HortScience 60(7):1171–1179. 2025. https://doi.org/10.21273/HORTSCI18586-25

Market Yield of Relay Cropped Leafy Greens in Urban Agriculture Production Systems

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Keywords. manure-based compost, organic production, plastic wading pools, square foot gardening, succession planting

Abstract. **Leafy greens are an ideal crop for the urban environment, given their shallow roots, short growing time, and high nutritional value. Yields of greens and their nutritional value can, however, be affected by the production system used and nutrient management practices. The purpose of this study was to explore two different types of urban agriculture production systems (raised beds and container plots) and four nutrient management treatments (conventional fertilizer, organic fertilizer, peat and compost plus organic fertilizer, and peat and compost only) to determine their impact on the yields of relay cropped leafy greens. Lettuce, arugula, mizuna, mustard greens, chard, kale, and spinach were planted in succession through the growing seasons of 2018 and 2019 and the amount of time it took to harvest, total yield, and marketable yield were measured. Significant differences between growing systems and among nutrient management strategies were few and inconsistent across measured harvest metrics and the crops observed. Results suggest that small plastic pool containers are a suitable container for urban production of greens. This study also tentatively supports the use of organic fertilizers and compost as a nutrient source in urban agriculture, as some greens responded favorably to organic fertilizers and the use of compost. The effects of nutrient management treatments may have been obscured by high insect pressure and the unusual weather patterns that took place during the study, which affected some crops more than others. Further research should refine the use of small plastic pools for relay cropping greens and optimize the order in which greens are grown in succession.**

The United States is currently facing agricultural difficulties as the size and number of family farms decreases and challenges such as a changing climate and loss of farmland to development reduce yields (Freedgood et al. 2020; Hinrichsen 1998). As our population continues to grow, developers are competing with growers for vacant land. Just over 11 million acres of agricultural land was lost to development in the United States between 2001 and 2016 (Freedgood et al. 2020). Kentucky lost 791,000 acres of farmland between 1992 and 2012 due to urban edge expansion and urban development (Eblen 2018). This trend is likely to continue as the global urban population is expected to increase by 68% by 2025, and 80% of the population of the United States already resides in urban areas (United Nations 2019). Providing fresh food and produce in urban areas is already problematic, with many areas suffering from a lack of grocery stores or food markets at which to make such purchases affordably. In 2019, 14.4% of Kentucky residents were food insecure, well over the national average of 10.9% (Feeding America 2020). Urban agriculture has the potential to play a large role in food production going forward by repurposing vacant urban land.

Urban agriculture has a multitude of benefits beyond local food production (Ackerman et al. 2014; Lin et al. 2015; Mok et al. 2014), including community building (Agnotti 2015; Dimitri et al. 2016; Ghose and Pettygrove 2014; Nogeire-McRae et al. 2018; Van Tuijl et al. 2018), education (Colman 2017; Dimitri et al. 2016; Ohly et al. 2016; Van Tuijl et al. 2018), and health and enjoyment (Bahamonde 2019; Nogeire-McRae et al. 2018; Ohly et al. 2016; Van Tuijl et al. 2018). Urban agriculture also has the ability to provide economic growth (The Ecology Center 2016). Urban farmers have demonstrated that there is potential to profit $50,000 on 0.25 acre (Stone 2016) and urban farmers engaged in direct marketing keep 100% of their profits as opposed to operations that wholesale where producers retain about 19% of the agricultural dollar (Hughes 2015). These operations also can help stimulate the local economy by spreading income and profits through the community and providing jobs and volunteering opportunities (Kumar 2016; Van Tuijl et al. 2018). Urban agriculture does, however, face several limitations. Competition for land with development is still an issue (Agnotti 2015; McDougall et al. 2019; Van Tuijl et al. 2018). When land is available it is often limited in size, may have large areas of impervious surface, and there can be issues with soil quality and soil contamination (Agnotti 2015; Kim et al. 2016; Salomon et al. 2020; USEPA 2011), all of which can limit production. These issues are often overcome through the use specific production systems and practices.

Raised beds and container plots are two common production systems used in urban farming (Oberholtzer et al. 2014). Raised beds and containers can be constructed and adapted to fit into small and confined spaces found within urban areas. Urban soil is often contaminated and unsafe to in which grow produce; raised beds and containers eliminate that risk by allowing for clean soil to be imported (USEPA 2011). Being able to control the nutrient content and organic matter of soil can help increase yields, which in turn can increase profits (Sainju and Jabro 2016) and the use of compost in urban agriculture is common (Cameira et al. 2014; Dewaelheyns et al. 2013; Small et al. 2019; Wielemaker et al. 2019). There can, however, be additional expenses. Nursery pots and commercially available planters can cost between about $40 and $127 per meter of growing area (Hummert International 2021; Lowe's 2021) and raised beds cost ∼$70 (Durham et al. 2018). This expense can cause urban growers to search for alternatives, such as small plastic pools (commonly known as kiddie or wading pools). These pools offer 1.026 m^2 of growing area at a relatively low cost, ∼$10 to $15 total and $12/m^2$ growing area (Lowe's 2021). These pools have been adopted in some urban agriculture settings for production on rooftops and other paved areas (Hell's Kitchen Farm Project 2020; Michaels 2021). They are made from similar plastics to traditional nursery pots and can be diverted from the landfill if pools that no longer hold water are repurposed. Raised beds and containers can also reduce soil compaction in the growing area by preventing foot traffic, which will allow for water to move more freely (Miernicki et al. 2018).

Relay cropping is a form of succession planting that enables a farmer to grow multiple crops in the same plot, one right after the other, during one growing season, potentially increasing yields and profits (Satzewich 2016; Satzewich and Christensen 2011; Stone 2016). This technique, sometimes used in combination with intercropping, can maximize food production in urban areas where space is limited. Leafy green vegetables are considered a desirable crop for relay cropping because of their short time to maturity (Satzewich 2016; Satzewich and Christensen 2011; Stone 2016). Leafy greens or simply "greens" can encompass a wide variety of vegetable crops with edible leaves (Kaiser and Ernst 2021). Since most leafy greens can be harvested after 20 to 30 d and have shallow root systems, they should be ideal for relay cropping in raised bed and container production systems. Leafy greens also have high nutritional value, making them especially attractive in areas where fresh fruits and vegetables are hard to obtain. They can be an important source of fiber; iron; magnesium; potassium; calcium; vitamins A, B, C, E, and K; carotenoids; and antioxidants (Bojilov et al. 2020; Carillo et al. 2020; Reda et al. 2020; Stagnari et al. 2015; Yan 2016).

Greens are also ideal for small urban spaces, a space as small as 1.22 × 1.22 m can feed a small- to medium-sized family for a year (Berle and Westerfield 2013). However, nutrient management could play a big role in potential yields and crop quality. Moderate increases in nutrient applications often results in higher yields, with diminishing returns at higher rates of application (Chakwizira et al. 2015; de Barros Slyvestre et al. 2019; Pereira et al. 2020; Stagnari et al. 2015). The source of the nutrients applied to greens can also affect yields, with some differences among types of organic and mineral nutrient sources (Coria-Cayupán et al. 2009; Iheshiulo et al. 2017; Pereira et al. 2020; Stagnari et al. 2007). Meta-analysis of research studies shows that organic yields are 25% lower than conventional farming overall, and between 25% and 30% lower for vegetables (Alvarez 2021). These differences are higher on farm studies (20%) than controlled experiments (7%), partially due to the effect of soil use index, or the fraction of years that cash crops were grown and harvested during a crop rotation. Differences in nitrogen applications for some crops and nitrogen availability from different sources, such as composts and manures (Alvarez 2021) and other production factors such as cover cropping or use of high tunnels can also affect the yields of greens (Bączek et al. 2019; Kornecki and Balkcom 2020; Thavarajah et al. 2019).

