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Urban farms represent highly heterogeneous environments, complicating on-farm food safety efforts

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Abstract

Urban agriculture is increasingly recognized for its capacity to mitigate food insecurity and to contribute to the development of more sustainable and equitable food systems, yet microbial and chemical pre-harvest food safety risks in urban farms remain underexplored in the United States. To address this gap, we surveyed 43 urban farms across 12 cities in three U.S. growing regions. Semi-structured interviews, field walk-throughs, and follow-up reviews of each farm's social media presence were used to characterize farm practices and histories as well as grower perspectives on microbial and chemical hazards. Findings revealed substantial heterogeneity between and within farms. Many farms prioritized community empowerment, education, and food access. Growers frequently expressed concern about legacy chemical contamination but reported limited training or awareness of microbial hazards. Structural constraints, such as insecure land tenure, limited resources, reliance on volunteers and donated materials, and staff turnover, further complicated consistent implementation of food safety measures. Improving food safety outcomes in urban agriculture will require flexible, field-specific risk assessment, alongside policies and technical assistance that address both knowledge gaps and structural barriers facing urban growers.

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Additional author details and funding disclosure on next page.

Keywords
urban farms, food safety, heavy metals, chemical hazards, microbial hazards, sustainability

Introduction

Urban agriculture is increasingly recognized for its capacity to mitigate food insecurity and to contribute to the development of more sustainable and equitable food systems (Nogeire-McRae et al., 2018; Siegner et al., 2018). Urban farms (UF) vary widely in form and scale, ranging from small backyard gardens to large food forests and controlled environment operations (Feldmann et al., 2023; Specht et al., 2014). Despite the potential socioecological benefits associated with urban farming (Orsini et al., 2020; Specht et al., 2021; Zasada, 2011), UF microbial food safety remains underexplored in the United States.

Studies on large-scale, commercial operations have shown that there are diverse, on-farm pathways for the introduction of microbial hazards, including the use of untreated biological soil amendments of animal origin or untreated irrigation water and wildlife intrusion into produce fields (Lee et al., 2019; D. Weller et al., 2015; Xiong et al., 2025). While UF operations are also susceptible to these routes of contamination, specific pathways and risks likely differ between urban and conventional farms due to differences in surrounding land use, operational models, and farm missions. Many UFs also fall below the sales thresholds for compliance with the federal Produce Safety Rule (PSR), and participation in voluntary Good Agricultural Practice (GAPs) programs is driven by market rather than regulatory requirements. A nationwide survey of urban farmers found that almost half earned less than US$10,000 annually (Pressman et al., 2016); farms are PSR exempt if annual sales are less than US$25,000 (U.S. Food and Drug Administration, 2024). Thus, UF practices are likely implemented under different regulatory or market expectations than large-scale, commercial operations. To better inform application and adaptation of existing GAPs and related frameworks to UF food safety, a comprehensive understanding of UF practices is needed.

UFs may also face unique food safety hazards that are not typically a concern for conventional farms. Many UFs operate on repurposed land with complex histories, resulting in legacy chemical contamination (e.g., from industrial activity; Yesilonis et al., 2008; Y. Zhou et al., 2020; Ziss et al., 2021). Because UFs are often near highways, railroads, active industry, or aging infrastructure, there is also the potential for the ongoing introduction of chemical contaminants. Proximity to residential or recreational areas could introduce the potential for novel microbial contamination from trespassers, litter, urban pests, or pets (Kopiyawattage et al., 2019; Sollins, 2016; Wijburg et al., 2025). Despite these unique hazards, UF food safety, particularly microbial, remains underexplored in the USA. Many studies of urban agriculture have focused on chemical hazards, and a substantial portion of the broader UF food safety literature has been conducted outside the USA (e.g., Entwistle et al., 2019; Taylor et al., 2021; Y. Zhou et al., 2020). In comparison, fewer studies have examined microbial hazards (Lupolt et al., 2021; Spliethoff et al., 2016). The existing literature, therefore, demonstrates the potential for microbial and chemical hazards to occur on UFs, but additional research is needed. This study addressed this gap by characterizing on-farm

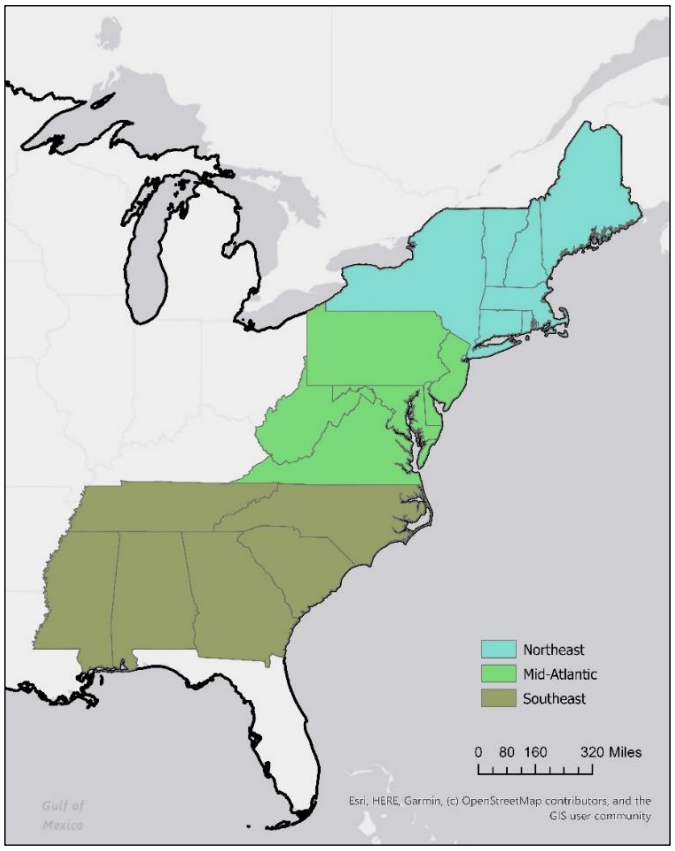
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Figure 1. States Considered Northeastern, Mid-Atlantic, and Southeastern for the Purposes of this Study



Note that 19 states are highlighted, but farms in seven states were sampled. This was done to ensure confidentiality due to the small number of urban farms in some states.

practices that could impact chemical and microbial hazard presence, in the context of farm history and grower priorities and perceptions.

Materials and Methods

Forty-eight UFs representing 12 Eastern USA cities were enrolled; five farms withdrew due to the COVID-19 pandemic (Figure 1). Farms were recruited through snowball sampling, beginning with existing contacts. The number of farms recruited in each city varied by city size, the number of UFs in each city, and our existing network in each city. For example, nine farms in City A enrolled, representing 18% of UFs there, while two farms from City B enrolled, representing all City B farms.

Between July and November 2020, each farm was visited once, and an approximately 45-minute semi-structured interview conducted. To inform the interview, we emailed growers before each visit to gather information on farm size, history, organic status, mission, organizational structure, and market channel.

