban waste (Shrestha et al., 2020), spent coffee grounds (Cervera-Mata et al., 2019) or biochar (Song et al., 2020), assuming they do not contain further contaminants and are suitable for plant cultivation (Beniston and Lal, 2012; Hardgrove and Livesley, 2016).

Climatic Conditions

UA is playing a crucial function on the city environmental sustainability. Based on Koppel's climate classification, world

TABLE 3 | Strategies for reduced contamination risk in urban grown vegetables.

Prevention strategy		Contamination source	Experimental evidence	References
Location	Distance from roads	Air	Main contamination from road is limited within 25 m	García and Millán, 1994; Reinirkens, 1996; Charlesworth et al., 2011; Vittori Antisari et al., 2015
	Rooftop cultivation	Air, soil	Reduced contamination risk in rooftop grown vegetables due to height and distance from roads	Vittori Antisari et al., 2015; Liu et al., 2016
	Adoption of hazard indexes	Air, soil, water	Importance of site-specific risk assessment to reduce the risk of contamination	Hough et al., 2004
	Adoption of tree barriers	Air	Vegetated barriers between roads and gardens allowed to reduce contamination	Vittori Antisari et al., 2015
	Identification of past land use	Soil	Contamination is higher in areas that hosted refineries, petrochemical processing, timber and textile processing or mining sites	El Hamiani et al., 2010; Hursthouse and Leitão, 2016
	Background geology	Soil	Heavy metal contamination may also result from paedogenesis (e.g., As, Pb)	Jean-Soro et al., 2014
Genotype	Crop selection	Air, soil, water	Breeding and cultivar/species selection reduce risks posed by heavy metal contamination	Grant et al., 2008; Ghosh et al., 2012; Ding et al., 2013
	Crop genetic engineering	Air, soil, water	Plants can be genetically engineered to increase tolerance to heavy metals	Edelstein and Ben-Hur, 2018
Agricultural practices	Grafting	Soil, water	Herbaceous grafting can enhance tolerance to heavy metals in vegetables	Edelstein and Ben-Hur, 2018
	Bioremediation	Soil	Use of plants with elevate accumulation capacity allow to clean-up target contaminants in soils	Cunningham et al., 1995; Austruy et al., 2014
	Soilless cultivation	Soil	Reduced contamination when soilless system is used as compared to soil	Pennisi et al., 2016, 2017
	Agrochemicals management	Soil	Overuse of fertilizers or pesticides may result in heavy metal contamination	Hursthouse and Leitão, 2016; Pennisi et al., 2016
	Irrigation	Water, soil	Water quality and both its distribution strategy and applied volumes may modify contaminant presence in soil	Hursthouse and Kowalczyk, 2009
Soil amendments	Manure and compost	Soil	Modify heavy metal phyto-availability and their immobilization	Janoš et al., 2010; Pérez-Esteban et al., 2014
	Zeolites	Soil	Allow to remediate plant uptake of heavy metal in highly contaminated soil	Li H. et al., 2009
	Biochar	Soil, water	Can increase soil pH and contribute to immobilization of heavy metals (Cd, Cu, Pb)	Tang et al., 2013; Zhang et al., 2013
	Soil liming material	Soil, water	Allow to increase pH decreasing heavy metal availability	Abd El-Azeem et al., 2013
	Ashes	Soil	Fly ash increase phyto-stabilization of heavy metal-contaminated agricultural lands	Ukwattage et al., 2013
	Mycorrhizae inoculation	Soil, water	May influence heavy metal availability and uptake by plants in the rhizosphere	Edelstein and Ben-Hur, 2018

global north areas are mainly located within two main climate groups (temperate, C, and continental, D) based on seasonal precipitation and temperature patterns. The temperate climate (C) is characterized by coldest month averaging temperature between 0 and 18°C, with at least 1 month averaging above 10°C. Continental (D) climate displays at least 1 month averaging below 0°C and at least 1 month averaging higher than 10°C (Kottek et al., 2006). Most updated climate models foresee that extreme heatwaves will become more frequent and more intensive also in the Global North due to climate change (Huttner et al., 2009). The development of green spaces and infrastructures reduces urban heat island effects, mitigates rainwater impacts, and improves urban climatic metabolism (Ackerman et al., 2014). Indeed, functionality of green infrastructures is highly connected to plant vegetation status and management. A study carried out in Freiburg (Germany) (Huttner et al., 2009) reported that when natural soils in the urban and periurban areas are not covered with vegetation or not wetted by irrigation or rainfall during heatwaves, their effects on the microclimate are comparable to those from asphalted roads, leading to higher radiative temperatures.

Urban climate is also affected by the city size and the population density. Urban environments in the Global North are today experiencing growing population trends. In Europe, more than 70% of the population is living in urban areas today, and according to updated predictions, this number is likely to increase above 80% by 2050 (Kabisch and Haase, 2011). Intensified urbanization combined with the highest frequency of heavy rainfall are the leading causes of amplified peak flows and increased flood risk in the cities worldwide (Chang and Franczyk, 2008). Major cities in Europe are characterized by elevated (50–75% or even higher) fractions of impervious surfaces (such as roads, buildings, parking lots etc.), which translate into reduced water drainage and elevated risk of pluvial flooding (Du et al., 2015). Urban vegetation and well-planned UA spaces (including green roofs and parks) can significantly improve stormwater management decreasing the impact on the surface of heavy rain and providing run-off regulation and cooling through evapotranspiration (Orsini et al., 2014; Langemeyer and Latkowska, 2016).

Urban Resources

UA may substantially contribute to fostering sustainable resource use within the city metabolism, particularly with reference to water, mineral nutrients and energy fluxes. In cities, water for irrigation generally comes from municipal supply systems, leading to environmental and agronomic concerns (Wortman and Lovell, 2013). Indeed, alternative sources may include both rainwater harvesting and greywater or wastewater regeneration. In a GIS-based study it was recently estimated that if rainfall would be harvested from rooftops of nearby buildings and conveyed toward vegetable gardens in Rome, water saving could be in measure of 20 to 40% (Lupia et al., 2017). Theoretical scenarios of implementing rooftop greenhouses on retail parks roofs in different world cities (including Barcelona, Lisbon, Utrecht, and Rotterdam) indicated that crop water requirements could be satisfied by rainwater harvesting from the greenhouse roof (Sanyé-Mengual et al., 2018d).