Studies conducted by the Center for Crop Diversification at the University of Kentucky have shown that consumers are interested in trying new and diverse products, including leafy greens (Kaiser and Ernst 2021). Although research on growing vegetable crops in urban areas is increasing, there is a lack of information about growing high-value crops in raised beds and container plots using a relay cropping production method and research on the use of small plastic pools as containers is especially limited. This research was conducted to examine the yields of relay cropping leafy greens in raised beds and small plastic pool containers with different nutrient management treatments. If small plastic pools are a suitable container system for urban agriculture, there will be little difference in yield between that system and the more traditional raised beds. It is also expected that there will be some differences in yield among the nutrient management treatments, specifically between the conventional fertilizer treatment and treatments composed of organic fertilizers and compost.

Materials and Methods

This study was conducted in 2018 at the Kentucky State University, Harold R. Benson Research and Demonstration Farm, located in Frankfort, KY, USA. Platforms were constructed in May of 2018 with 1.22 m × 1.22 m pressure-treated lumber 0.6 m off the ground. They were topped with 1.22 m × 1.22 m severe weather common square southern yellow pine plywood sheeting. Sixteen container plots were then set on top of the platforms and the remaining 16 were topped with a raised bed. The container plots were 114 × 114-cm Summer Waves Wading Pools (Polygoup, Meidian, ID, USA) (1.02 m^2 of growing area). Two 0.27-cm holes drilled in the front of each pool, even with the bottom of the pool, to let water drain. The holes were fitted with 0.27-cm Eastman PVC clear vinyl tubing that attached to gutters for water collection. After installation, a small amount of Rooflite® drainage material (Skyland LLC, Landenberg, PA, USA) was set in the pools inside the drainage holes to prevent them from clogging and improve water flow. Pools were filled with 0.1 m^3 of premium shredded topsoil (Table 1).

The raised beds had a depth of 30.48 cm and were constructed out of 0.6 × 1.8-m pressure-treated lumber, treated with Ecolife™ (Viance, LLC, Charlotte, NC, USA), lined with black Smartpond Nylon Mesh Pond Liner (1.49 m^2 of growing area) and filled with 0.277 m^3 of premium shredded topsoil (Table 1). The pond liner was chosen as a barrier between the growing soil and the treated lumber. Many raised beds are built with a similar barrier between the wood and the underlying soil. Gutters were attached to the front of each raised bed, where there is a 5-cm gap in the front of the raised beds covered with Phifer Super Solar Charcoal Fiberglass Replacement Screen (Phifer, Inc., Tuscaloosa, AL, USA) to let water drain out and keep soil in. All materials for the construction of the platforms and raised beds were purchased from Lowe's Company Inc. (Mooresville, NC, USA).

Nutrient management treatments used in both the raised beds and container plots were a conventional fertilizer treatment (10–10–10 Twin Pines™ all-purpose fertilizer, Know, IN, USA), organic fertilizer treatment (Espoma® 3–4–6 Tomato Tone, Espoma® 12–0–0 Blood Meal, and Espoma® 4–12–0 Bone Meal, Milleville, NJ, USA), peat and compost only (PC) treatment applied at 14.42 kg/m^2 (0.1–0.1–0.1, Michigan Peat Garden Magic® Compost and Manure, Houston, TX, USA), and peat and compost plus organic fertilizer (PCO) treatment, for which 7 kg/m^2 of compost was applied and supplemented with organic fertilizer. The full breakdown of nutrients and their sources in the fertilizers and composts used can be found in Supplemental Table 1. The experimental design was a randomized block design with modifications to reduce edge effects, which was found necessary due to varying topography and shading within the study area, with four replicates of each nutrient management treatment in each of the two growing systems (small plastic pool container and raised bed). Compost was applied once at the beginning of each growing season (Table 2). The fertilizers and compost used are readily available to urban farmers and growers in the region. Fertilizers were applied to the appropriate plots at the planting of each crop (Table 2) to supply a target of 19.61 g N/m^2, 16 g P_2O_5/m^2, and 16 g K_2O/m^2 as recommended by the College of Agricultural and Environmental Sciences at the University of Georgia for greens. The conventional fertilizer treatment was applied to supply the recommended amount of N. The organic fertilizer treatment

Table 1. Analysis results of the premium shredded topsoil as provided by the University of Kentucky Soil Testing Laboratory.

Component	Analysis result
Soil texture	Loam
Sand (%)	44.13
Silt (%)	37.71
Clay (%)	18.16
pH	6.82
Organic matter (%)	4.56
Nutrient content	
Total N (ppm)	1,870
P (ppm)	596
K (ppm)	214
Ca (ppm)	4,531
Mg (ppm)	244
Zn (ppm)	12.4
B (ppm)	0.72

Received for publication 17 Mar 2025. Accepted for publication 15 Apr 2025.
Published online 26 Jun 2025.
Funding for this project was provided by US Department of Agriculture National Institute of Food and Agriculture Evans-Allen Capacity Grant Project Number 1014334. This research would not have been possible without the many people who aided in plot setup, plot maintenance, planting, and harvest, including Jessica Eggleston, Nanaaishat Umar, Kristal Thornton, Tom Trivette, Pradip Poudel, Christine Jackson, and other volunteers. We would also like to thank the staff at the Kentucky State University Harold R. Benson Research Farm for aid in maintaining the research platforms and surrounding grounds. Thanks to Drs. Scott Williams and Srijana Thapa Magar for their help with editing the manuscript.
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Table 2. Nutrient management, planting, and harvesting timeline for the 2018 and 2019 growing seasons.

Activity	2018	2019
Compost added	16 May	4 Apr
Fertilizer added and lettuce planted	—	11–12 Apr
Lettuce harvest	—	23–24 May
Fertilizer spread and arugula planted	4 Jun	28 May
Arugula harvest	11 Jul	19–21 Jun
Fertilizer spread and mizuna planted	11 Jul	21 Jun
Mizuna harvest	6 Aug	11 Jul
Fertilizer spread and mustard planted	6 Aug	11–12 Jul
Mustard harvest	30 Aug	5 Aug
Fertilizer spread and Swiss chard planted	—	6 Aug
Swiss chard harvest	—	12–13 Sep
Fertilizer spread and kale planted	30 Aug	13 Sep
Kale harvest	26 Sep	16–17 Oct
Fertilizer spread and spinach planted	26 Sep	—
Spinach harvest	22 Oct	—

used the three listed fertilizers to supply the recommended amounts of all three nutrients. The nutrient contributions of the low compost treatment were estimated to be 6.59 g/m^2 nitrogen and 7.21 g/m^2 phosphorus and potassium based on the listed product nutrient content, so small amounts of all three organic fertilizers were used to supply the remaining nutrients to meet the full nutrient recommendation at each planting. The PC treatment was estimated to supply 14.42 g/m^2 of phosphorus and potassium, based on the listed product nutrient content. A full list of the amount of nutrients applied by each fertilizer treatment can be found in Supplemental Table 2. When needed, precipitation was supplemented with drip irrigation to provide 2.5 cm of water total each week (Durham et al. 2021). The experiment was conducted over the course of the growing seasons for 2018 and 2019 (Table 2).

The crops chosen for relay cropping were *Lactuca sativa* (Encore lettuce mix), *Eruca sativa* (arugula), *Brassica rapa* (mizuna Asian greens), *Brassica juncea* (red giant mustard greens), *Beta vulgaris* (fordhook giant Swiss chard), *Brassica napus* (red Russian kale), and *Spinacia oleracea* (covair spinach). All seeds were organic and purchased from Johnny's Selected Seeds (Fairfield, ME, USA), except for the corvair spinach, which was purchased from Harris Seeds™ (Rochester, NY, USA). All crops were chosen because of their short maturity rate between 20 and 40 d, which is a key factor in relay cropping (Johnny's Selected Seeds, 2024a, 2024b, 2024c, 2025a, 2025b). These crops are also considered high-value crops in central Kentucky (Kaiser and Ernst 2021). Crops were planted from seed, at the recommended seeding rates (Table 3), following the schedule outlined in Table 2. Due to the late start after plot construction in 2018, *L. sativa* was not planted during that growing season. *B. vulgaris* was introduced in 2019 during the warmest part of the growing season because of its higher heat tolerance than other green species included in the study. Drought conditions during Aug and Sep 2019 slowed crop growth such that there was no longer time to plant *S. oleracea* before the first frost.