After each interview, a walk-through was conducted to get detailed information on the practices used in a randomly selected subset of beds. Standard questions about land use history and management practices during the last 365 days were asked (Supplemental Figure S1). To select beds for inclusion, farm maps were obtained before each visit and used to delineate fields and beds in ArcGIS. Fields were defined as any land used for horticultural production in the last year (e.g., fields, orchards, high tunnels), including mixed-use plots where horticulture occurred alongside other activities, such as cuniculture. Fields were grower-defined and included at least one bed. Beds were defined as a single management unit:

1. with a shared land-use history,
2. where the same crop or crops were cultivated, and
3. where the same management practices were used during the last 365 days.

GPS coordinates were randomly generated within bed areas using ArcGIS. Beds containing a random point were visited during the walk-through. The number of beds ranged from five for farms less than 0.1 acre (0.04 hectares) to 70 for farms greater than 3.0 acres (1.2 hectares; Figure 2).

Follow-ups were conducted by phone or email, if needed. Farm websites and social media were reviewed to collect information on organizational structure and farm mission.

The data collected were used to generate two tidy datasets. The first captured farm-wide data (e.g., on market channel, organizational structure, food safety training, mission, and farm history). Land-use data for propeties immediately adjacent to each farm[1] and socioeconomic data for each farm's census tract[2] were included in this first da-

[1] https://www.mrlc.gov/data

[2] https://www.ahrq.gov/data/innovations/clh-data.html

taset. The second dataset focused on bed-specific practices, such as if, how, and when a bed was last irrigated or amended.

Results

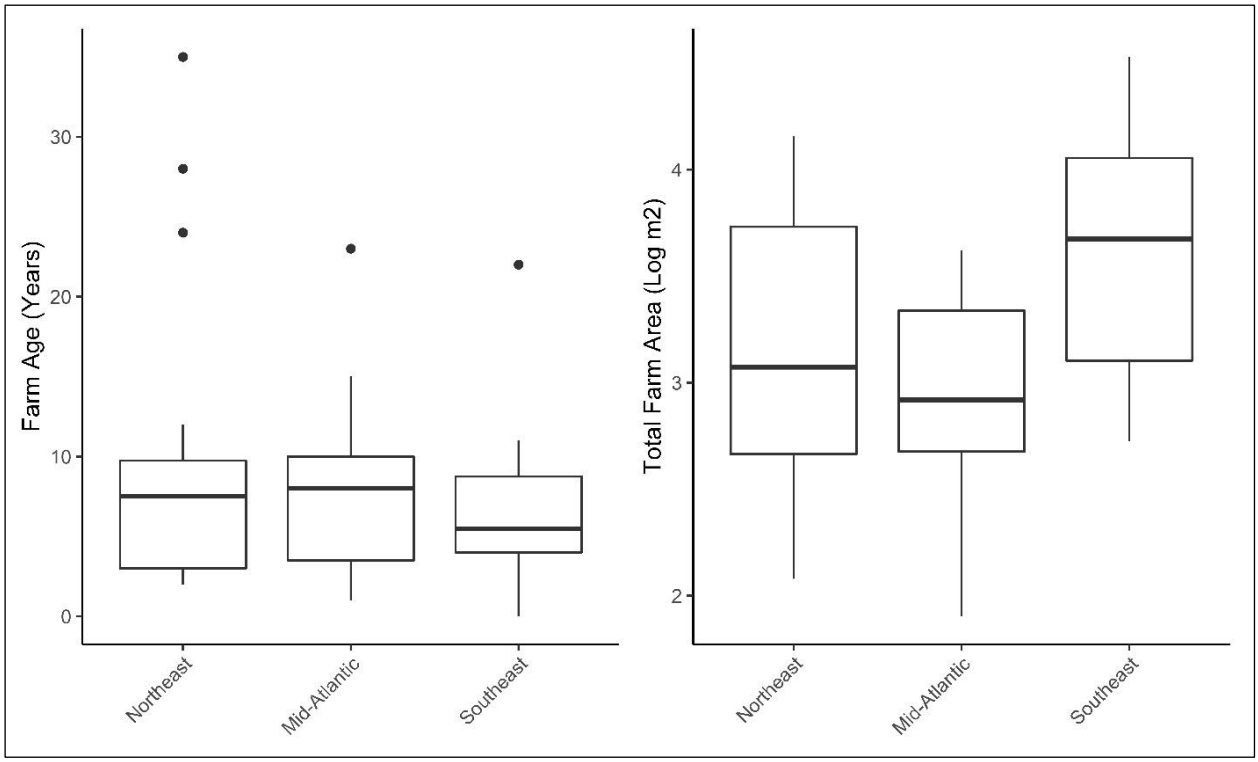
Data were collected from 43 UFs (Northeast = 18; Mid-Atlantic = 11; Southeast = 14; Table 1). Several farms were operated by a single parent organization but functioned independently and had different farm managers, market channels, and missions. Regional and city-specific patterns were observed. However, practices, perspectives, and challenges varied substantially at all scales, including within and between farms, fields, and beds, and over time.

Farm Missions

All farms had a defined mission, most of which were public and outward-facing, reflected through the farms' strong social media and community presence. Many farms emphasized supporting underserved or historically marginalized communities (Northeast = 83%; Mid-Atlantic = 55%; Southeast = 79%), a commitment that often reflected the socioeconomic characteristics of the neighborhoods where the farms was located (Figure 3).

Farm missions often reflected how, why, and by whom the farm was founded. Some farms were established by the communities they served, which created a strong connection between the farms and their communities. Other farms began as nonprofit arms of for-profit companies or through municipal green space programs. Thus, farm missions often focused on community needs (e.g., education, environmental justice, food security, community empowerment) rather than commercial-scale food production. Fifty-six percent of farms had missions emphasizing education, including programming on gardening, entrepreneurship, activism/leadership, and nutrition, as well as afterschool programs, youth internships, and collaborations with schools and community groups. UFs' community-focused missions also often translated into activities that reflected community priorities, including preserving heirloom seeds, growing medicinal herbs/

Figure 2. Distribution of Farm Age and Area by Region for the 43 Sampled Farms (Northeast = 18 farms; Mid-Atlantic = 11 farms, Southeast = 14 farms)



dye plants, and improving food access for cancer patients.

Market Channels

Growers reported >15 distinct channels, including donation (60%; e.g., to food banks), on-site sales (53%), community-supported agriculture (30%), and wholesale (26%; e.g., to grocery stores, restaurants; Table 1). Forty-two percent of farms included a "direct provision" channel in the form of community gardens (33%) and food forests (9%). Farms often combined growing and distributing farm products with other activities, such as renting space to other businesses or teaching classes for a fee.

Workers and Volunteers

The number of persons, including paid workers,

Table 1. Summary Statistics for the Surveyed Farms by Region

	Farms (%)							
	By Market Channel/Food Distribution Method [a, b]							
Region (No. of farms)	Comm. Garden [c]	Direct-to-Consumer [d]			Donate [e]	Other [f]	Food Forest	Wholesale [g]
		CSA	Off-Site	On-Site				
Northeast (18)	44	33	39	67	72	50	6	17
Mid-Atlantic (11)	18	36	45	45	55	45	18	45
Southeast (14)	29	21	43	43	50	50	7	21
Overall (43)	33	30	4	53	60	49	9	26

	Whose Mission Emphasizes			By Organizational Type				
				Independent, For-Profit [j]		Nonprofit [k]		
Region (No. of farms)	Access to Green Space [h]	Education	Support for Underserved Comm.[i]	Commercial	Hobby	Comm. Org. or Co-Op	Govt.	NGO
Northeast (18)	72	61	83	11	6	22	0	67
Mid-Atlantic (11)	36	45	55	9	9	18	18	64
Southeast (14)	36	57	79	29	7	7	7	50
Overall (43)	51	56	74	16	7	16	7	60

[a] These are presence-only data obtained from (a) grower interviews, (b) on-site observations by the researchers, and (c) review of the farm's web presence.