The use of regenerated greywater may also significantly reduce the water footprint of UA, although concerns associated with pH or salinity may arise (Li F. et al., 2009), altogether with non-balanced mineral contents or microbiological load (Hanjra et al., 2012). With reference to the mineral nutrition of crops, the integration of composting of the organic waste and pruning residues was shown to markedly contribute to the urban horticultural production, although sanitary aspects shall be carefully considered in order to avoid risks associated with both microbiological load and heavy metal contamination (Brown and Jameton, 2000). Studies have demonstrated the viability of employing urban compost in substrate mixtures for UA (Grard et al., 2018). Moreover, as ambient CO_2 concentrations can be up to 80 ppm greater in urban areas relative to adjacent rural areas due to the combustion of fossil fuels, increased photosynthetic rates may also be experienced in UA (Ziska and Bunce, 2007). With reference to the urban energy balance, the distribution and presence of green infrastructures throughout the urban fabric may significantly reduce the so-called urban heat island effect, both resulting in improved city liveability and reduced heat associated mortality during warmer seasons (Qiu et al., 2013). On a smaller scale, when building-integrated agriculture takes place (e.g., in rooftop greenhouses), an integrated building metabolism was shown to improve water, energy and carbon fluxes, while also supplying a range of ES (Piezer et al., 2019).

MAIN TYPOLOGIES OF UA SYSTEMS

In recent years, also in northern global areas, UA has been considered a strategy to contribute to food security and city environmental sustainability (Taylor and Taylor Lovell, 2014). Within the coming sections, established typologies of UA systems popular in Global North are described (**Table 4**), mainly focussing on allotment gardens, extensive periurban farms and community gardens. Furthermore, this section will introduce some innovative growing systems specifically developed for the urban environment. These range from building-integrated agriculture systems, taking place on building rooftops (e.g., rooftop gardens and greenhouses) or even inside them (e.g., indoor or vertical farms with artificial lighting). Furthermore, the section also explores new crops that are increasingly adopted in UA, thanks to the market opportunities provided by the urban environment and the proximity to consumers.

Allotment Gardens

Private and public urban gardens for vegetables production are widespread all over the world. Historically, allotment gardens were set up with the primary goal to mitigate poverty by providing fresh food among factory workers during the industrial revolution or later during wars and depression times (Barthel et al., 2013). Their relevance was dramatically increased during the first half of the twentieth century, during the two World Wars, when agricultural products could not easily reach the city markets and were sold at elevated prices or on the black market. Consequently, foodstuffs' production, especially fruit and vegetables, became essential for the survival of cities' inhabitants. Urban gardening was then considered as a patriotic act, enabling to feed citizen and the army, while governmental propaganda called for action in the so-called "war gardens" or "victory gardens" (Miller, 2003; Lawson, 2004). As a result, in those years, the number of vegetable gardens rose dramatically in almost all cities touched by the war where not only family and urban gardens but also public parks and roadways' edges were cultivated. During the conflict, areas destroyed by bombing were also used for growing crops. After the war, reconstruction activities began: jobs, industries, cities were growing, the price of building land dramatically raised and the phenomenon of allotments gardens significantly decreased. But the gardens did not disappear; they moved from the city center to the suburbs and frequently reappeared as squatting. They were commonly associated with the concurrent migration process experienced from the rural areas to the city's outer skirts (Tei et al., 2009). Then, since the 1980s, a "renaissance" of UA has been noticed. Urban gardens originally aimed at ensuring food security evolved, addressing other key roles (ecological-environmental, aesthetic-recreational, social-educational, therapeutic) in relation to the changed economic and socio-cultural conditions (Crouch, 2000; Wells, 2000; Hynes and Howe, 2004; Tei et al., 2009; Meneghello et al., 2016; Righetto et al., 2016).

During the last 50 years, the local municipalities promoted the establishment of urban gardens by providing the land, establishing a water system, and eventually fencing the area. In most cases, urban allotment gardens are organized in associations

TABLE 4 | Main UA system typologies in the Global North.

UA system	Typology	Products	Technology level	User type
Allotment gardens	Traditional	Vegetables	Low level	Society
Extensive periurban farms	Traditional	Vegetables, processed products, animal products	Low to medium level	Farmers
Urban community gardens	Traditional	Vegetables	Low level	Society
Rooftop farms	Innovative	Vegetables	Medium to high level	Farmers, society
Vertical farms with artificial lighting	Innovative	Vegetables	High level	Farmers
Microgreens	Alternative	Vegetables	Low to high level	Farmers, society
Food-forestry	Alternative	Fruits	Low level	Society
Aquaponics	Alternative	Fish, vegetables	High level	Farmers
Urban beekeeping	Alternative	Bee products	Low level	Farmers, society

or committees for decision making (Bell et al., 2016). Sometimes, they also appear to be integrated within urban agricultural parks, as for the cities of Rome and Barcelona (Colantoni et al., 2017). Allotment gardeners are generally requested to pay a small rent for the plot and attend specific association duties. Production is intended exclusively for self-consumption or limited to donation, as in most cases the sale is not allowed by municipal regulations (Barthel et al., 2013). Today food production is not anymore the only primary purpose but also other functionalities are acknowledged, including aesthetic-recreational and educational (Wells, 2000), social (Tei et al., 2009), or therapeutic (Crouch, 2000). Also in Italy these types of gardens have evolved in their form in the last decades (La Malfa et al., 2009), mainly under the framework of the Italian association for recreation, culture and gardens (*Associazione Nazionale dei Centri Sociali Ricreativi Culturali ed Orti—ANCeSCAO*), that provides gardeners with administrative and insurance support (Gasperi et al., 2012) and today accounts for more than 360,000 members, and manages 1,400 social centers and 22,000 vegetable gardens. Similar organizations are found in Germany such us *Kleingaerten and Schrebergaerten* (Drescher, 2001), *Real Food Wythenshawe* in UK (Bell et al., 2016), *Gezonde Gronden* in The Netherlands (van der Schans, 2010), *Pispala allotment* in Finland (Bell et al., 2016), and *ROD Obroncow Pokoju* in Poland (Bell et al., 2016) and have proven to be a useful means for learning democratic rules as well (Gasperi et al., 2012).