Greens were harvested at the baby stage, ∼30 d after planting (Table 2), to maximize crop turn around. At the time of harvest, the following data were collected for each crop in each plot: number of plants, the amount of time it took to harvest (referred to as harvest time), total yield, and marketable yield. Marketable yield was determined by visual examination. If there were obvious signs of insect damage, or discoloration, leaves were deemed unmarketable. All yield metrics were normalized for plot area to account for the difference in growing areas in the containers and raised beds.

Statistical analyses were performed using R (Version 4.1.1; The R Foundation for Statistical Computing, Vienna, Austria). Data for all variables that did not conform to a normal distribution were transformed for analysis using either an inverse transformation (marketable yield of mustard) or a logarithmic transformation with a base of 10 (total and marketable yield of arugula, harvest time and total and marketable yield of mizuna, marketable yield of kale, harvest time of Swiss chard). All variables were analyzed using analysis of variance (ANOVA) using growing system and nutrient management treatment as fixed effects. For crops planted during both growing seasons, year was included in the ANOVA model as a fixed effect as well. Significant differences among treatments were separated using multiple comparisons by least significant difference with an alpha of 0.05. All means are presented as untransformed data.

Table 3. Recommended plant spacings and seeding rates for each crop planted in 2018 and 2019.

Crop	In-row plant spacing (cm)	Seeding rate (seeds per 0.09 m^2)	Square foot gardening spacing (plants per 0.09 m^2)
Leaf lettuce	1.25[i]	20–30[i]	4[iii]
Arugula	10.1[ii]	30–50[ii]	4[iii]
Mizuna Asian greens	25[ii]	15[ii]	16[iii]
Mustard greens	7.6[i]	20[i]	16[iii]
Red Russian kale	20.3–30.5[i]	4–6[i]	1[iii]
Swiss chard	15.2–20.3[i]	8–10[i]	4[iii]
Spinach	10.1–15.2[i]	6[i]	9[iii]

[i] Durham et al. 2021.

[ii] Johnny's Selected Seeds 2024a, 2024b, 2024c, 2025a, 2025b.

[iii] Bartholomew 2005.

Results

Weather conditions. Temperatures in both years of the study were close to the climatic normal (Fig. 1). Temperatures were slightly higher in 2018 than 2019 in May and June, and lower in 2018 than 2019 in July, and September. Total precipitation was 1045 mm for the 2018 growing season and 829 mm for the 2019 growing season. Precipitation in 2018 was generally higher than normal, and higher in August and September than the other months (Fig. 1). Precipitation was also higher than normal and higher than other months in 2019 in February and October. Precipitation from July to September of 2019 was lower than normal, with a drought in Kentucky from 28 Aug and 6 Oct, during which there was only 10 mm of rain.

Harvest time. Model simplification was performed to remove nonsignificant interactions with an alpha level of 0.05. The only significant three-way interaction between growing system nutrient management treatment, and year was for mustard (Supplemental Table 3). The only significant two-way interactions were nutrient management system and year and growing system and year for mizuna (Supplemental Table 3). Growing system had no significant effect on the harvest times of arugula, Swiss chard, or kale, and nutrient management treatment had no significant effect on any crop except Swiss chard (Supplemental Tables 3 and 4).

Harvest time of the raised bed plots was significantly longer than the container plots for lettuce ($P = 0.001$) (Table 4). Harvest time of the container plots was significantly longer than the raised bed plots for mizuna in 2019 ($P = 0.002$) and spinach ($P = 0.010$). The only instance in which a difference between the growing systems that was not statistically significant represented a statistical trend was with mustard in 2018 in the PC treatment ($P = 0.082$) (Table 5).

There were no significant differences in harvest time among nutrient management treatments in 2018 for mizuna or mustard in either growing system, or for mustard in the raised beds in 2019. The conventional fertilizer treatment had the shortest harvest time for mizuna in 2019 and was significantly lower than the PCO fertilizer and the PC treatments ($P = 0.042$ and $P = 0.029$, respectively), but not the organic fertilizer treatment ($P = 0.158$) (Table 4). For mustard grown in containers in 2019, the PC treatment had the longest harvest time but was only significantly longer than the

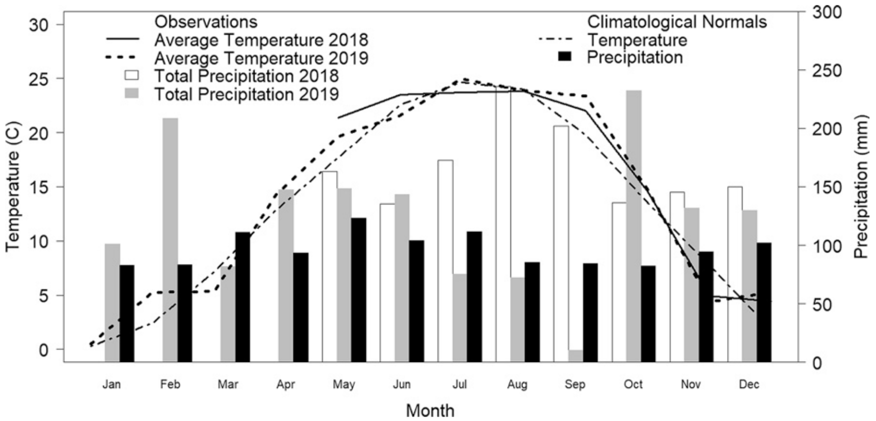

Fig. 1. Monthly total precipitation (mm) and average temperature (°C) for the period of study between May 2018 and Dec 2019 and 30-year (1981–2010) climatological normal (NOAA 2020).

PCO treatment (P = 0.035) (Table 5). The harvest time of Swiss chard was longest for the organic fertilizer treatment but was only significantly longer than the PC treatment (P = 0.019). The PCO treatment had the second highest harvest time, but only suggested a statistical trend when compared with the PC treatment (P = 0.092).

Harvest times in 2018 were significantly longer than those of 2019 for mizuna within the raised bed plots (P = 0.012) and within the conventional fertilizer treatment (P = 0.043) (Table 4). Harvest times in 2019 were significantly longer than those of 2018 for mustard in the container plots with the PC treatment plots ($P < 0.001$) (Table 5) and for kale ($P < 0.001$) (Table 4).

Total yields. Model simplification was performed to remove nonsignificant interactions with an alpha level of 0.05. The three-way interaction between growing system, nutrient management treatment, and year was only significant for mizuna (Supplemental Table 5). For the other crops, the only significant two-way interactions were for nutrient management treatment and year for arugula, mustard greens, and Swiss chard (Supplemental Table 5). Growing system had no significant effect on arugula or kale (Supplemental Table 5). Nutrient management treatment had no effect on the total yield of kale (Supplemental Table 5) or spinach (Supplemental Table 6).

Total yield from the raised bed plots was significantly higher than that of the container plots for lettuce ($P < 0.001$), mustard (P = 0.011), and Swiss chard (P = 0.004) (Table 6). There was no significant difference between the total yields of the raised beds and container plots for mizuna within any combination of nutrient management treatment and year (Table 7). Total yield of spinach was significantly higher in the container plots than the raised beds (P = 0.008).

For lettuce, total yield was highest in the PCO treatment, although it was only significantly higher than the PC treatment (P = 0.005) (Table 6). Despite the significant two-way interaction between nutrient management treatment and year, there were no significant differences among nutrient management treatments within either year for arugula or mizuna (Table 6). There were no significant differences in total yield among the nutrient management treatments of mustard in 2018 (Table 6). In 2019, total yield of mustard in the PC treatment had the highest yield and was significantly higher than the conventional and organic fertilizer treatments (P = 0.002 and P = 0.001, respectively) (Table 6). The PCO treatment had the second highest yield but was not significantly different from any nutrient management treatment. For Swiss chard, total yield was highest in the organic fertilizer treatment, followed closely by the PCO treatment (Table 6). The organic fertilizer and PCO treatments were significantly higher than the PC treatment (P = 0.014 and P = 0.021 respectively), but not the conventional fertilizer treatment (P = 0.718 and P = 0.972, respectively).