[b] Key revenue sources not captured here include (a) individual or corporate donations of time, money, and resources, and (b) grant funding from local, state, and federal agencies and non-governmental organizations, including research grants (e.g., Sustainable Agriculture Research and Education) submitted independently and in collaboration with academic partners.

[c] Comm. = Community; Community Garden includes both community gardens and cooperative (co-op) gardens.

[d] CSA = Community shared agriculture. Off-site = includes but is not limited to selling through farmers' markets, mobile markets, pop-ups, and other venues. On-site = farm stand or store.

[e] Includes donating food and non-food products directly to individuals (e.g., free food boxes), distribution centers (e.g., food banks), and nonprofits, and selling food at reduced cost. Several farms foraged produce from public areas around their city, which they donated. Many farms accepted WIC and SNAP benefits.

[f] Includes u-picks; growing and selling nursery plants and/or Christmas trees; selling other products raised/made on-site, off-site, or by another group (e.g., seeds, animal products, medicinal herbs/salves, fermented products, teas, wine, syrups, cider, spice mixes, handicrafts); providing landscaping services; charging for field trips (as opposed to providing educational access for free); teaching courses for a fee; or renting to other businesses (e.g., art/yoga studios).

[g] Includes selling, for profit, to restaurants, distribution centers, and other groups.

[h] Includes farms whose mission explicitly includes providing recreational, green, or open space. These farms were often partially fenced or fully unfenced, and frequently incorporated ecosystem stewardship into their missions.

[i] Support for underserved communities includes efforts to address food insecurity and improve access to food, employment, community resources, green space, and culturally relevant foods for historically underserved populations.

[j] Independent for-profit companies were either commercial farms or hobby farms. Hobby farms were (a) operated by individuals whose primary occupation was not farming, (b) sold produce for profit, (c) did not have a philanthropic mission, and (d) tended to have fewer resources or support than commercial farms.

[k] Nonprofit farms fell into three categories: those operated by government agencies, nonprofit organizations (including churches, hospitals, and philanthropic organizations), and community groups. Resource availability varied across organization types.

volunteers, and community gardeners, on each farm varied (Table 3). Farms with community gardens, educational missions, and a reliance on volunteers generally reported more persons on-site. For-profit farms generally reported fewer, and hobby farms the fewest.

Many farms relied heavily on volunteers, interns, or temporary workers. One organization operating five Northeastern farms was staffed primarily by AmeriCorps volunteers, with long-term continuity supported by a strong community volunteer network. More broadly, volunteer models varied across regions, with Northeastern farms tending to "ask less of many" volunteers, whereas Mid-Atlantic and Southeastern farms often relied on deeper commitments from fewer individuals.

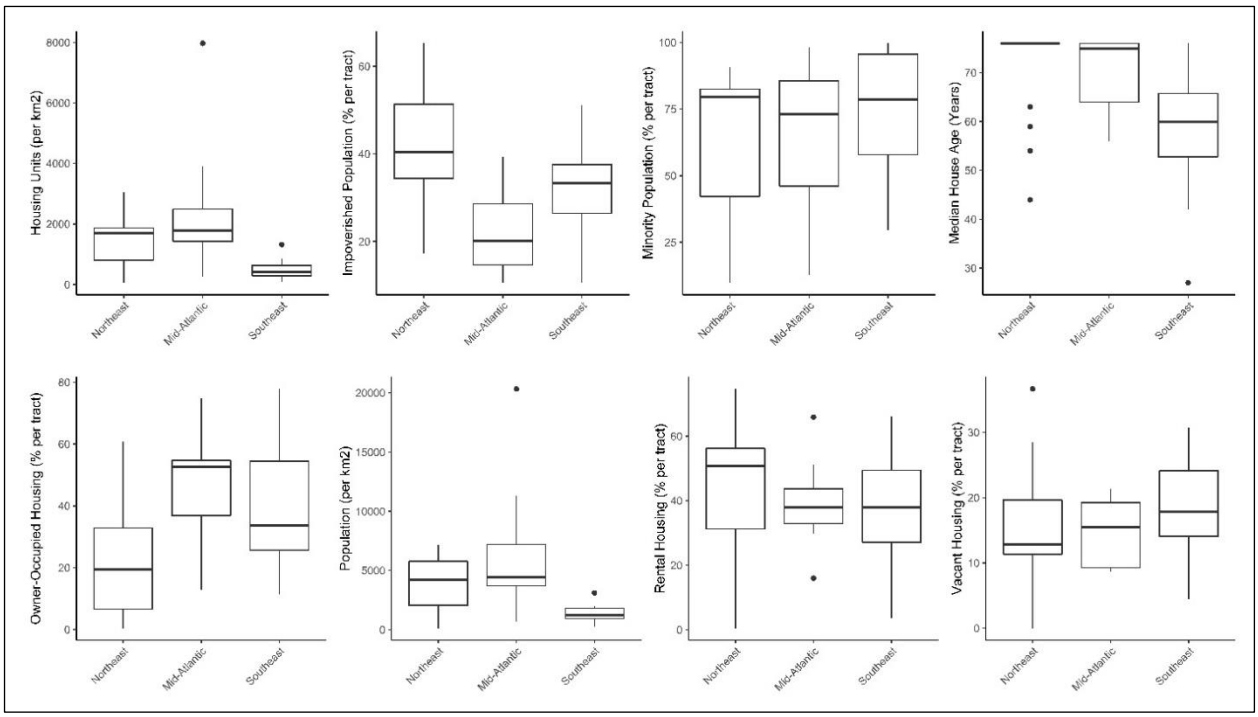
Crop Diversity

Although crops such as peppers, tomatoes, and strawberries were common across farms, substantial varietal diversity was observed. Overall, more than 190 different plant species were cultivated by participating farms (Supplemental Table S1). There were distinct regional and municipal patterns in the crops grown, reflecting local climate, culture, and environment. Crops also sometimes reflected the farm's mission or the grower's personal identity or interests, or those of the communities the farm served. The primary mission of the farm with the greatest tree crop diversity was to act as a publicly accessible food forest, while the farm cultivating rice, sugarcane, and stevia marketed these crops as seed stock and nursery plants instead of food products. The only farms cultivating pigeon pea and long bean primarily sold to Caribbean and Nepalese communities, respectively. Crops could also reflect a farm's structural constraints. For example, a farm with limited acreage grew fruit salad trees (trees with multiple related species grafted to them).