Extensive Periurban Farms

In recent years, the relevance of urban and periurban farming in terms of food production in cities and their contribution to food security has been a matter of extensive research. Whether or not to include periurban farms as a part of UA has been discussed in several ways, with most authors suggesting their inclusion and adopting the more general definition of Urban and Periurban Agriculture (UPA) (van der Schans and Wiskerke, 2012; Mok et al., 2014) or metropolitan agriculture (Heimlich, 1989), both synonyms of the more general concept of UA adopted in the present manuscript. While UA's primary purpose is still meeting food needs mainly at the household level (Petts, 2005), extensive periurban agriculture can provide more substantial quantities and has broader distribution pathways, allowing for significant contributions in terms of food supply at city level in the Global North. Extensive periurban agriculture farms nowadays provide goods and services both for the local and global markets (Opitz et al., 2016). These farms emerge within the "transition area" between urban and rural environments, characterized by lower population density with lesser infrastructures and buildings, whilst concurrently featuring a more limited land availability for agriculture use as compared to rural areas (Allen, 2003; Piorr et al., 2011).

In extensive periurban farms, multifunctionality at the farm level appears, with farms providing not only agricultural goods and food, but also services to the community as well as public functionalities (Le and Dung, 2018). Representative case studies of periurban farms are found within metropolitan areas in several cities of the Global North. In Bologna (Italy), *Spazio Battirame* (https://www.etabeta.coop/spaziobattirame/), is a place of socio-recreational and educational activities created and developed as an urban regeneration project by the social cooperative Eta Beta (Gasperi et al., 2016). In *Spazio Battirame*, cultural events, handcraft laboratories and concerts are organized, while organic vegetables are produced over 4 hectares of open-fields and marketed through solidarity buying groups and participation in weekly farmer's markets. A professional kitchen serves a bar-restaurant and hosts cooking courses and food-related activities. The project has a strong social connotation, and functions include inclusive job creation, education and training, urban regeneration and sustainable growth (Cavallo and Rainieri, 2018). In the fringes of the city of Angers (France), proximity agriculture takes place at *Le jardin de l'avenir* (The future garden, https://www.jardindelavenir.fr/). The farm, extended over almost 9 hectares, operates on a pick-your-own scheme, where local residents may access the farm and harvest fruits and vegetables based on their needs and then weight and pay them at the counter. The farm is managed following principles of organic farming and permaculture, while environmental sustainability is also targeted through the co-generation of electricity for the farm needs and the local energy supplier. A similar scheme is adopted by the farm *Hof Mertin* (Germany), placed in the densely urbanized and industrial region of the Ruhr (Pölling et al., 2017). The farm (https://hof-mertin.de/) extends over around 120 hectares, out of which 40 are devoted to strawberry cultivation and integrated in a pick-your-own scheme or used for educational or socio-recreational workshops. In Ontario (Canada), a survey involving 21 periurban farmers highlighted that, while proximity to city may open up new marketing opportunities, the overall sustainability of the sector strongly depends on the existence of infrastructural and policy measures to link UPA with the local market (Akimowicz et al., 2016). It appears that while periurban farmers may benefit from the nearly rural conditions of their environment, a set of diversified and adaptive strategies must be integrated in order to attract local citizens and involve them into alternative food networks, as also evidenced in a recent study in the city of Barcelona (Spain) (Paül and McKenzie, 2013).

Urban Community Gardens

The term "community garden" refers to "open spaces which are managed and operated by members of the local community where food or flowers are cultivated" (Holland, 2004; Pudup, 2008). Nowadays, community gardens are growing in popularity in response to the shift toward cooperative forms of spatial design and land-use, and reflect the shift from government to governance including changing roles, responsibilities and impact of government agencies and local citizens (Rosol, 2010). They can involve a wide range of groups such as schools, prisons, youth, the elderly, hospitals, and neighborhood residents (Pudup, 2008; Teig et al., 2009). Different studies emphasized that community gardens are not only a source of food but provide other benefits, such as community building, education, and promoting health (Turner, 2011). Indeed, the most common motivation to take part of a community garden by citizens are: to consume fresh foods, social development or cohesion such as community building and culture exchange, to improve health among members and to make or save money by eating from the garden or selling the produce (Guitart et al., 2012). It was recently estimated that 86% of community gardens in USA were used to grow food, flowers and native vegetation. The same study also revealed that 82% of community gardens were operated by non-profit organizations, including cultural and neighborhood groups (Guitart et al., 2012). Further research studies confirm that community garden members are rather heterogeneous in terms of education, age, gender and financial aspect and usually lack previous gardening experience (Bell et al., 2016).

Community gardens can also be classified based on their own government structures (Fox-Kämper et al., 2018). Nettle (2016) observed that community gardens can be classified as either top-down or bottom-up governance structures depending on who initiated them. McGlone et al. (1999) noted the difference between gardens that were managed by external professionals (top-down) and those that were managed by community members including professionals (bottom-up). Top-down community gardens are implemented with the help of enabling legislation passed by local or central government (Nettle, 2016) and external/private officials carry out the management of the garden in order to meet government-set outcomes (McGlone et al., 1999). On the other hand, bottom-up community gardens build upon a direct involvement of the local community. Indeed, in the latter case, the community garden is planned and devised through collaboration by community groups (Okvat and Zautra, 2014) as well as the implementation with the help of enabling legislation passed by local or central governments (Nettle, 2016). The community also collaborates to devise a management scheme for the garden (McGlone et al., 1999). Among the most famous cases of community gardening in the Global North may be found several initiatives in the city of Berlin (Germany), including *Allmende Kontor* (https://www.allmende-kontor.de/) in the former Tempelhof airport, *Ton Steine Garten* (http://gaerten-am-mariannenplatz.blogspot.com/) in the Kreuzberg area or experiences of community entrepreneurship found in both Prinzessinengarten (https://prinzessinnengarten.net/) and Himmelbeet (https://himmelbeet.de/) (Wunder, 2013; Bradley and Hedrén, 2014).

Rooftop Farms

Within cities, plant cultivation on the rooftops of buildings has been recently gaining global attention (Orsini et al., 2017). It may take place both in protected (rooftop greenhouse) and non-protected (open-air rooftop farm) conditions (Sanyé-Mengual et al., 2015b). Among growing technologies, soil-based (e.g., soil-filled containers) or soil-less (e.g., hydroponics, aquaponics) systems are commonly adopted (Nasr et al., 2017). Due to the peculiar specificities of the environment where it takes place, rooftop agriculture may be constrained by the rooftop structural loading capacity, its accessibility to people and to agricultural input and tools, and the elevate solar radiation and temperature ranges (Caputo et al., 2017). On the other hand, benefits may be associated with rooftop gardening, including potential energy saving up to 15% thanks to the thermal insulation provided by the green cover (Wong et al., 2003). Besides, when a rooftop greenhouse is present, further advantages may be associated with its integration within the building metabolism (e.g., in terms of energetic fluxes and both water and carbon recirculation) (Sanyé-Mengual et al., 2015b).