Total yields were significantly higher in 2019 than 2018 for mustard in the PC treatment ($P < 0.001$) and for kale ($P < 0.001$) (Table 6). There were no other significant differences between years for total yields for arugula within any compost treatment or mizuna (Tables 6 and 7).

Marketable yields. Model simplification was performed to remove nonsignificant interactions with an alpha level of 0.05. The three-way interaction between growing system, nutrient management treatment, and year was significant for mizuna (Supplemental Table 7). For the other crops, the only significant two-way interactions were for nutrient management treatment and year for arugula and mustard greens, growing system and year for mustard greens (Supplemental Table 7), and growing system and nutrient management treatment for Swiss chard (Supplemental Table 8). The main effects of growing system, nutrient management treatment, and year had no effect on the marketable yield of kale (Supplemental Table 7).

Marketable yields from the raised bed plots were significantly higher than marketable yields from the container plots for lettuce ($P < 0.001$), arugula (P = 0.025), and mustard in 2018 ($P < 0.001$) (Table 8). Marketable yield from the container plots was significantly higher than that of marketable yield from the raised bed plots for spinach (P = 0.003). There were no significant differences between the container and raised bed systems for mizuna for any nutrient management treatment in either year or Swiss chard (Table 9).

There were no significant differences among marketable yields of fertilizer treatments for lettuce and arugula in 2018, mizuna in either year, mustard in 2019, for Swiss chard in the container plots, or spinach (Tables 8 and 9). For all crops except mizuna, the PC treatment had the lowest marketable yields. For arugula in 2019, the PC treatment was significantly lower than all of the other treatments ($P < 0.001$ for all comparisons). The PCO treatment, which had the highest marketable yield, was

Table 4. Harvest time (s/m^2) means for all crops for each growing system and nutrient management treatment. Values in parentheses represent the standard error. Means represent 16 observations for each growing system and eight observations for each nutrient management treatment. Lower case letters denote differences among nutrient management treatments and capital letters denote differences between growing systems. Values in bold denote differences between years.

		Growing system		Nutrient management treatment				Year	
Crop	Year	Container (s/m^2)	Raised Bed (s/m^2)	Conventional (s/m^2)	Organic (s/m^2)	Peat and compost plus organic (s/m^2)	Peat and compost only (s/m^2)	2018 (s/m^2)	2019 (s/m^2)
Lettuce	2019	279 (55) B	695 (88) A	432 (108)	531 (147)	499 (139)	486 (142)	—	—
Arugula	2019	890 (129)	731 (109)	720 (134)	752 (196)	1077 (184)	693 (150)	—	—
Mizuna	2018	53 (11)	**49 (11)**	**44 (11)**	62 (10)	41 (12)	58 (18)	—	—
	2019	274 (67) A	**43 (22)** B	**24 (24)** b	207 (116) ab	233 (81) a	169 (67) a	—	—
Swiss chard	2019	264 (36)	321 (93)	230 (41) ab	479 (172) a	314 (52) ab	147 (27) b	—	—
Kale	[i]	113 (189)	128 (17)	115 (29)	98 (20)	134 (25)	134 (28)	**58 (7)**	**182 (19)**
Spinach	2018	154 (16) A	91 (15) B	123 (31)	132 (16)	124 (32)	109 (17)	—	—

[i] Growing system and nutrient management treatment means are averaged over the 2 years.

Table 5. Harvest time (s/m^2) means for crops for each combination of growing system, nutrient management treatment, and year for mizuna for which there was a significant three-way interaction. Values in parentheses represent the standard error. Means represent four observations. Lower case letters denote differences among nutrient management treatments within growing system and year. Values in bold denote differences between years within growing system and nutrient management treatment.

Crop	Year	Growing system	Nutrient Management Treatments			
			Conventional (g/m^2)	Organic (g/m^2)	Peat and compost plus organic (g/m^2)	Peat and compost only (g/m^2)
Mustard greens	2018	Container	57 (29)	100 (21)	89 (22)	**14 (10)**
		Raised bed	115 (27)	111 (5)	120 (32)	157 (57)
	2019	Container	147 (34) ab	146 (33) ab	132 (30) b	**286 (34)** a
		Raised bed	90 (6)	83 (20)	159 (25)	200 (17)

also significantly higher than the conventional fertilizer treatment, but not the organic fertilizer treatment ($P = 0.038$ and $P = 1.000$, respectively). The marketable yield of the PC treatment was only significantly lower than the organic fertilizer treatment for mustard in 2018 ($P = 0.021$) and the conventional fertilizer treatment for Swiss chard ($P = 0.049$). For comparisons that were not significantly different, the PC treatment only suggested a statistical trend when compared with the PCO treatment for lettuce and spinach ($P = 0.0502$ and $P = 0.075$, respectively).

Marketable yield for arugula was significantly higher in 2018 than 2019 for the PC treatment ($P < 0.001$). This was the only nutrient management treatment for which there was a significant difference between years for arugula (Table 9). In 2019, marketable yields for mizuna and mustard were zero for all study plots (Tables 7 and 8). Even so, marketable yield was only significantly higher in 2018 than 2019 for mustard in the container system ($P < 0.001$) and in the PC treatment ($P < 0.001$).

Discussion

For most of the crops, nutrient management treatments, and harvested metrics, there were no significant differences between the raised bed and pool container growing systems. Lettuce, mustard, and spinach were the only crops to show significant differences between the growing systems in more than one of the measured metrics. Lettuce and mustard performed better in the raised beds for three and two metrics, respectively, but spinach performed better in the pool containers for all three metrics (Tables 4, 6, and 8). When factoring in the crops for which there was only a significant difference in one metric as well, the raised beds outperformed the pool containers only slightly more than they did not. Additional research on the pool container gardens will be needed to determine if the differences observed here represent an adverse growing environment or are an artifact of the growing conditions observed in this study. One area for future research is possible drainage strategies for the pool gardens, which could help to optimize production. The pool containers experienced some drainage issues following heavy rainstorms early in 2018, which could have affected production of the early crops. However, there were no visible signs of nitrogen (N) deficiencies which could indicate either lack of N availability or loss of N in poorly drained soils.

Fewer differences among nutrient management treatments were observed than expected. It has been well established that there is typically a yield gap between organic and conventional crop production, with organic yielding 25% less, depending on the crop and other operational factors (Alvarez 2021). In this study, the conventional fertilizer treatment had higher average total or marketable yield than the organic fertilizer treatments as often as the organic fertilizer treatment had higher average total or marketable yield. None of these differences were statistically significant but range from 4% to 74% lower in the former case and between up to an order of magnitude difference in the latter case. This is likely because of the variability in yields observed in this study. When compared with all of the organic treatments (organic fertilizer, PCO, and PC), the conventional fertilizer treatment was never significantly different from all of the organic treatments, and was significantly higher than one treatment including compost as often as it was significantly lower than one treatment including compost. Crop responses to compost containing treatments are likely due to differences in the amount of nutrients supplied by the PC treatment and how well different greens respond to the nutrient sources in the compost. The amount of nitrogen supplied by the nutrient management treatments was the same for the conventional and organic fertilizer treatments (Supplemental Table 2). Although the amount of phosphate and potassium supplied by the organic fertilizer treatment was slightly lower than the conventional fertilizer treatment, it met the recommended application rate. The estimated amount of nutrients supplied by the PCO treatment were slightly lower than the fertilizer-only treatments (Supplemental Table 2) but does not appear to have adversely impacted total or marketable yield as this treatment was highest or second highest for most crops (Tables 6–9). The much lower estimated amount of nutrients supplied by the compost treatment, about 86% lower than that of the fertilizer treatments, did appear to negatively impact marketable yield (Tables 8 and 9). Although this runs counter

Table 6. Total yield (g/m^2) means for all crops for each growing system and nutrient management treatment for which there were no significant three-way interactions between growing system, nutrient management treatment, and year or two-way interactions between growing system and nutrient management treatment. Values in parentheses represent the standard error. Means represent 16 observations for each growing system and eight observations for each nutrient management treatment per growing season. Lower case letters denote differences among nutrient management treatments and capital letters denote differences between growing systems. Values in bold denote differences between years.