Land Use History

Many farms had long and varied histories (Table 2). One Southeastern farm, for instance, was established on land that had been a colonial-era mine and later became, in order, a church, school, shooting range, home, and parking lot. Multiple farms described their history on their website or social media. Growers with the most detailed farm history knowledge had (a) institutional support to

Figure 3. Socioeconomic Characteristics of the Census Tracts in Which the Farms were Located



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Table 2. Urban Landscape Around Each Farm, Including Past Land Use on Each Site (if Known), Adjacent Land Use (as Reported by the Grower or Interviewer)

Many farms had complex land histories with different parts of the farm being used for different purposes at different times.

	On-Farm Land Use and Land Cover (% of Farms) [a]							
	Historical [a]					Current		
Region (No. of Farms)	Agricultural [b]	Dump Site [c]	Industry [d]	Park or Forest	Resid/Comm. [e]	Fenced in [f]	Non-Crop Veg. [g]	Wind Breaks [h]
Northeast (18)	0	17	11	11	83	61	56	28
Mid-Atlantic (11)	18	18	18	18	55	64	45	100
Southeast (14)	23	14	29	21	57	79	79	50
Overall (43)	12	16	14	16	67	67	60	53

	Land Use and Land Cover on Parcels Surrounding Farm (% of Farms)								
							Surface Water		
Region (No. of Farms)	Forest-Wetland	Highway	Industry	Mowed Fields	Resid/Comm.	Park	Lake/Pond	Stream/River [k]	Vacant
Northeast (18)	11	33	11	44	94	17	17	8	22
Mid-Atlantic (11)	0	9	36	27	91	18	0	0	36
Southeast (14)	43	29	36	21	100	14	7	43	36
Overall (43)	19	26	26	33	95	16	9	23	30

[a] Most plots of land have held multiple structures over the years, and it was difficult to ascertain the type and duration of past structures, or the age of current structures, with the information available.

[b] "Agricultural" refers to land that was either used as pasture or cropland.

[c] Junkyards and other lots where non-organic refuse was dumped or used as infill. For example, one Southeastern farm is downhill of several automotive shops and partially overlaps a former railroad yard; both the shops and railroad dumped refuse, including machinery and car parts, on the current farm site.

[d] While only 14% of farms were on land used for industrial purposes, the type of industry varied considerably, including galvanized steel plants, pallet factories, saw mills, railroad yards, mining, car repair shops, and bus depots, among others.

[e] Resid = residential. Comm = commercial.

[f] All or part of the farm is fenced in, and the fence was sufficient to prevent people and dogs from entering the growing area.

[g] Non-crop vegetation was considered to be present if a substantial amount of non-crop, non-ornamental plants, including grasses, shrubs, and trees, were present and could function as wildlife habitat. Farms were counted if non-crop vegetation was observed around one or more of the fields visited.

[i] Windbreaks included rows of trees or shrubs, or elemental structures (e.g., sheds, houses) that blocked the wind, and would inhibit the movement of airborne contaminants into the growing area. Farms were counted if windbreaks were observed around one or more of the fields visited.

[k] One Mid-Atlantic farm was built on top of an enclosed and channelized stream. While the subsidence of the infill placed on top of the buried stream created unstable foundations and resulted in the abandonment of the property in the 1970s, this farm is not included in the percentage here since the stream remains enclosed and inaccessible by humans or wildlife.

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Table 3. Short Description of Growing Practices Across Regions [a]

	Growing Practices (% of Farms)										
	Growing In [b]				Soil Barriers						
					Used for						
			Raised [c]		Raised			Made of [d]			
Region (No. of farms)	High Tunnels	In-ground	Beds	Rows	In-ground	Beds	Rows	Cardboard	Fabric	Other	Plastic
Northeast (18)	33	72	78	44	45	64	75	64	36	18	36
Mid-Atlantic (11)	27	64	45	27	0	80	0	50	25	25	0
Southeast (14)	21	100	74	36	7	44	20	25	50	75	50
Overall (43)	28	79	65	37	18	61	44	53	37	32	32

	Raised Beds													
		Material (% of Farms) [e]							Percent of Farms Using, in ≥ 1 Field,					
									Tillage [f]					
										< 1 Year				
Region (No. of farms)	Mean Height (in.; SD; Range)	Brick	Concrete	Metal	Plastic	Recycled Materials	Stone	Wood	Never	No	Yes	Perma-culture Practices	Low Tunnels [g]	Median No. of Workers (IQR)
Northeast (18)	11.6 (4.4; 6.0-26.0)	0	7	0	14	40	0	86	100	0	24	77	11	15 (4–35)
Mid-Atlantic (11)	18.1 (9.0; 5.0-28.0)	20	20	0	0	7	0	100	56	22	100	77	27	4 (2–6)
Southeast (14)	17.8 (15.6; 6.0-91.4)	11	11	22	11	22	7	100	85	15	62	93	14	6 (3–10)
Overall (43)	14.2 (9.2; 5.0-91.4)	7	11	7	11	18	4	93	85	10	54	79	16	6 (3–19)

[a] For each growing practice, a farm was counted in the percentage if the practice was used in ≥ 1 bed.
[b] A farm was counted in these percentages if ≥ 1 field was grown using the given approach.
[c] Raised rows were built from a variety of materials, including soil (from the farm site and from other locations), logs, wood chips, straw, manure, and compost, often using hügelkultur approaches.
[d] The denominator for these percentages is the total number of farms using soil barriers for the given region. Two farms each used (a) wood chips and cardboard together, (b) gravel, and (c) metal (e.g., old roofing). One farm each used (a) wood chips, (b) coconut husk plus cardboard, (c) concrete, (d) recycled plastic drums, and (e) and pond liners.
[e] These are broad categories for the materials raised beds were constructed of. However, within these categories, there was considerable variation. For example, the wood used to build raised beds included new and recycled treated, untreated, and painted wood as well as various wood types (e.g., bamboo, cedar, pine).
[f] In fields where permaculture practices were used, orchards, raised beds, and raised rows were not included in the denominators when calculating these percentages since tillage would not normally be practiced as part of these growing practices.
[g] Low tunnels and shade cloths.

Table 4. Short Description of Soil Amendment and Soil Cover (e.g., for Weed Suppression) Practices [a] [b]

	Soil Amendments Used on Site (% of Farms)											
	Animal Origin [c]							Plant-Based [f]				
				Poultry								
Region (No. of farms)	Blood Meal	Bone Meal	Other BSAAO [c]	Poultry Litter	Other	Chemical Fertilizer [d]	Minerals [e]	Alfalfa Meal	Brewer's Grains	Charcoal and Ash	Com-post [g]	Seaweed Emulsion [h]
Northeast (18)	0	0	27	11	0	39	6	6	0	0	89	11
Mid-Atlantic (11)	18	18	9	9	9	18	27	9	0	0	82	36
Southeast (14)	0	0	7	21	7	43	29	0	14	7	86	57
Overall (43)	5	5	14	14	5	35	19	5	5	2	86	33

	Soil Covers Used										
Region (No. of farms)	Black Plastic [i]	Cardboard[j]	Cover Crop [k]	Fabric	Leaves	Mulch	Peat Moss	Pine Straw	Salt Hay	Straw	Weeds
Northeast (18)	22	28	22	11	11	78	0	0	0	44	11
Mid-Atlantic (11)	36	27	45	0	45	82	18	18	18	27	45
Southeast (14)	43	21	64	14	71	86	0	29	0	50	43
Overall (43)	33	26	49	9	40	81	5	14	5	42	30

[a] For each growing practice, a farm was counted in the percentage if the practice was used in ≥ 1 bed.