The majority of rooftop agriculture projects is represented by open-air rooftop farms or gardens that use low-tech systems such as raised beds filled with soil (Thomaier et al., 2015). While the absence of physical barriers may be associated with higher exposure to the atmospheric pollutants' deposition, the higher elevation and the adoption of hydroponics were shown to generally limit the contamination risk in rooftop farms (see section Environmental Contamination, Vittori Antisari et al., 2015). On the other hand, rooftop greenhouses are generally associated with sophisticated technologies, targeting both increased production capacity and resource use efficiency (Sanyé-Mengual et al., 2015b). While open-air rooftop agriculture is widely adopted in the Global South, high tech commercial rooftop farms generally take place in North America, Asia and Europe in the form of business-oriented start-ups with economic profitability as the first aim (Specht et al., 2015). However, rooftop farms are also often associated with non-profit aims, e.g., the amelioration of urban living quality or communities' involvement in social, recreational and educational activities (Thomaier et al., 2015). Furthermore, rooftop cultivation can also represent a marketing action for hotels and restaurants, which offering fresh and self-produced products to customers can ameliorate their image and gain preference among the public (Thomaier et al., 2015).

Rooftop farms may either be located in existing buildings or integrated in new constructions (Buehler and Junge, 2016). In the former case, higher costs for refitting, less rational use of the rooftop space and a limited range of applicable cultivating techniques are commonly experienced (Caputo et al., 2017). Nevertheless, due to a slow uptake of rooftop farming technologies among estate operators and building companies, adaptation of existing buildings still represents the majority of rooftop farming projects (Thomaier et al., 2015).

Vertical Farms With Artificial Lighting

One of the most technologically oriented growing solution for cities is the use of plant factories with artificial lighting (PFALs). PFALs are cultivation systems where the environmental factors (e.g., air temperature and humidity, light, CO_2 concentration) are controlled by minimizing exchanges between indoor and outdoor environments, thanks to the adoption of insulated cultivation room where a minimum amount of air and heat is exchanged with the outside (Kozai and Niu, 2016). The enclosed system also enables the farm to achieve resilience to extreme events and easier control of pest and pathogens as compared to more traditional cultivation systems (Kozai, 2019). Nevertheless, it has also been suggested that when pest outbreaks take place in PFALs, their impact may be dramatic, due to the combined effects of the relative proximity of plants (both in vertical and horizontal dimensions), as well as the intense air circulation fluxes needed to guarantee environmental uniformity (Roberts et al., 2020).

Among the advantages of PFALs, one extremely relevant in the urban environment is the reduced pressure on land, obtained by exploring the vertical direction through multilayers cultivation systems fed by artificial lighting devices (Beacham et al., 2019). Besides, the benefits associated with hydroponics and possible de-humidification and water recovery from the internal atmosphere allow for elevated water use efficiency (Pennisi et al., 2020a), in the range of 30–50-folds the measured values in greenhouses and open-field cultivation (Kozai, 2013). On the other hand, the elevated energetic requirements (mainly due to electricity consumption associated with artificial lighting, Paucek et al., 2020) are still hindering the large-scale applicability of these systems (Kozai, 2019). Indeed, while technology is rapidly evolving, strategies for reducing the environmental burdens associated with PFALs are also being identified (Son et al., 2016; Martin and Molin, 2019; Pennisi et al., 2019c, 2020c; Orsini et al., 2020) and will likely foster the large-scale application of these technologies in the near future. To date, the most common plant species grown in PFALs are leafy vegetables (e.g., lettuce, basil, microgreens), medicinal plants (e.g., cannabis or other crops used in the preparation of pharmaceutical, herbal or cosmetic products), small fruit (e.g., berries), edible flowers and seedlings (e.g., grafted vegetable) (Kozai, 2013).

Beyond Vegetables: Alternative Farm Products in Urban Environments

UA takes many forms and involves a diversity of actors and products. Among new forms of UA, *microgreens* cultivation is gaining relevance and popularity in the Global North. Initiated in the early 80s in California, microgreens are tiny edible greens harvested just after the first set of true leaves, known for their high rate of antioxidants and micronutrients. Because of their limited space needs and their elevated water use efficiency (Durham, 2017), microgreens are well-adapted to UA and, as a matter of fact, many worldwide urban PFALs and vertical farms are dedicated to or include microgreens cultivation (Kozai, 2018; Butturini and Marcelis, 2020). Furthermore, their post-harvest storage requirements may be substantially reduced when they are grown in proximity to consumers, an important feature given their limited shelf-life (Durham, 2017). Alternatives to the conventional purchasing and large-scale retail trade are the sale to-order (e.g., *Brooklyn Grange* rooftop garden in New York City) and the "in-store farming" through modular automated incubators that can be placed in a variety of customer-facing city locations (Butturini and Marcelis, 2020). Homemade self-production is also greatly increasing. Similarly to microgreens, *edible flowers* are also gaining relevance in UA projects, where they find commercial uses thanks the growing interest from chefs and top-class restaurants, their elevated nutritional properties and their limited shelf-life (Mlcek and Rop, 2011).

Another growing strategy in UA is associated with *food-forestry* (crop and animal farming coupled with cultivation of woody perennial plants). Strategic combination of fruit- and nut-producing trees and herbaceous crops meets a multifunctional role of UA contributing to *provisioning* (food production) and *regulating* ES (carbon storage, runoff management, air quality improvement, soil erosion control, climate mitigation) (Clark and Nicholas, 2013). Urban food-forestry projects have been described for at least 37 cities in USA (Clark and Nicholas, 2013), 47 municipalities in Canada (Konijnendijk and Park, 2020) and a growing number of cities in Europe (Park et al., 2019). Related to urban forestry is the concept of *urban foraging*. The renewed interest for the harvesting of forest and rural edible wild species is also becoming popular in many worldwide urban contexts of developed countries (Shackleton et al., 2017; Konijnendijk and Park, 2020).