Crop	Year	Growing system		Nutrient management treatment				Year	
		Container (g/m^2)	Raised bed (g/m^2)	Conventional (g/m^2)	Organic (g/m^2)	Peat and compost plus organic (g/m^2)	Peat and compost only (g/m^2)	2018 (g/m^2)	2019 (g/m^2)
Lettuce	2019	417 (80) B	1018 (98) A	740 (185) ab	707 (166) ab	1003 (169) a	425 (78) b	—	—
Arugula[i]	2018	478 (60)	613 (60)[ii]	426 (46)	359 (50)[ii]	510 (49)	309 (44)	—	—
	2019	—	—	606 (68)	827 (127)	1097 (110)	198 (20)	—	—
Mustard greens[i]	2018	98 (18) B	159 (23) A	101 (36)	93 (16)	75 (20)	**52 (24)**	—	—
	2019	—	—	102 (17) b	98 (20) b	205 (57) ab	**294 (48)** a	—	—
Swiss chard	2019	104 (12) B	180 (26) A	131 (27) ab	186 (36) a	180 (29) a	70 (15) b	—	—
Kale	[iii]	169 (35)	175 (30)	158 (43)	132 (36)	246 (61)	150 (37)	**67 (11)**	**277 (36)**
Spinach	2018	35 (6) A	16 (4) B	26 (8)	32 (6)	32 (11)	12 (2)	—	—

[i] Growing system means are averaged over year, as the two-way interaction between growing system and year was not significant for arugula (F = 2.171, $P = 0.147$) or mustard (F = 0.427, $P = 0.516$).

[ii] These means represent one fewer observation due to missing data.

[iii] Growing system and nutrient management treatment means are averaged over the 2 years.

Table 7. Total yield (g/m^2) means for crops for each combination of growing system, nutrient management treatment, and year for mizuna for which there was a significant three-way interaction. Values in parentheses represent the standard error. Means represent four observations.

			Nutrient management treatments			
Crop	Year	Growing system	Conventional (g/m^2)	Organic (g/m^2)	Peat and compost plus organic (g/m^2)	Peat and compost only (g/m^2)
Mizuna	2018	Container	35 (8)	11 (2)	14 (7)	17 (3)
		Raised bed	7 (3)	84 (68)	14 (8)	9 (4)
	2019	Container	2 (2)	51 (22)	73 (6)	13 (7)
		Raised bed	0 (0)	9 (8)	15 (15)	49 (47)

to findings that yields from conventional fertilizer treatments were equal or surpassed yields from compost treatments (Mays et al. 1973), this lack of difference has been observed with greens before (Gent 2002; Knewtson et al. 2009). The results of this study also run counter to other findings that organic production can have higher yields than conventional production in drought years (Lotter et al. 2003; Pimentel and Burgess 2014). Use of compost in organic systems, including irrigated vegetable systems, has been linked with increased water holding capacity (Lal 2020; Nguyen et al. 2012), which should lead to better outcomes under drought conditions. The crops grown during the 2019 drought, Swiss chard and kale, did not show consistent increased yields with compost use or increased yields with higher compost addition. Two factors could have contributed to this lack of difference, the use of raised beds on platforms and containers, which tend to dry out faster than in ground plantings (Durham et al. 2021), and the use of consistent irrigation, which could have prevented the plots from drying to the point that there would be observable differences between compost containing treatments.

The total yields observed in this study were low compared with those expected based on yields from traditional agriculture and estimates for home gardening (Table 10) across all crops, growing systems, nutrient management treatments, and study years. As low as 0.65% if the traditional agriculture yields in spinach and as high as 49.85% in lettuce. Yields were also on the medium to low end of the range reported in the peer-reviewed literature on these greens and urban agriculture (Table 10), likely a result of insect pest issues and weather conditions during the study. Marketable yield was heavily impacted by the presence of flea beetles, which are also a common pest for arugula, mizuna, and mustard. Diatomaceous earth was used to control the problem, more successfully in 2018 than in 2019. Damage was noted in 2018 in only the arugula and mizuna crops and may have impacted crop quality. In 2019, the flea beetles caused some damage to arugula and significant damage to mizuna and mustard across all treatments. Both mizuna and mustard had no marketable yield (Table 9) because of the flea beetle damage in 2019. It is possible that total yield also suffered because of the insect pressure and contributed to yields lower than those reported by other studies (Table 10), but the higher pressure in 2019 did not significantly lower total yields of mizuna or mustard when compared with yields in 2018 (Tables 6 and 7). Flea beetles in the summer of 2019 in this part of Kentucky were a significant problem, and other farmers noted an inability to adequately control them using multiple organic methods (Olsen R, personal communication). The kale crop was also affected by caterpillar damage, especially in 2018.

The 2018 growing season was unusually wet compared with the climatic normal, with August bringing in 23.57 cm of rain and September with 20.19 cm (Fig. 1). Precipitation would come in large storm events, but was spaced evenly throughout the growing season, so irrigation was rarely needed during this growing season. Despite wetter conditions in 2018, no evidence of fungal diseases or water logging was observed during the wettest parts of that growing season. Precipitation in 2019 was lower than normal, with a drought between 28 Aug and 6 Oct. Irrigation was, therefore, relied on more during the second growing season than the first, especially during the drought. This drought combined with warmer than average temperatures in September likely affected production. Both the Swiss chard that was planted on 6 Aug and the kale that was planted on 13 Sep took longer than the expected 30 d to reach the baby stage and be ready for harvest, despite providing adequate irrigation. Swiss chard took 37 d, and the kale took 33 d, 6 d longer than it took in 2018. During those two periods, the optimal growing temperatures for both Swiss chard and kale were exceeded ∼25% of the time (Johnny's Selected Seeds 2025a, 2025b), but this did not significantly reduce kale total or marketable yields below those of the 2018 growing season (Tables 6 and 8).

Temperatures also played a role in the performance of the other greens grown. Arugula is a crop that thrives in temperatures of 15 to 20 °C (Johnny's Selected Seeds 2024a). The average temperature for the arugula rotation was 18.4 to 30.6 °C in 2018, exceeding the optimal range on all but three of 38 d. The higher than ideal temperatures caused the arugula to bolt the last few days before harvesting. Earlier planting in 2019 (Table 2) seemed to alleviate the bolting issues. Although there were no significant differences in total yields (Table 5) and few differences in marketable yields (Table 9) between the two growing seasons, temperatures exceeded the optimal range for arugula less. Average temperatures ranged from 15.0 to 25.6 °C, with only 15 of 25 d exceeding the optimal temperature. Mustards are a more heat-tolerant

Table 8. Marketable yield (g/m^2) means for all crops for each growing system and nutrient management treatment for which there were no significant three-way interactions between growing system, nutrient management treatment, and year or two-way interactions between growing system and nutrient management treatment. Values in parentheses represent the standard error. Means represent 16 observations for each growing system and eight observations for each fertilizer treatment per growing season. Lower case letters denote differences among nutrient management treatments and capital letters denote differences between growing systems. Values in bold denote differences between years.

		Growing system		Nutrient management treatment				Year	
Crop	Year	Container (g/m^2)	Raised bed (g/m^2)	Conventional (g/m^2)	Organic (g/m^2)	Peat and compost plus organic (g/m^2)	Peat and compost only (g/m^2)	2018 (g/m^2)	2019 (g/m^2)
Lettuce	2019	264 (39) B	769 (65) A	505 (133)	570 (133)	636 (123)	355 (70)	—	—
Arugula[i]	2018	259 (46) B	363 (52)[ii] A	248 (44)	219 (34)[ii]	310 (46)	**170 (24)**	—	—
	2019	—	—	259 (88) b	446 (93) ab	802 (88) a	**14 (8)** b	—	—
Mustard greens	2018	**38 (15)** B	96 (16) A	89 (35) ab	86 (15) a	53 (20) ab	**39 (21)** b	—	—
	2019	**0 (0)**	0 (0)	0 (0)	0 (0)	0 (0)	**0 (0)**	—	—
Kale	[iii]	80 (16)	80 (17)	79 (21)	72 (24)	120 (31)	49 (9)	58 (10)	101 (20)
Spinach	2018	12 (3) A	3 (1) B	8 (3)	10 (3)	11 (5)	0 (0)	—	—

[i] Growing system means are averaged over year, as the two-way interaction between growing system and year was not significant for arugula ($F = 0.019$, $P = 0.892$).