[b] Due to poor soil quality or contamination concerns, most farms brought in large quantities of soil (e.g., as part of raised bed/row construction, to supplement existing soils, to replace contaminated soils that were removed). Several farms reported continuing to amend or top-dress with imported soil.

[c] Biological soil amendments of animal origin (BSAAO) from sources other than poultry litter and fish-containing seaweed emulsions. Other BSAAOs were often donated by local hobby farmers or livestock operations. Several farms with rabbits on site used the rabbit pellets as an amendment.

[d] Includes organic and nonorganic fertilizer mixes, such as Super N, Cheep Cheep, and Osmocote.

[e] Amendments such as boron, carbonate, azumite, and gypsum.

[f] Raised beds and raised rows built using plant material (e.g., logs, straw bales, wood chips, leaves) were not included in the numerators here since the use of these materials occurred more than 2 years before the survey was performed, and/or "amendment" with these materials was concomitant with creation of the raised bed/row.

[g] Includes, but not limited to, materials composted on site, vermicompost, and compost from commercial mushroom production. Multiple farms reported using food scraps for their compost, and some solicited food scrap donations from community members. Both treated compost and untreated compost were used.

[h] Some seaweed emulsion also included fish.

[i] Several growers reported tilling in their black plastic.

[j] Many growers reported that cardboard decayed over the course of the growing season and would be fully or partially integrated into the soil during tillage.

[k] Cover crops included buckwheat, clover, oats, sorghum, sunflowers, and vetch, among others. Several growers also used perennial herbs, mowed grass, and non-crop vegetation as cover; if these areas are excluded from the numerator, then the proportions become 17%, 45%, and 35% for Northeastern, Mid-Atlantic, and Southeastern farms, respectively.

research it, (b) concerns about legacy chemical contamination, and/or (c) strong ties to the local community, which provided access to oral accounts or personal records. A minority of growers in the Northeast and Mid-Atlantic obtained information from government partners or municipal websites.

Almost all growers knew the most recent land use and structures present before their farm was established, but fewer knew about earlier land uses or structures. Even when knowledge of earlier land uses was limited, on-farm structures often reflected the history of the surrounding neighborhood and city. Within a single city, a farm located in the historic downtown was on the site of a former apartment complex, while a farm in a historically industrial neighborhood had previously held an ice-house, canal, rail yard, gas station, and single-family homes. Similar patterns were observed across the study. The five farms with agricultural legacies were all located in historically peri-urban or exurban areas that urbanized rapidly during the late 20th and early 21st centuries. Although the details of past agricultural activities were often difficult to reconstruct, most retained legacy fruit trees, and one food forest occupied the site of a former horse pasture.

Horticultural Practices

Production systems varied substantially across farms and included growing produce inground (79%) and using raised beds (65%), raised rows (37%), high tunnels (28%), and low tunnels or shade clothes (16%; Table 3). One farm used container production, and one used straw-bale production. Raised rows were made of mounded organic matter built using hügelkultur principles. Raised beds varied in composition, shape, size, and age (Table 3). Much of the material used to build raised beds was recycled or donated, including plastic bakery carts, pond liners, landscaping fabric, pallets, railroad ties, and downed trees, as well as waste brick, concrete, stone, metal roofing, and fencing.

Soil Barriers

Soil barriers were used for in-ground, raised-bed, and raised-row production to suppress weeds and reduce contact between production soils and underlying endemic soils that might contain legacy chemical contaminants (Table 3). Cardboard, burlap, and plastic were the most common materials used, but growers also reported using wood chips, coconut husk, concrete, gravel, and metal sheeting, reflecting opportunistic use of materials on hand.

Soil Covers and Cover Crops

Most farms used soil covers in at least one bed to suppress weeds, support soil fertility and moisture retention, and protect crops during winter (Table 4). Although most farms used multiple cover types, the most common, in order, were wood chips and mulch (81%), straw (42%), leaves (40%), black plastic (33%), chopped weeds or other vegetative material (30%), and cardboard (26%). Certain covers were more common in certain regions and cities. Pine straw was used by 29% of Southeastern farms, while salt hay was only used by farms in one coastal Mid-Atlantic city.

Forty-nine percent of farms used cover crops (Supplemental Table S1). Several growers used perennial herbs (e.g., mint, thyme), mowed grass, and other non-crop vegetation as cover crops in mixed-use plots, livestock pens, and orchards (Table 4).

Soil Amendments

All farms used soil amendments, with the most common being compost, chemical fertilizers, seaweed emulsion or fish meal, and minerals (Table 4). Even within a single farm, amendment use varied across beds according to crop needs and amendment availability. Many amendments were obtained through donations or local partnerships and selected based on availability and sustainability goals rather than standardized food safety criteria. Some were intermittently available as waste products from local businesses (e.g., spent brewer's grain, coffee grounds), other farm enterprises (e.g., rabbit manure, mushroom compost), or community donations (e.g., untreated or composted manure from hobby farms).

Irrigation Practices

All farms used irrigation in at least bed, but most also maintained unirrigated production areas, most commonly orchards, mixed-use areas, and perma-

culture beds. Most farms used a combination of hand, drip, and overhead irrigation across different production areas, depending on crop needs and available infrastructure (Table 5).

Municipal water was the most common irrigation source, although a minority of growers used untreated surface water. The only Northeastern farm irrigating with surface water drew its water from a creek with a documented history of microbial impairment, of which the grower was unaware. Several growers also collected rainwater through roof-catchment systems or rain barrels, although one reported using roof-collected rainwater only on nonedible crops because of concerns about contaminants from roofing materials.

Livestock and Wildlife

Many farms raised livestock on the same property as their produce production (Table 6). A small number of Southeastern farms raised animals, including ducks, goats, alpaca, and emus, on noncontiguous properties not sampled here. Companion animals were also common, and several farms allowed visitors to bring dogs on site. Growers noted, and researchers observed, intrusion into fields of domestic animals owned by farm staff and by unaffiliated persons (e.g., neighbor's dog, stray cat). Several growers used livestock or pets (e.g., chickens, cats, dogs) for pest management or other livestock for fertilization (e.g., rabbits, chickens). Wildlife intrusion was also widespread; growers reported, and researchers observed, animals such as raccoons, groundhogs, deer, coyotes, foxes, opossums, skunks, reptiles, amphibians, and songbirds visiting production areas. Although animals are recognized in the GAPs framework as potential sources of microbial food safety hazards, no growers expressed food safety concerns about the presence of domestic animals on-farm or within fields, and relatively few expressed concerns about wildlife intrusion.