Aquaponics combines fish farming in smart water environment (aquaculture) and soilless plant production systems (hydroponics). The system is based on a closed water cycle in which fish dejections become inputs for plants development thanks to nitrifying bacteria's action, whereas plants act as filter to clean the water, which can be re-circulated back to the fish tank. Economic and ecological (primarily because the decrease in freshwater availability) sustainability of aquaponics is under investigation (Quagrainie et al., 2018). Interestingly, aquaponic systems can be combined with building-integrated wastewater management in cities (Steglich et al., 2020). An important pilot case is the *Berlin Roof Water Farm* (RWF) in which gray water, treated and mixed with rainwater, is used to irrigate the rooftop aquaponics system, and black water (rich in nutrients) is processed into a liquid fertilizer for UA purpose (Steglich et al., 2020).

A systemic and multifunctional approach is also at the base of the integration of *microalgae* production systems into innovative urban infrastructures. Production of microalgae as food for humans and feeds for animal and fish (e.g., Spirulina) or as energy-based biomass, can outperform other renewable resources with their potential to absorb CO_2, recycle wastewater, and release O_2 (Peruccio and Vrenna, 2019).

Urban bee keeping has been established in ancient times within the Mediterranean basin (Mavrofridis, 2015). Bees (both wild and reared) easily adapt to the urban environment thanks to the warmer temperatures, a wider variety of plants for pollination and foraging, and lower level of pesticide pollution in comparison with agricultural landscapes (Blum, 2017; Hall et al., 2017). Born as an activity linked to urban ecology and the decline of pollinators and honeybees' populations (Lebuhn et al., 2013), urban beekeeping has recently boomed in popularity. Beehives can be found in many cities of the Global North (e.g., New York City, London, Berlin), including in private (e.g., hotels) and public (e.g., operas) buildings, mainly motivated by the cultural and experimental interests of city dwellers (McCallum and Benjamin, 2012). Although, there is a substantial lack of quantitative data on the production and marketing of honey and other beehive products (e.g., wax, propolis, venom) coming from urban beekeeping, economic value of urban apiculture is rising, also in relation to educational and recreational side activities. Some concerns have however been raised on the possible negative effects that domesticated beekeeping could have on the native urban bee fauna, mainly related to competition for flora and disease spreading (Mallinger et al., 2017).

THE UA ECONOMIC DIMENSION: TOWARD A CLASSIFICATION OF BUSINESS MODELS (BMs)

The narrative of economic development in cities from the Global North has recently started to associate UA to key sustainability indicators. The definition of economic viability of UA experiences is however a complex and multifaceted exercise. Financial performances of UA are often benefitting from both external funding and availability of unpaid/voluntary workforce, which often follow alternative, non-capitalist economic logics, as recently analyzed in UA projects in Boston (Massachusetts, USA) (Biewener, 2016). Consistently, a comparative study integrating qualitative and quantitative data from self-harvesting, intercultural and community gardens in Germany revealed that participants are often more concerned on benefits than costs and that sharing and self-governance are predominant ambitions over economic viability (Krikser et al., 2019). Economic indicators and employment opportunities are also highly variable among UA projects (mainly due to the economy of scale and mechanization), as observed in Denver (Colorado, USA) (Fisher and Karunanithi, 2014). Nevertheless, and despite the potential role UA may play toward social and economic justice, policies and financial support often tend to concentrate on UA economic competitiveness, perceived as indicator of enduring and sustainable urban planning (Walker, 2016). Accordingly, and as UA assume growing economic relevance, several attempts have also been made to classify its emerging business models (BMs) (van der Schans, 2010; Liu, 2015; Pölling et al., 2016b; van der Schans et al., 2016). While some models are recurring within all existing literature (e.g., *cost-reduction* BM, *differentiation* BM, and *diversification* BM), emerging strategies are also being integrated as they become commonly adopted. This include the so-called innovative operations (Liu, 2015, now more commonly referred to as *experimental* BM), but also "the commons" (van der Schans et al., 2016, hereby referred to as *share economy* BM) and the *experience* BM (van der Schans et al., 2016).

In the present paper, reference will be made to the more recent classification of BMs in urban farming projects resulting from the EU project Urban Green Train (Urban Green Education for Enterprising Agricultural Innovation) (Magrefi et al., 2018) (**Table 5**).

Cost-Reduction BM

Cost-reduction BM includes farms that build their success on reducing costs associated with crop production. As for traditional agriculture, reducing costs and increasing profit through efficient economy of scale may also prove viable in urban environments (Zasada, 2011). For instance, it is the case of greenhouse farms in the periurban fringes that benefit from the increased market opportunities provided by the proximity of the consumers (Péron and Geoffriau, 2007). The economic viability of proximity farms may also benefit from in-farm shops, participation in farmers market, or integration in consumer delivery schemes, as for the cases of the so-called solidarity buying groups (Opitz et al., 2016), where direct delivery at distribution points within the city is practiced. In this last option, users often purchase a fixed amount of fruits and vegetables, whose composition will reflect the seasonal availability of locally produced goods (Vogl et al., 2003). *Cost-reduction* farms often evolve toward other business models in order to take benefit from the existing and multiple marketing offer (e.g., services associated with food distribution and marketing, as for the following BM categories) that the city can provide (Gasperi et al., 2016). Benefits associated with the proximity from consumers can be associated with reductions in requirements for transport, packaging (Sanyé-Mengual et al., 2013), as well as reducing food losses (Dimitri et al., 2016).

Diversification BM

Diversification BM includes farms that produce a diversified variety of products and services. There are two main categories of diversified urban farms, depending on their original core business. The first typology encompasses those cases where farmers may decide to integrate additional products and services to their main agricultural production. These may be urban peasants that integrate their food production and marketing with services (Dixon et al., 2007). Alternatively, there may be the case of the so-called "new farmers," represented by entrepreneurs, private companies or non-for-profit bodies that have their core business in other sectors and start to explore agriculture in the urban settings. Under this category often fall socially involved

TABLE 5 | Main business models associate with UA systems in the Global North.