[ii] These means represent one fewer observation due to missing data.

[iii] Growing system and nutrient management treatment means are averaged over the 2 years.

Table 9. Marketable yield (g/m^2) means for crops for each combination of growing system, nutrient management treatment, and year for which there were significant three-way interactions between growing system, nutrient management treatment, and year or two-way interactions between growing system and nutrient management treatment. Values in parentheses represent the standard error. Means represent four observations. Lower case letters denote differences among nutrient management treatments within growing system and year and capital letters denote differences between growing systems within nutrient management treatment and year. Values in bold indicate differences between years within growing system and nutrient management treatment.

			Nutrient management treatments			
Crop	Year	Growing system	Conventional (g/m^2)	Organic (g/m^2)	Peat and compost plus organic (g/m^2)	Peat and compost only (g/m^2)
Mizuna	2018	Container	**28 (6)**	**7 (1)**	12 (6)	**13 (2)**
		Raised bed	5 (3)	**75 (62)**	**11 (6)**	6 (3)
	2019	Container	**0 (0)**	**0 (0)**	0 (0)	**0 (0)**
		Raised bed	0 (0)	**0 (0)**	**0 (0)**	0 (0)
Swiss chard	2019	Container	19 (9) B	43 (15)	35 (12)	7 (4)
		Raised bed	74 (11) aA	25 (12) ab	52 (15) ab	17 (10) b

Table 10. Expected crop yields (g/m^2) from traditional agriculture as reported by the USDA (2018, 2020), expected crop yields for home vegetable production (Durham et al. 2021), and yields reported in peer-reviewed literature.

Crop	Traditional agriculture (g/m^2)	Home vegetable production (g/m^2)	Peer-reviewed literature (g/m^2)
Leaf Lettuce	2,042–2,732	2,930	90.5–6,150 (Carillo et al. 2020; Coria-Cayupán et al. 2009; de Barros Sylvestre et al. 2019; Gent 2002; Govedarica-Luĉić et al. 2020)
Arugula	No data available	No data available	964–3,500 (Gent 2002; Silva et al. 2021; Souza et al. 2016)
Mustard greens	1,607	3,255	477–1,700 (Gent 2002; Yusuf et al. 2020)
Swiss chard	No data available	1,465	59.37–1,200 (Dumani et al. 2021; Libutti et al. 2020; Libutti and Rivelli 2021)
Kale	2,247	2,170	2–4,285 (Antonious et al. 2014; Gent 2002; Iheshiulo et al. 2017; Kornecki and Balkcom 2020; Thavarajah et al. 2019)
Spinach	1,656–1,833	1,172	240–2,520 (Gent 2002; Knewtson et al. 2009; Stagnari et al. 2007)

Brassica crop, with optimum growing conditions centered around 25 °C (Johnny's Selected Seeds 2024b, 2024c). Temperatures for mizuna and mustard ranged from 20.1 to 25.7 °C and 18.3 to 26.7 °C, respectively, in 2018 and 20.1 to 26.4 °C and 19.7 to 28.4 °C, respectively, in 2019. Despite earlier planting in 2019, temperatures were similar in the two years and were not far off the optimum for these two crops. Temperatures for the spinach rotation in 2018 dropped from ~24 °C to ~10 °C in early October. While spinach can and does grow at these cooler temperatures (Palka 2023), the significant temperature shift so close to the first frost may have slowed growth and contributed to low yields in the unprotected spinach (Tables 6 and 8).

Conclusions

The result of this study supports the conclusion that leafy greens can be relay cropped in urban agriculture production systems. The few differences between the raised bed and small plastic pool container growing systems suggest that small plastic pools could be a suitable production alternative in urban areas. Further study of the small plastic pool containers should include examination of optimal drainage strategies and other potential microclimatic effects. More data would help to determine why differences were seen in some crops and not others, and what effect the growing conditions observed during this study had on the results. Although some greens responded favorably to organic amendments and the use of compost, not all did. There was no clear pattern of dose response to compost additions and/or of how the conventional fertilizer treatment compared with the organic amendment treatments. This study also highlights the influence that other factors can have on urban crop production. Insect pests had a significant effect on marketable yields in this study and weather patterns likely also influenced outcomes, possibly obscuring the effects of nutrient management treatments. High temperatures and the drought from 28 Aug and 6 Oct in 2019 slowed crop growth. This could have implications for production in urban heat islands and under changing climate conditions.

References Cited

Ackerman K, Conard M, Culligan P, Plunz R, Sutto M-P, Whittinghill L. 2014. Sustainable food systems for future cities: the potential of urban agriculture. Econ Soc Rev. 45(2):189–206.

Alvarez R. 2021. Comparing productivity of organic and conventional farming systems: a quantitative review. Arch Agron Soil Sci. 68(14):1947–1958. https://doi.org/10.1080/03650340.2021.1946040.

Antonious G, Turley ET, Hill RR, Snyder JC. 2014. Chicken manure enhanced yield and quality of field-grown kale and collard greens. J Environ Sci Health B. 49(4):299–304. https://doi.org/10.1080/03601234.2014.868681.

Agnotti T. 2015. Urban agriculture: Long-term strategy or impossible dream? Lessons from prospect farm in Brooklyn, New York. Public Health. 129:226–341.

Bączek K, Kosakowska O, Gniewosz M, Gientka I, Węglarz Z. 2019. Sweet basil (*Ocimum basilicum* L.) productiity and raw material quality from organic cultivation. Agronomy. 9(6):279. 279–204. https://doi.org/10.3390/agronomy9060279.

Bahamonde A. 2019. Mental health through the art of gardening. J Therapeutic Hort. 29(2):27–44.

de Barros Slyvestre T, Braos LB, Filho FB, da Cruz MCP, Ferreira ME. 2019. Mineral nitrogen fertilization effects on lettuce crop yield and nitrogen leaching. Sci Hortic. 255:153–160.

Bartholomew M. 2005. All new square foot gardening: grow more in less space. Cool Springs Press, Brentwood, TN, USA.

Berle D, Westerfield R. 2013. Raised garden bed dimensions, Community and school gardens. The University of Georgia Cooperative Extension Circular 1027-4. https://secure.caes.uga.edu/extension/publications/files/pdf/C%201027-4_1.PDF. [accessed 29 Nov 2018].

Bojilov D, Dagnon S, Kostadinov K, Filipov S. 2020. Polyphenol composition of lettuce cultivar affected by mineral and bio-organic fertilization. Czech J Food Sci. 38(6):359–366. https://doi.org/10.17221/97/2020-CJFS.

Cameira MR, Tedesco S, Leitão TE. 2014. Water and nitrogen budgets under different production systems in Lisbon urban farming. Biosystems Eng. 125:65–79. https://doi.org/10.1016/j.biosystemseng.2014.06.020.

Carillo P, Giordano M, Raimondi G, Napolitano F, Di Stasio E, Kyriacou MC, Sifola MI, Rouphael Y. 2020. Physiological and nutraceutical quality of green and red pigmented lettuce in response to NaCl concentration in two successive harvests. Agronomy. 10(9):1358–1376. https://doi.org/10.3390/agronomy10091358.

Chakwizira E, de Ruiter JM, Maley S. 2015. Effects of nitrogen fertiliser application rate on nitrogen partitioning, nitrogen use efficiency and nutritive value of forage kale. New Zeal J Agr Res. 58(3):259–270. https://doi.org/10.1080/00288233.2015.1016538.

Colman A. 2017. Community and home gardening develop lifelong healthy habits. Parks Rec. 52(8):34–35.

Coria-Cayupán YS, de Pinto MIS, Nazareno MA. 2009. Variations in bioactive substance contents and crop yields of lettuce (*Lactuca sativa* L.) cultivated in soils with different fertilization treatments. J Agric Food Chem. 57(21):10122–10129. https://doi.org/10.1021/jf903019d.