Intra-Farm Heterogeneity

Many farms contained multiple zones of activity that did not always follow field and bed boundaries, and a single area often supported multiple, overlap-

Table 5. Short Description of Irrigation Practices and Other Considerations Relevant to Microbial and Chemical Food Safety

	Heavy Metal Contamination (%)		Irrigation Practices (%) [c]							
			Water Source				Method [f]			
Region (No. of farms)	Expressed Concern [a]	Past Testing [b]	City [d]	Rain [e]	Surface Water	Well	Drip	Hand	Overhead	With Handwashing Facilities
Northeast (18)	44%	44%	83%	39%	6%	11%	39%	39%	44%	61%
Mid-Atlantic (11)	36	18	91	27	0	0	36	73	9	55
Southeast (14)	36	14	57	86	7	36	57	57	14	86
Overall (43)	40	28	79	51	5	16	44	53	26	67

[a] This refers to a farm that expressed concerns during the site visit. These percentages may therefore underestimate the number of growers who were aware of chemical contamination risks due to historical or current land use in the farm area.
[b] Includes farms where testing has occurred ≥ 1 times, and where testing was done by the grower, extension, or a government agency (e.g., the city government or EPA as part of soil remediation).
[c] For each growing practice, a farm was counted in the percentage if the practice was used in ≥ 1 bed. One Mid-Atlantic and one Southeastern farm were in the process of being established, and irrigation had not yet been set up at the time of the farm visit.
[d] Includes both city water available through on-site connections and water made available by adjacent landowners (e.g., neighbors, a library, an office complex, a fire station).
[e] Includes farms that actively harvest rainwater for use in irrigation (e.g., roof rain collection system, rain barrels), and farms that did not perform active irrigation (e.g., relied on direct rainfall; mainly in orchard and permaculture areas).
[f] Hand irrigation includes irrigating using a hose, watering can, or other container. Spray irrigation includes any form of overhead, spray, or sprinkler irrigation.

ping functions (e.g., orchards were also used for community gatherings, grazing chickens, or herb and flower production). As a result, management practices frequently differed over short distances within the same farm. While a given bed may have been drip irrigated, amended with compost, or fenced, an adjacent bed may have been hand irrigated, unamended, and unfenced. Several farms maximized space by placing in-ground beds around the edges of raised beds or rows; these "adjacent" beds were usually managed differently because different crops were grown in them. This heterogeneity in management practices was most pronounced among less well-resourced farms and farms distributed across multiple noncontiguous properties, which often differed in layout, infrastructure, use patterns, and surrounding environmental conditions.

Because many growers relied on donated, repurposed, or low-cost materials, management decisions were often opportunistic and based on what was available when practices were implemented. For example, one farm primarily relied on municipal compost but reported a one-time application of untreated manure to a subset of beds after receiving a donation from a local hobby farm.

Grower Food Safety Concerns

Approximately 40% of growers expressed concern about heavy metal contamination, but concern about microbial hazards was limited to a small subset of farms, primarily those with personnel who had received microbial food safety training. These concerns often translated into management actions. Concerns about legacy contaminants led farms to adopt mitigation strategies such as removing and replacing contaminated soil, growing in raised beds or rows, and using soil barriers. The presence and intensity of concern about heavy metal contamination varied by city and were greatest in cities with industrial legacies and where municipal policies sometimes required soil testing and mitigation; these were largely concentrated in the Northeast. For example, all farms in City H, a Northeastern Rust Belt city with regulations governing urban agriculture on contaminated soils, expressed concern about heavy metal contamination and had implemented mitigation measures. In contrast, no growers in City F expressed concern about chemical contamination, despite several farms being located near automotive shops, highways, railways, or former junkyard sites.

Concern about microbial hazards was largely confined to growers with prior food safety training (Table 6). Relatively few growers expressed concerns about microbial hazards, although most had handwashing and bathroom facilities on-site. These facilities ranged from simple improvised stations consisting of a water container and soap to permanent sinks and bathrooms located in packinghouses, farm offices, or other affiliated buildings. Some farms also used facilities in nearby buildings not owned or operated by the farm, including

Table 6. Short Description of Domestic Animal Presence On Site, and Food Safety Training Attended by Growers

	Domestic Animals Present On-site (% of farms) [a]						Food Safety Training (% of farms) [b]			
							Pre-Harvest			Food Handling and Processing (e.g., ServeSafe)
Region (No. of farms)	Bees	Cats	Chickens	Dogs	Ducks	Rabbits	GAPs	PSA	Total	
Northeast (18)	28	11	17	17	6	0	7	0	11	0
Mid-Atlantic (11)	27	45	45	18	9	9	27	0	36	36
Southeast (14)	21	36	29	14	7	7	14	21	36	14
Overall (43)	26	28	28	16	7	5	14	7	26	14

[a] One Mid-Atlantic farm kept pigs.

[b] Not all growers knew or specified the type of produce safety training they received. Food handling and processing training includes ServSafe and USDA Hazard Analysis and Critical Control Point.

neighboring homes, parks, libraries, and office complexes. Two Northeastern farms, consisting of multiple noncontiguous parcels, had handwashing and bathroom facilities at only one parcel. Another farm lacked handwashing facilities but planned to install them by the start of the 2021 growing season. Due to the ongoing COVID-19 outbreak at the time of sampling, almost all farms had ample hand sanitizer on-site.

Structural Constraints

Infrastructure such as packinghouses, fencing, and farm offices varied considerably between farms and reflected available resources, community support, and the security of land access. Insecure land tenure resulting from short-term leases or informal agreements with property owners was common and appeared to limit growers' willingness or ability to invest in infrastructure, soil remediation, or other improvements. Several growers specifically cited concerns about losing access to the property before reaping the benefits of these investments. One farm exemplified this; after six years of renting land from a church and making substantial site improvements, the grower was evicted when church leadership decided to establish its own farm. The eviction resulted in significant financial hardship and a prolonged legal dispute before the grower was able to rebuild at a new location.

Discussion

Variation in management practices within farms created distinct hazard profiles within individual fields and beds, complicating risk management. Past studies have linked management practices to increased or decreased odds of preharvest contamination on commercial farms (Devarajan et al., 2023; D. Weller et al., 2015). The use of spray irrigation has been associated with an elevated risk of contamination, while drip irrigation has a lower risk (Devarajan et al., 2023). Studies have also linked on-farm pathogen prevalence to landscape structure on and around farms, and to wildlife and domestic animal intrusion into fields (Devarajan et al., 2023; D. L. Weller et al., 2022). While many of these studies were conducted on large, commercial farms and focused on practices common to these operations, several practices unique to UFs, including the use of roof-harvested rainwater, have also been linked to elevated contamination risks (Hamilton et al., 2018; Mendez et al., 2011). Indeed, several produce-associated outbreaks have been putatively linked to some of these practices or to animal intrusion (Gelting et al., 2015; Kangas et al., 2008; Osborn et al., 2024).

In the present study, all urban growers used at least one practice considered higher risk (Devarajan et al., 2023), but these practices were not applied uniformly across farms or fields. Instead, practices associated with differing levels of risk were often used concurrently within adjacent, and even the same, beds, and frequently changed throughout the growing season in response to crop rotation and resource availability. Similarly, many farms used whatever water source was closest to a given field for irrigation, with almost all farms relying on two or more water sources. As a result, hazard profiles became spatially and temporally heterogeneous, creating conditions in which some beds, or even portions of individual beds, may have a higher or lower risk of contamination than others. Because GAPs are easier to implement when practices are applied uniformly across a defined production unit, this variability, combined with donated inputs of uncertain provenance, may make both compliance and risk management challenging. Furthermore, several characteristics common to urban farms, including high worker turnover, reliance on volunteers, the prevalence of community gardens and food forests, use of farms as unfenced community spaces, and intentional integration of livestock for fertilization and pest management, may further complicate implementation of GAPs recommendations related to worker hygiene and animal intrusion.