BM type	Strategy	Examples
Cost-Reduction	Building success on reducing costs associated with crop production, toward economy of scale	Periurban greenhouse farms benefitting from the increased market opportunities provided by the proximity of the consumers
Diversification	Production of diversified variety of products and services	Socially-involved institutions, horse-riding farms, agro-tourism and educational farms
Differentiation	Differentiation from competitors for the uniqueness of their specific product or production protocol	Organic and biodynamic certifications
Share-Economy	Collective management, where production risks are shared within a community	Grassroots experiences (e.g., cooperatives)
Experience	Revenues mainly associated to the marketing of a specific experience rather than a farm product *per-se*	Cooking experiences, learning experiences (e.g., workshops)
Experimental	Exploration of high levels of innovation, generally linked to new food producing technologies or adaptation of existing solutions to the urban environment	Indoor vertical farms, rooftop greenhouses or aquaponics

institutions (including those providing job opportunities to disadvantaged users, Gasperi et al., 2016), which initially started in other sectors (e.g., handcrafting, catering) and more recently also engaged in agricultural activities thanks to the grown public awareness of sustainable food systems (Sanyé-Mengual et al., 2018b). A further classification is adopted to identify whether the *diversification* stands on a business-to-business (B2B) scheme (e.g., when electricity is produced through solar panels installed in the farm premises and energy is sold to the local energy supplier, Nelkin and Caplow, 2007, or when local compost plants that process urban bio-waste supply the organic matter that is then used for plant cultivation, Deelstra and Girardet, 2000), or on a business-to-consumer (B2C) scheme (e.g., when additional services are provided to the final users, including horse-riding farms, agro-tourism and educational farms, Pölling et al., 2017).

Differentiation BM

Differentiation BM includes farms that differentiate themselves from the competitors for the uniqueness of their specific product or production protocol. Urban farms that operate into the *differentiation* BM may concentrate on a specific niche product (e.g., an ancient tomato cultivar, van der Schans, 2010), or a special production factor specifically available in the city (e.g., rainwater collected from neighboring buildings and used for plant irrigation), a special strategy to target the consumer (e.g., pick-your-own fields, Vogl et al., 2003, or rent-a-field schemes, Pölling et al., 2016b) or determinate standards for food production (e.g., an organic or biodynamics certification scheme, Beauchesne and Bryant, 1999). Interestingly, when vertical integration is set in place (e.g., by implementing transparent, reliable and personal relationships between producers and consumers), differentiated farms may benefit from important market opportunities. These may reflect in more traditional B2C schemes, but also in B2B commercial agreements, where restaurants, canteens or food festivals are engaged in promoting locally-produced food (Pölling et al., 2016a).

Share-Economy BM

Share-economy BM includes collectively managed projects where the production risks are shared within a community. From an economic dimension, the *share-economy* BM entails for the highest level of innovation. They originate from the concept of "commons," bringing together communities into collaborative efforts toward the achievement of a shared objective. In France known as AMAP (Tang et al., 2019), elsewhere generally referred to as Community Supported Agriculture (CSA) schemes (van der Schans et al., 2016), they generally originate and grow from grassroots experiences of groups of activists and environmentally concerned citizens. In these experiences, citizens move from consumer's concept and become so-called prosumers, capable of influencing the structure and overall sustainability of their food systems. A crucial element (that constitutes the main evolution from the previously described farmers markets or solidarity buying groups) stands in the recognition that agriculture plays a main functional role in the society and that responsibility of food systems sustainability shall be distributed. Accordingly, the production risk (which is also being exacerbated by price fluctuations in a global market and uncertainty of production in response to climate change) is distributed among the different food stakeholders rather than placed only on farmers (Pölling et al., 2016a). Beside CSA schemes, citizens are also engaging in collective actions in the Global North, including the establishment of so-called Food Policy Councils, where active citizenships results in modifying public procurement schemes (e.g., in schools and prisons), as occurred in the city of Berlin, where the establishment of the local Ernahrungsrat (Food Policy Council) in 2015, significantly contributed to the creation of a food strategy and a dedicated municipal office (Berlin Isst so—Unsere Ernahrungsstrategie) devoted to improve sustainability of the food system (Braun et al., 2018).

Experience BM

Experience BM includes projects where the revenues are mainly associated with marketing a specific experience rather than a farm product *per-se* (Pölling et al., 2015). The BM targets the growing necessity in urban citizens to reconnect with nature and experience traditional cooking recipes (e.g., recovering traditional ways to process a tomato sauce, or hand-making of pasta) or learn gardening skills (e.g., recognizing wild edible species, or acquiring synergistic or permacultural cropping techniques) (Pölling et al., 2017). Experience may take place in the form of intensive workshops (as for the "kill-your-own chicken" workshops organized at *Nettle Farm*, Rhode Island, USA, *La Bibioteca*, Fermo, Italy, or *Uit Je Eigen Stad* in Rotterdam, The Netherlands, Gustafsson and Olsson, 2016), but also as non-organized activities that are made accessible within the farm (e.g., sensorial paths or pick-your-own fields, Yoshida et al., 2019).

Experimental BM

Experimental BM includes projects that retain a high level of innovation, generally linked to new food producing technologies or adaptation of existing solutions to the urban environment. Innovation may fall within the production technology (e.g., indoor vertical farms, rooftop greenhouses or aquaponics, Calone et al., 2019), but also in the processing stage (e.g., through integration of urban waste flows or the set-up of circular schemes, Pulighe and Lupia, 2019) or in the functions (e.g., regeneration of abandoned districts or brownfields revitalisation, Gasperi et al., 2016). In these systems, technology is often at beta stage, and the project sustainability often benefits from available public or private funding for research and innovation activities (O'Sullivan et al., 2019).