Dewaelheyns V, Elsen A, Vandendriessche H, Gulinck H. 2013. Garden management and soil fertility in Flemish domestic gardens. Landsc Urban Plan. 116:25–35. https://doi.org/10.1016/j.landurbplan.2013.03.010.

Dimitri C, Oberholtzer L, Pressman A. 2016. Urban agriculture: Connecting producers with consumers. Brit Food J. 118(3):603–617. https://doi.org/10.1108/BFJ-06-2015-0200.

Dumani A, Silwana TT, Mpambani B, Celliers RP, Mbangcolo MM. 2021. Effect of bioslurry effluent on growth, biological yield and nutritional content of Swiss chard (*Beta vulgaris* L.). J Agr Ext Rural Devel. 13(3):173–181. https://doi.org/10.5897/JAERD2021.1221.

Durham R, Lee B, Osborne A. 2018. Gardening in small spaces. University of Kentucky Cooperative Extension Service ID 248.
Durham R, Rudolph R, Williams M, Wright S, Bessin R, Lee B. 2021. Home vegetable gardening in Kentucky. University of Kentucky Cooperative Extension Service ID-128.
Eblen T. 2018. Kentucky has been rapidly losing farmland. Where most of it went may surprise you. Lexington Herald Leader. https://www.kentucky.com/news/local/news-columns-blogs/tom-eblen/article209422854.html. [accessed 14 Nov 2018].
The Ecology Center. 2016. 10 ways urban farms benefit the community. https://www.theecologycenter.org/resources/10-ways-urban-farms-benefit-the-community/. [accessed 28 Oct 2018].
Feeding America. 2020. The impact of the coronavirus on food insecurity in 2020. https://www.feedingamerica.org/sites/default/files/2020-10/Brief_Local%20Impact_10.2020_0.pdf. [accessed 2 Nov 2021].
Freedgood J, Hunter M, Dempsey J, Sorensen A. 2020. Farms under threat: The state of the states. American Farmland Trust: Washington, DC, USA. https://farmlandinfo.org/publications/farms-under-threat-the-state-of-the-states/.
Gent MPN. 2002. Growth and composition of salad greens as affected by organic compared to nitrate fertilizer and by environment in high tunnels. J Plant Nutr. 25(5):981–998. https://doi.org/10.1081/PLN-120003933.
Ghose R, Pettygrove M. 2014. Urban community gardens as spaces of citizenship. Antipode. 46(4):1092–1112. https://doi.org/10.1111/anti.12077.
Govedarica-Luĉić A, Perković G, Rahimić A, Bušković I, Pašić S. 2020. Influence of fertilization on growth and quality of lettuce. Agri For. 66(3):73–80.
Hell's Kitchen Farm Project. 2020. https://www.hkfp.org/. [accessed 6 Jul 2020].
Hinrichsen D. 1998. Feeding a future. US National Library of Medicine, National Institutes of Health. 7(1):6–9. https://www.ncbi.nlm.nih.gov/pubmed/12348766. [accessed 2 Nov 2018].
Hughes A. 2015. Can small farmers make a profit at farmers' markets? Seedstock. http://seedstock.com/2015/10/12/can-small-farmers-make-a-profit-at-farmers-markets/. [accessed 14 Nov 2018].
Hummert International. 2021. Round containers. https://www.hummert.com/containers-round/. [accessed 3 Nov 2021].
Iheshiulo EM-A, Abbey L, Asiedu SK. 2017. Response of kale to single-dose application of K humate, dry vermicasts, and volcanic minerals. Int J Veg Sci. 23(2):135–144. https://doi.org/10.1080/19315260.2016.1219437.
Johnny's Selected Seeds. 2024a. Arugula (standard) organic salad arugula seed. https://www.johnnyseeds.com/vegetables/greens/arugula-roquette/arugula-standard-organic-salad-arugula-seed-2891.html. [accessed 4 Jan 2024].
Johnny's Selected Seeds. 2024b. Mizuna organic Asian green seed. https://www.johnnyseeds.com/vegetables/greens/asian-greens/mizuna-organic-asian-green-seed-2883.html. [accessed 4 Jan 2024].
Johnny's Selected Seeds. 2024c. Red giant organic mustard green seed. https://www.johnnyseeds.com/vegetables/greens/mustard-greens/red-giant-organic-mustard-green-seed-2884.html. [accessed 4 Jan 2024].
Johnny's Selected Seeds. 2025a. Fordhook giant organic Swiss chard seed. https://www.johnnyseeds.com/vegetables/swiss-chard/fordhook-giant-organic-swiss-chard-seed-701G.html. [accessed 9 Jan 2025].
Johnny's Selected Seeds. 2025b. Red Russian organic kale seed. https://www.johnnyseeds.com/vegetables/kale/red-russian-organic-kale-seed-363G.html. [accessed 9 Jan 2025].
Kaiser C, Ernst M. 2021. Organic lettuce and leafy greens. Center for Crop Diversification Crop Profile. CCD-CP-109. https://www.uky.edu/ccd/sites/www.uky.edu.ccd/files/organiclettuce.pdf. [accessed 2 Feb 2024].
Kim L, Jeon JW, Lee Y-S, Jeon H-J, Park B-J, Lee H-S, Choi S-D, Lee S-E. 2016. Monitoring and risk assessment of polychlorinated biphenyls (PCBs) in agricultural soil collected in the vicinity of an industrialized area. Appl Biol Chem. 59(4):655–659. https://doi.org/10.1007/s13765-016-0207-2.
Knewtson SJB, Griffin JJ, Carey EE. 2009. Application of two microbial teas did not affect collard or spinach yield. HortScience. 44(1):73–78. https://doi.org/10.21273/HORTSCI.44.1.73.
Kornecki TS, Balkcom KS. 2020. Organic kale and cereal rye grain production following a sunn hemp cover crop. Agronomy. 10(12):1913–1929. https://doi.org/10.3390/agronomy10121913.
Kumar R. 2016. How urban agriculture is revitalizing local economies. Huffington Post. https://www.huffingtonpost.com/rohit-kumar/revitalizing-local-economies_b_3380472.html. [accessed 14 Nov 2018].
Lal R. 2020. Soil organic matter and water retention. Agron J. 112(5):3265–3277. https://doi.org/10.1002/agj2.20282.
Libutti A, Trotta V, Rivelli AR. 2020. Biochar, vermicompost, and compost as soil organic amendments: Influence on growth parameters, nitrate and chlorophyll content of swiss chard (*Beta vulgaris* l. Var. Cycla). Agronomy. 10(3):346. https://doi.org/10.3390/agronomy10030346.
Libutti A, Rivelli R. 2021. Quanti-qualitative response of swiss chard (*Beta vulgaris* L. var. cycla) to soil amendment with biochar-compost mixtures. Agronomy. 11(2):307. https://doi.org/10.3390/agronomy11020307.
Lin BB, Philpott SM, Jha S. 2015. The future of urban agriculture and biodiversity-ecosystem services: Challenges and next steps. Basic Appl Ecol. 16(3):189–201. https://doi.org/10.1016/j.baae.2015.01.005.
Lotter DW, Seidel R, Liebhardt W. 2003. The performance of organic and conventional cropping systems in an extreme climate year. Am J Alt Ag. 18(3):146–154. https://doi.org/10.1079/AJAA200345.
Lowe's. 2021. Lawn and garden: Plastic pots and planters. https://www.lowes.com/pl/Plastic–Pots-planters-Planters-stands-window-boxes-Plants-planters-Lawn-garden/4294612569?refinement=4294965728. [accessed 3 Nov 2021].
Mays D, Terman G, Duggan J. 1973. Municipal compost: Effects on crop yields and soil properties. J Env Quality. 2(1):89–92. https://doi.org/10.2134/jeq1973.00472425000200010011x.
McDougall R, Kristiansen P, Rader R. 2019. Small-scale urban agriculture results in high yields but requires judicious management of inputs to achieve sustainability. Proc Natl Acad Sci U S A. 116(1):129–134. https://doi.org/10.1073/pnas.1809707115.
Michaels K. 2021. How to make a garden planter from a plastic kiddie pool. The Spruce. https://www.thespruce.com/make-a-kiddie-pool-into-a-garden-planter-848239. [accessed 6 Jul 2020].
Miernicki EA, Lovell ST, Wortman SE. 2018. Raised beds for vegetable production in urban agriculture. Urban Agric Regnl Food Sys. 3(1):1–10. https://doi.org/10.2134/urbanag2018.06.0002.
Mok HF, Williamson VG, Grove JR, Burry K, Barker SF, Hamilton AJ. 2014. Strawberry fields forever? Urban agriculture in developed countries: A review. Agron Sustain Dev. 34(1):21–43. https://doi.org/10.1007/s13593-013-0156-7.
National Oceanic and Atmospheric Administration National Climate Data Center (NOAA). 2020. Normals daily station details Frankfort Capital City Airport, KY, USA. http://www.ncdc.noaa.gov/cdo-web/datasets. [accessed 17 June 2020].
Nguyen TT, Fuentes S, Marschner P. 2012. Effects of compost on water availability and gas exchange in tomato during drought and recovery. Plant Soil Environ. 58(11):495–502. https://doi.org/10.17221/403/2012-PSE.
Nogeire-McRae T, Ryan EP, Jablonski BBR, Carolan M, Arathi HS, Brown CS, Saki HH, McKeen S, Lapansky E, Schipanski ME. 2018. The role of urban agriculture in a secure, healthy, and sustainable food system. BioScience. 68(10):748–759. https://doi.org/10.1093/biosci/biy071.
Oberholtzer L, Dimitri C, Pressman A. 2014. Urban agriculture in the United States: Characteristics, challenges, and technical assistance needs. J Ext. 52(6):v52–6.a1.
Ohly H, Gentry S, Wigglesworth R, Bethel A, Lovell R, Garside R. 2016. A systematic review of the health and well-being impacts of school gardening: Synthesis of quantitative and qualitative evidence. BMC Public Health. 16(1):286–236. https://doi.org/10.1186/s12889-016-2941-0.
Palka L. 2023. Growing spinach, a cool-season vegetable. Pennsylvania State University Extension. https://extension.psu.edu/growing-spinach-a-cool-season-vegetable. [accessed 15 Feb 2024].
Pereira MB, Dias TJ, Lima NR, Justino ES, Oliveira DS, Martins-Veras ML. 2020. Plant growth and yield of butter kale (*Brassica oleracea* L. var. acephala), as influenced by the combined application of bovine manure and rock powder. Acta Agron. 69(1):38–45. https://doi.org/10.15446/acag.v68n4.75174.
Pimentel D, Burgess M. 2014. An environmental, energetic and economic comparison of organic and conventional farming systems, p 41–166. In: Pimentel D, Peshin R (eds). Integrated Pest Management: Pesticide Problems. Vol 3. Springer, Dordrecht.
Reda T, Thavarajah P, Polomski R, Bridges W, Shipe E, Thavarajah D. 2020. Reaching the highest shelf: A review of organic production, nutritional quality, and shell if of kale (*Brassica oleracea* var. *acephala*). Plants People Planet. 3(4):308–318. https://doi.org/10.1002/ppp3.10183.
Sainju U, Jabro J. 2016. Cover crops: Improving soil quality and productivity. United States Department of Agriculture: Agriculture Research Service. https://www.ars.usda.gov/plains-area/sidney-mt/northern-plains-agricultural-research-laboratory/agricultural-systems-research/asru-docs/cover-crops-improving-soil-quality-and-productivity/. [accessed 14 Nov 2018].
Salomon MJ, Watts-Williams SJ, McLaughlin MJ, Cavagnaro TR. 2020. Urban soil health: A city-wide survey of chemical and biological properties of urban agriculture soils. J Clean Prod. 275:122900. https://doi.org/10.1016/j.jclepro.2020.122900.
Satzewich W. 2016. SPIN-Farming: A new way to learn to farm. https://spinfarming.com/tips/tag/relay-cropping/. [accessed 29 Nov 2018].
Satzewich W, Christensen R. 2011. SPIN farming basics. Thinking of farming? Think again there's a new way to farm. SPIN Farming LLC, Philadelphia, PA, USA.
Silva PHS, Filho ABC, Reis IDS, Reyes SMR, Da Cruz MCP. 2021. Nitrogen rates on growth,