Variation in contamination risk was not driven solely by management practices. Growers in this study reported cultivating more than 190 crops and crop varieties, often comingled within individual beds, and crops differ in their susceptibility to both microbial contamination and chemical uptake. For example, crops where the edible portion directly contacts the soil (e.g., melon, carrots) may be more likely to become contaminated than crops that

don't (e.g., peppers). Plant physiology and crop-specific management practices may also influence bacterial transfer from environmental sources to crops, as well as bacterial attachment to and survival on plant surfaces and in soils (Islam et al., 2005; Park et al., 2022). Risks to human health may vary according to both how crops are consumed and their propensity to accumulate contaminants. Crops that are typically cooked, such as potatoes, may pose lower direct risks from microbial contamination, although they can still contribute to post-harvest cross-contamination. Similarly, crops differ in their ability to take up and translocate chemical contaminants from soil (H. Zhou et al., 2016). As a result, contamination risk is not only spatially and temporally heterogeneous, but also crop-dependent, with exposure pathways and potential health impacts varying among commodities even when they are grown in the same bed using the same practices.

These findings do not suggest that UFs are uniquely heterogeneous relative to large-scale commercial farms. Prior studies have consistently demonstrated spatial variation in microbial contamination risks on commercial farms (e.g., Harrand et al., 2020; D. Weller et al., 2016). However, the variability observed here often operated at finer spatial and temporal scales. For example, practices in the present study frequently differed within individual beds, whereas previous work on large-scale commercial farms primarily identified variation at the farm or field level (D. Weller et al., 2015). These findings suggest that the scale at which risk is typically assessed and managed may not align with the fine-scale heterogeneity present on many UFs. When hazard-relevant practices vary within beds and change over time in response to shifting resource availability, whole-farm or whole-field approaches may obscure meaningful differences in contamination risk. Adapting produce safety guidance to account for bed-level variability and improving growers' ability to identify combinations of practices associated with elevated contamination risk may support more effective implementation of GAPs.

Grower concerns, which centered on chemical, not microbial hazards, were shaped by regulatory visibility and land history. This study and prior studies have shown that UFs exist within an urban landscape of overlapping historical and concurrent land use (Romero & Harris, 2019; Valley & Wittman, 2019). Many farms occupied former industrial, commercial, or mixed-use sites and bordered a diverse range of neighboring land uses, conditions that have been associated with both legacy soil contaminants and ongoing chemical exposures from surrounding environments (A. A. Paltseva et al., 2022). While past studies have identified several potential sources of these contaminants (Gamble et al., 2018; Kaiser et al., 2015; Laidlaw & Filippelli, 2008; A. Paltseva et al., 2018), additional research is needed to place the human health risks associated with these contaminants in the context of the broader health and societal benefits provided by UF. This is particularly important because contaminant accumulation in edible tissues varies among crops and is influenced by soil conditions, contaminant characteristics, and management practices. On the other hand, overall human health impacts are likely driven by cumulative exposures from multiple dietary and environmental sources.

Historical land use, combined with local regulations, appears to have influenced growers' knowledge and priorities regarding on-farm hazards. Many growers expressed concern about the food safety implications of legacy chemical contamination, whereas only a small subset expressed concern about microbial hazards. Similar patterns have been reported in studies of urban growers in Atlanta and Baltimore, where concerns about chemical contamination predominated (Harms et al., 2013; Kim et al., 2014). This imbalance may reflect differences in the visibility of chemical and microbial hazards within regulatory, educational, and outreach frameworks (Santo et al., 2021). Most UFs are exempt from federal produce safety regulations because annual sales fall below the US$25,000 threshold (Pressman et al., 2016; Standards for the Growing, Harvesting, Packing, and Holding of Produce for Human Consumption Relating to Agricultural Water, 2024). In contrast, many growers are subject to local policies addressing heavy metal contamination in urban soils (Halvey et al., 2021; Lupolt et

al., 2022), and extensive guidance on mitigating chemical hazards, particularly lead, are available through municipal governments, NGOs, and extension services. This emphasis may help explain why lead was the primary heavy metal of concern in both the present and previous UF studies (Balotin et al., 2020; Kim et al., 2014). More broadly, research on risk perception suggests that hazards receiving sustained institutional attention are more likely to be perceived as important (Kasperson et al., 1988; Zhu & Liu, 2021), potentially shaping how growers prioritize risk management. Indeed, access to information appears to have shaped how growers understood and responded to on-farm food safety hazards. Growers with institutional support or strong community ties were better able to identify and mitigate hazards associated with past land uses. Awareness of land history and surrounding land uses contributed to concern about contaminants and shaped mitigation strategies, including soil removal, raised-bed construction, and installation of soil barriers. However, consistent with prior research, many growers were unaware of established best management practices for managing chemical hazards, and several mitigation strategies reported here have been shown to be ineffective at or of limited value for reducing chemical exposures (Kim et al., 2014; A. A. Paltseva et al., 2022).

Despite widespread concern about heavy metal contamination, many growers lacked the resources needed to assess or address these hazards. Several growers in the present study reported concerns about heavy metals but were unable to afford testing, a barrier also documented among urban growers in Atlanta and Baltimore (Balotin et al., 2020; Kim et al., 2014; Santo et al., 2021). One farm removed approximately half of its land from cultivation after preliminary test results suggested contamination, but lacked funding for the additional testing needed to precisely delineate affected areas. Portions of the site were subsequently repurposed (e.g., storage, parking). These findings indicate that contamination risk management on UFs is influenced as much by social and institutional factors as by environmental conditions. Access to information, technical support, and affordable testing appeared to play important roles in determining whether growers recognized potential hazards and were able to respond effectively.

Structural constraints, including insecure land tenure, may limit food safety capacity. Many farms operated as nonprofits and, consistent with findings from a national grower survey, farming was often not the sole source of income even among for-profit operations (Pressman et al., 2016). Nearly all farms relied heavily on volunteers or part-time workers, contributing to high turnover and variability in experience and training. In several cases, farm managers were AmeriCorps members, community volunteers, or staff embedded within larger organizations (e.g., churches or hospitals) who had limited or no prior agricultural training. Similar organizational structures have been described in other studies of urban farms (Gilbert et al., 2020; Kelly, 2023; Pressman et al., 2016; Rangarajan & Riordan, 2019). High staff and volunteer turnover, combined with limited resources, may also help explain why relatively few farms in the present study had personnel who had received formal pre-harvest food safety training. Similar barriers, including capital constraints, limited time, and uncertainty about where to seek training, have been reported among urban growers in New York City (Cohen & Reynolds, 2015). These findings suggest that the volunteer-based and frequently changing workforce observed on many UFs may not align well with conventional approaches to implementing GAPs, which often rely on consistent worker training, supervision, and documentation. New training and education approaches designed specifically for infrequent, temporary, volunteer, or youth workers may therefore be needed.