BUILDING AN INVENTORY OF UA PROJECTS IN THE GLOBAL NORTH

To date, a comprehensive census of UA projects and initiatives in the Global North has not yet been compiled, although some attempts of building local inventories exist, mainly in the framework of national and international projects. Entrepreneurial UA projects in Europe were recently listed in two highly comprehensive inventories in the framework of both the COST project TD1106 Urban Agriculture Europe (http://www.urban-agriculture-europe.org, Pölling et al., 2016b) and the Eramus+ project Urban Green Train (https://site.unibo.it/urbangreentrain/en/, Renting et al., 2016), altogether with classifications based on adopted business models. Similarly, a list of urban municipal gardens was compiled in the framework of the COST project TU1201 Allotment Gardens in European Cities (https://www.urbanallotments.eu/, Bell et al., 2016). Educational school gardens were also analyzed within the Erasmus+ project GardensToGrow (http://www.gardenstogrow.eu/, Pennisi et al., 2020b). The sustainability assessment of UA projects was mainly targeted within the H2020 MSCA project SustUrbanFoods (https://susturbanfoods.com/, Sanyé-Mengual et al., 2019) and the ClimateKIC action UrbaClim (http://www2.agroparistech.fr/Projet-URBACLIM.html, Lelièvre and Clérino, 2018). Similar research is also conducted within the JPI Urban Europe project FEW-Meter (http://www.fewmeter.org/en/home/), which targets assessment of resource use in UA projects in both Europe and North America (Ponizy et al., 2018). Moving to North America, among the mostly acknowledged projects, CarrotCity (https://www.ryerson.ca/carrotcity/), evolved from a book that aimed to compile a comprehensive database of UA experiences (Nasr and Komisar, 2014) and allowed for the creation of a mobile exhibition of featured case studies, which between 2009 and 2015 was displayed in cities across North America, Europe, Africa and Asia. Within the present manuscript a comprehensive inventory of UA projects built on all abovementioned databases was compiled (**Supplementary Table 1**), comprising all projects established in countries with developed economies (United Nations, 2020). The search provided no queries associated with some countries within the list, namely Finland, Luxemburg, Croatia, Cyprus, Estonia, Hungary, Latvia, Lithuania, Malta, Romania and New Zealand. Nevertheless, a total inventory of 470 UA projects (respectively, 288 in Europe, 97 in North America, 5 in Asia, and 80 in Oceania) was compiled, whose main features (including area, farming purpose and business models adopted) are hereby summarized (**Figure 2**). For comparative purposes, the main farming purpose and main business model were reported for each project, although these can be combined with other farming purposes and business models. The database shall be considered as updated at May 2020. Out of the 470 cases considered, surface data on the cultivated area was provided by 417 cases.

Statistically significant association [X^2 (25) = 92.568, $p < 0.000$] between projects dimension class and business model typologies was observed (**Figure 3A**, $n = 399$). Share-economy business model is highly (>49% of the total) diffuse in small projects with a surface area lower than 5,000 m^2, while in general experience and experimental business models are less frequent for all the considered projects dimension class. From the standardized residual analyses, it emerged that diversification business model was more common (38.7%) for projects with a surface area ranging 25,001 to 100,000 m^2 (see **Supplementary Table 2**) as compared to the other projects dimension classes, while differentiation business model resulted more represented in the biggest project dimensions category (surface area > 100,000 m^2), where, on the other hand, share-economy business model resulted statistically underrepresented.

A statistically significant association [X^2 (20) = 137.519, $p < 0.000$] between class of projects dimension and farming purposes was observed (**Figure 3B**, $n = 407$). In general, it was observed that social and educational purpose is highly represented (>54% of the total) in small projects with a surface area lower than 5,000 m^2, while for the biggest project category purpose is more common (80% of the total). From the standardized residual analyses, it resulted that projects with commercial purpose were underrepresented in small project category (surface area ≤1,000 m^2), but more common in projects belonging to the highest projects dimension class, trend which resulted completely inversed for social and educational projects (see **Supplementary Table 3**). Furthermore, also projects with image purpose resulted overrepresented in the smallest project dimension class.

Contrarily, chi-square test did not show a statistically significant relation between class of projects dimension and cities

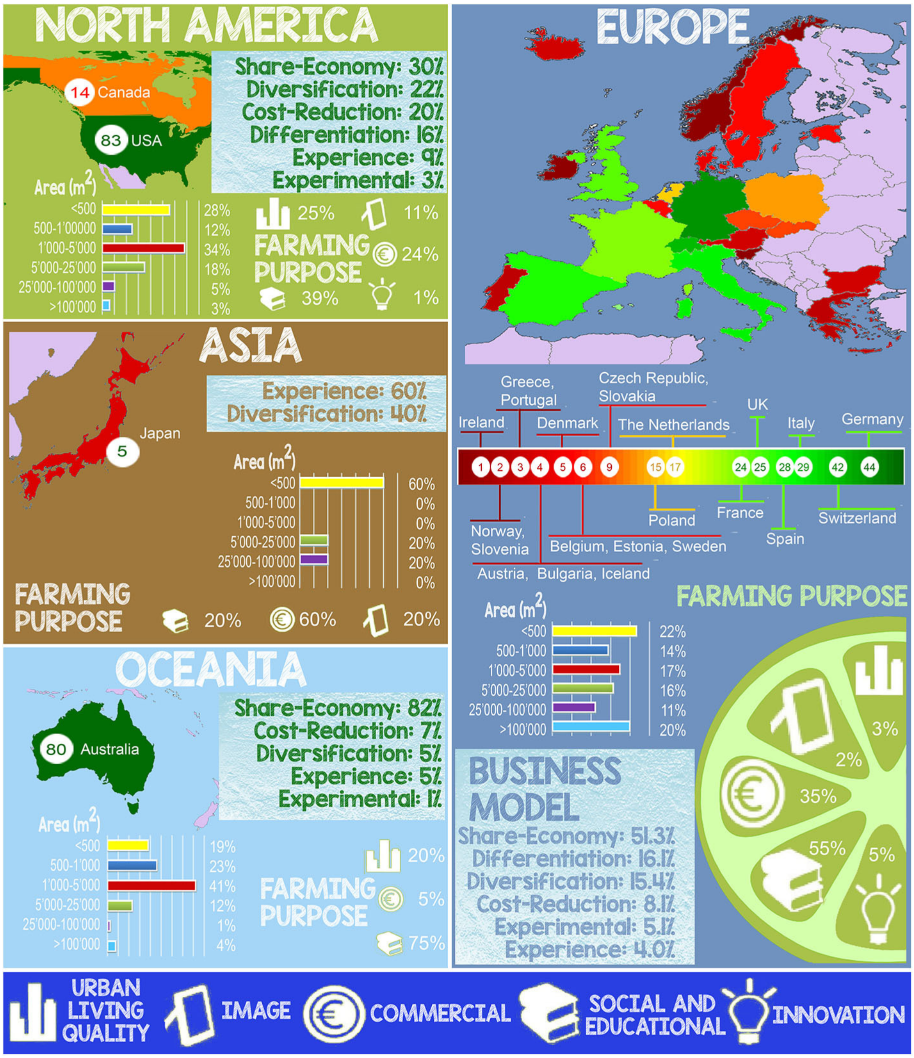

FIGURE 2 | Infographics on the inventory of UA projects in the Global North countries. In white circles the number of cases per country, also reflected within country color over the heatmap (e.g., red 0–10 projects per country, orange-yellow 10–20 projects per country, green more than 20 projects per country). In each World Region, figures on farm area, business model and farming purpose are integrated. Area charts represent the distribution frequency in the different size classes. Business models are classified according to Pölling et al. (2015) in the six categories: cost reduction, diversification, differentiation, share economy, experience, and experimental and placed in order of frequency. Farming purposes are classified accordingly to Thomaier et al. (2015) in five categories: urban living quality, image, commercial, social and educational, innovation. Sample composed of 417 UA projects.

population [X^2 (25) = 41.639, p = 0.05, n = 417], between class of projects dimension and category of city density [X^2 (10) = 12.157, p = 0.275, n = 386] and between class of projects dimension and city climate [X^2 (115) = 20.543, p = 0.152, n = 417] (data not shown).