yield, and nitrate foliar content of arugula. Rev Caatinga. 34(2):380–387. https://doi.org/10.1590/1983-21252021v34n214rc.

Small G, Shrestha P, Metson GS, Polsky K, Jimenez I, Kay A. 2019. Excess phosphorus from compost applications in urban gardens creates potential pollution hotspots. Environ Res Commun. 1(9):091007. https://doi.org/10.1088/2515-7620/ab3b8c.

Souza EGF, Santana FMS, Martins BMN, dos Santos MG, de Cerqueira Júnior EP, Barros Júnior AP, da Silveira LM, Neto FB, Lins HA, de Albuquerque JRT. 2016. Agronomic response of arugula to green fertilization with rooster tree during two culture times. Afr J Agr Res. 11(48):4931–4938.

Stagnari G, Bitetto VD, Pisante M. 2007. Effects of N fertilizers and rates on yield, safety and nutrients in processing spinach genotypes. Sci Hortic. 114(4):225–233. https://doi.org/10.1016/j.scienta.2007.06.016.

Stagnari F, Galieni A, Pisante M. 2015. Shading and nitrogen management affect quality, safety and yield of greenhouse-grown leaf lettuce. Sci Hortic. 192:70–79. https://doi.org/10.1016/j.scienta.2015.05.003.

Stone C. 2016. The Urban Farmer: Growing food for profit on leased and borrowed land. New Society Publishers, Gabriola Island, BC, Canada.

Thavarajah D, Siva N, Johnson N, McGee R, Thavarajah P. 2019. Effect of cover crops on the yield and nutrient concentration of organic kale (*Brassica oleracea* L. var. *acephala*). Sci Rep. 9(1):10374. https://doi.org/10.1038/s41598-019-46847-9.

United Nations. 2019. World urbanization prospects. The 2018 revision. United Nations Department of Economic and Social Affairs. https://population.un.org/wup/Publications/Files/WUP2018-Report.pdf. [accessed 21 Dec 2022].

US Department of Agriculture (USDA). 2020. Vegetables 2019 summary. United States Department of Agriculture National Agriculture Statistics Service. https://usda.library.cornell.edu/concern/publications/02870v86p. [accessed 18 Dec 2022].

US Department of Agriculture (USDA). 2018. National statistics for greens. United States Department of Agriculture National Agriculture Statistics Service. https://www.nass.usda.gov/Statistics_by_Subject/result.php?5445A0F9-26AD-3063-9962-26DF3D585ECA&sector=CROPS&group=VEGETABLES&comm=GREENS. [accessed 19 Dec 2022].

US Environmental Protection Agency (USEPA). 2011. Reusing potentially contaminated landscapes: Growing gardens in urban soil. Environmental Protection Agency. Office of Superfund Remediation and Technology Innovation. https://www.epa.gov/sites/production/files/2014-03/documents/urban_gardening_fina_fact_sheet.pdf. [accessed 14 Nov 2018].

Van Tuijl E, Hospers G-J, Van Den Berg L. 2018. Opportunities and challenges of urban agriculture for sustainable city development. ESR&P. 25(2):5–22. https://doi.org/10.18778/1231-1952.25.2.01.

Wielemaker R, Oenema O, Zeeman G, Weijma J. 2019. Fertile cities: Nutrient management practices in urban agriculture. Sci Total Environ. 668:1277–1288. https://doi.org/10.1016/j.scitotenv.2019.02.424.

Yan L. 2016. Dark green leafy vegetables. United States Department of Agriculture Agricultural Research Service. https://www.ars.usda.gov/plains-area/gfnd/gfhnrc/docs/news-2013/dark-green-leafy-vegetables/. [accessed 17 Nov 2021].

Yusuf R, Mas'ud H, Syakur A, Afriana DS, Kalaba Y, Kristiansen P, Bahrudin. 2020. Application of local seaweed extracts on growth and yield of mustard greens (*Brassica juncea* L.). IOP Conf Ser: Earth Environ Sci. 484(1):012066. https://doi.org/10.1088/1755-1315/484/1/012066.