Land insecurity and limited land access represent particularly important constraints (Pressman et al., 2016; Santo et al., 2021). While not always explicitly framed as a food safety issue by growers, insecure tenure discouraged long-term infrastructure investment, including improvements that might have improved on-farm food safety outcomes (e.g., fencing, handwashing facilities; Pressman et al., 2016). In Baltimore, 39% of urban growers were on private land owned by someone else, and 49% were on city land; 29% of growers were only some-

what confident and 6% doubted that their operation had sufficiently secure tenure to remain a farm in the future (Santo et al., 2021). Overall, these findings suggest that food safety on UFs is not solely a technical or knowledge issue. Insecure tenure, rotating staff, limited infrastructure, multifunctional missions, and community-facing design all shape what practices can be consistently implemented. Ensuring food safety in urban agriculture therefore requires attention not only to technical guidance but also to the structural conditions that shape whether and how such guidance can be implemented (Cohen & Reynolds, 2015).

Co-managing food safety alongside sustainability and community goals poses challenges for UFs. Consistent with past work (Pressman et al., 2016), the farms surveyed here generally balanced food production with other aims. Indeed, UFs frequently pursued multiple objectives simultaneously, including soil remediation, ecological restoration, waste diversion, community engagement, food security, and education (Pressman et al., 2016; Santo et al., 2021). Unlike conventional production systems, these objectives were frequently pursued within the same physical space by a small number of staff and volunteers. Consequently, management decisions often involved balancing competing priorities, and practices intended to advance one objective or reduce one risk could create new challenges in another area. Raised beds, soil amendment, and soil barriers may reduce crop contact with and uptake of soil chemical contaminants (Barbillon et al., 2023; Binns et al., 2004; Moskal & Berthrong, 2018). However, implementing these strategies often requires importing soils, amendments, or construction materials. When these inputs are recycled or donated, their provenance and prior use may be unknown, creating opportunities for the introduction of chemical or microbial hazards. For example, many farms obtained leaves, weeds, and other organic materials for composting and top-dressing from neighbors, local organizations, and municipal programs without knowledge of their source histories, despite evidence that historic use of lead-arsenate pesticides and lead paint can contribute to persistent lead contamination in urban and farm environments (Turner & Lewis, 2018; Wolz et al., 2003). Similarly, recycled treated wood used in raised beds has been identified as a potential contamination source (Kessler, 2013) and was used by several of the farms participating here. The use of compost, manure, and food waste may support soil health and circular economy goals, but when information on source, treatment status, and storage conditions is unavailable, the potential for introducing chemical and microbial hazards may be difficult to assess (Yang et al., 2024). Spatial constraints further shaped these trade-offs. Because many UFs operated on small or fragmented parcels, opportunities to spatially separate potentially conflicting activities (e.g., composting, production, community use) or implement spatially explicit food safety practices (e.g., non-crop buffers) were limited. Collectively, these findings suggest that, as seen among conventional farms (Baur, 2020), food safety on UFs cannot be considered independently of the broader social, environmental, and community objectives that shape management decisions. Practices adopted to support sustainability, remediation, food access, or ecological stewardship may also influence contamination pathways, highlighting the need to evaluate risks and benefits across multiple domains simultaneously.

UFs are often characterized by small production areas, fragmented layouts, and the presence of non-crop vegetation associated with food forests, hedgerows, windbreaks, and open-space programs. Together, these features may increase opportunities for interaction between crops, domestic animals, and wildlife relative to conventional farms (Ries et al., 2004; Tscharntke et al., 2005). Although domestic and wild animals have been repeatedly identified as vectors for pathogen introduction and dispersal (Berry et al., 2015; Jay et al., 2007; Loewald et al., 2024), most growers in the present study were concerned about crop loss rather than food safety, a pattern also reported in Baltimore (Kim et al., 2014). Some farms embraced wildlife presence as part of their urban ecology, documenting these challenges through signs such as "Dear rats, please leave our squash alone" and social media posts noting that "The invasion of the critters continues… ." At the same time, growers recognized that animals provided valuable services, including pest

and weed control, soil fertility, and other ecosystem functions documented elsewhere (Jones et al., 2019; Karp et al., 2016; Olimpi et al., 2022). Similar tensions existed with respect to people. Prior research has identified humans as potential vectors for pathogen introduction (Dato et al., 2003; Shaw et al., 2015). However, because many farms prioritized community access as part of their broader mission, restricting human and animal entry was often impractical, if not contrary to farm values. As a result, approaches to managing access varied considerably across sites, ranging from fully fenced farms to partially fenced or entirely open operations.

In practice, growers were managing overlapping risks and aims operating across chemical, microbial, ecological, and social domains. Management decisions often reflected trade-offs among sustainability, affordability, labor availability, regulatory requirements, public service commitments, and community expectations, with food safety concerns often secondary to these more immediate priorities. While similar challenges of co-managing competing objectives have been documented in conventional agriculture (Adalja et al., 2023; Baur, 2020; Karp et al., 2016; Olimpi et al., 2019), UFs frequently navigated these goals within the context of insecure tenure, limited infrastructure, and rotating labor, as discussed above. Thus, UF food safety cannot be understood solely as a matter of regulatory compliance but must instead be considered within the broader environmental, organizational, and resource constraints that shape farm management decisions. Supporting food safety in urban agriculture will require training, guidance, and support that recognize these trade-offs and help growers co-manage competing objectives.

Limitations

This study relied on snowball sampling and voluntary participation, which may limit the representativeness of the sample. Participating farms were located in the Northeast, Mid-Atlantic, and Southeast USA; findings may not reflect practices in other regions, including the West Coast. Data were based on interviews and site observations conducted during a single growing season and represent a cross-sectional snapshot rather than longitudinal trends. Practices were self-reported and may not fully capture all management decisions, particularly for farms with informal or diffuse management structures. Accordingly, findings should be interpreted as illustrative of variability patterns rather than being representative of urban growers across the USA.

Conclusion

UFs in this study exhibited substantial variation in land-use history, management practices, infrastructure, workforce structure, and organizational mission. Hazard-relevant practices often varied not only between farms but also within individual farms, fields, and beds, creating fine-scale differences in potential contamination pathways. Growers' perceptions and management of hazards were influenced by local regulations, access to information, resource availability, and historical land use, while food safety was frequently balanced against, and secondary to, broader goals. Growers demonstrated resourcefulness in navigating structural challenges, such as insecure land tenure, limited infrastructure, and reliance on volunteers, through adaptive practices like raised beds, soil barriers, and creative use of materials. However, these same conditions constrained the consistent implementation of food safety practices and highlighted the limitations of conventional frameworks designed for commercial, rural farms. Supporting safe food production in urban agriculture will require policy, technical assistance, and training models that reflect the unique operational realities of these systems, addressing not only knowledge gaps but the structural barriers that limit growers' ability to access and act on that knowledge. Together, these findings highlight the diversity of urban farming systems and the complexity of managing food safety within multifunctional UF landscapes. Supporting food safety in urban agriculture will require guidance, training, and technical assistance that account for fine-scale variability in hazards, competing objectives, and resource constraints that characterize many urban farms.



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