CONCLUSIONS

Within the present review paper, 470 UA projects distributed across different world regions of the so-called Global North are identified and classified, according to their main business models, farming purposes and surface covered (**Figure 2**). UA's *main ecosystems services* in the Global North span from food provision to health functions, social inclusion and justice and contribution to ecological and environmental sustainability. Main *factors that affect UA development and diffusion* include the existing legal framework, land access, contamination risks, local climatic conditions and resource availability. A diversified number of *typologies of farming systems* were observed, including allotment gardens, extensive periurban farms, urban community gardens, rooftop farms and indoor vertical farms, as well as specific systems associated with the production of niche food products (e.g., microgreens, aquaponics, urban honey). With reference to *farm size*, in all world regions considered, a large share of UA projects operate on small surface (<1,000 m^2). Larger farms

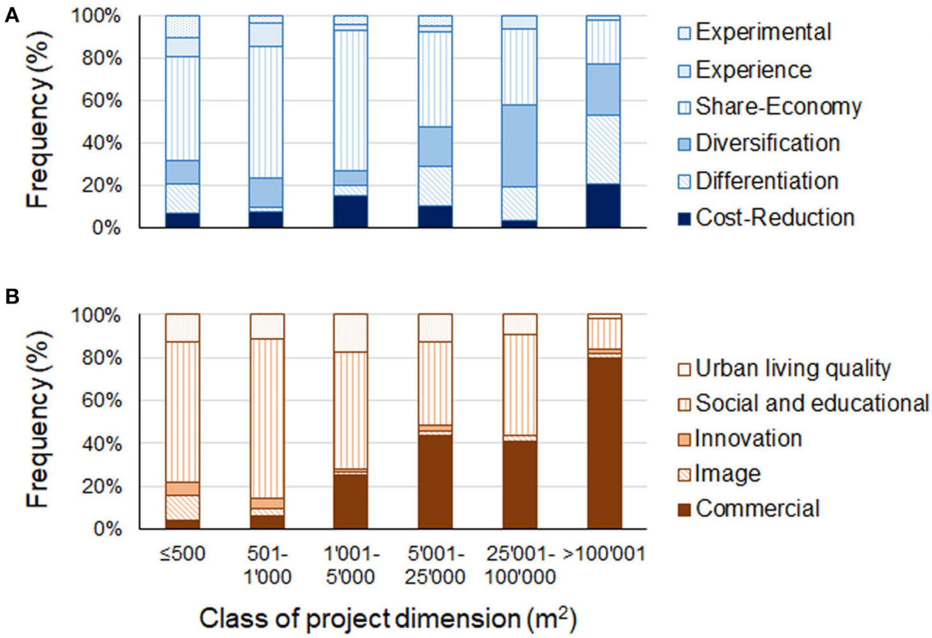

FIGURE 3 | Relative distribution frequency (%) of business models (**A**, Pölling et al., 2015, $n = 399$) and farming purposes (**B**, Thomaier et al., 2015, $n = 407$) with respect to the class of project dimension among the case studies included in the database.

(e.g., above 10 ha), represent a fifth of the cases in Europe, whereas about 3–4% in both America and Oceania. Among *business model strategies*, in Europe, North America and Oceania, the largest share of UA projects followed share-economy BM, but diversification and experience business models were also found in all world regions. Specifically, share-economy business model resulted to be diffuse in projects with small surface area (<5,000 m^2), while differentiation and diversification were the predominant business models in the biggest project dimensions category (e.g., above 10 ha) (**Figure 3A**). Among *farming purposes*, social and educational farming were the most frequent cases in Europe, Oceania and North America, while commercial projects were indeed predominant within the few cases reported in Japan. Considering farming purposes in relation to project surface areas, it emerged that commercial projects were underrepresented in small project category (≤1,000 m^2) but the most common among largest projects, contrarily to social and educational projects which resulted more common in small projects but quite rare for big (above 10 ha) projects (**Figure 3B**). Looking at city population, city density and city climate, no statistically significant relations were highlighted with project surface area categories. The collected data may allow for further design and implementation of successful UA experiences, while also fostering cross-pollination among initiatives and enabling the environment for sustainable urban farming. It overall emerges that, although with smaller figures in terms of food production capacity as compared with rural agriculture, the UA sector has a clear potential in fostering food security in time of emergency (e.g., in response to pandemics or extreme climate events), as well as promoting the overall city sustainability (with the associated benefits in terms of reduced environmental footprint, social justice, ecology and microclimate). However, further research effort is needed to substantiate the estimated potential with actual figures at city scale and enable the environment for the implementation of appropriate legal frameworks and guidelines toward large-scale diffusion of sustainable UA initiatives. Moreover, the application of the hereby adopted methodologies and classifications to UA projects from the Global South could also allow for comparative assessment of successful strategies.

AUTHOR CONTRIBUTIONS

FO drafted the paper and coordinated the preparation of the manuscript and data visualization. GP, NM, and ES-M created the inventory of case studies and contributed to sections Ecosystem Services (ES) Associated with UA, Factors That Affect Development and Diffusion of UA, and Main Typologies of UA Systems. GB contributed to section Ecological Aspects and Building an Inventory of UA Projects in the Global North. AM contributed to section Introduction. GG contributed to sections Introduction, Defining Urban Agriculture (UA), Health, Laws and Regulations, and Main Typologies of UA Systems. All authors critically revised the manuscript.

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SUPPLEMENTARY MATERIAL

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