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Influence of ground cover and tunnels on production of Red Russian kale in urban gardens

M.L. Richardson, C.G. Arlotta, L. Monroe-Lord (*)
College of Agriculture, Urban Sustainability and Environmental Sciences, University of the District of Columbia, United States of America, 4250 Connecticut Ave, NW, Washington, DC 20008, USA.

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(*) **Corresponding author:**
lmonroelord@udc.edu

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Abstract: Kale, *Brassica oleracea* L. var. *acephala*, is an important urban crop for human health and may potentially be grown year-round even in a temperate climate. We investigated black plastic and straw mulch compared to bare soil cover in low tunnels at 10 urban garden sites and in low tunnels within a high tunnel in the USA to ascertain the influence on yield and nutrients of Red Russian kale, soil temperature, air temperature, weed pressure, and aphid abundance. Kale had low yield in garden sites, likely because the outside environment was too cold for low tunnels to gain and retain heat. Cultivating kale in a high tunnel resulted in good yields, especially when paired with a low tunnel and plastic or straw mulch, which resulted in the highest air and soil temperatures. The amount of minerals in plants within the high tunnel largely did not vary across combinations of low tunnels and ground covers, except for copper and sulfur, which were lowest in plots with no low tunnel or ground cover. Also, dietary fiber was higher when no low tunnel or ground cover was used compared to plots with a low tunnel and no ground cover. Weeds were suppressed by straw and black plastic mulch, but none of the ground covers influenced aphid abundance. Overall, our work demonstrates that Red Russian kale can be grown in a temperate climate during winter with some combinations of tunnels and ground covers.

1. Introduction

As urban agriculture becomes more common worldwide, analyses of its benefits, limitations, and role within sustainable cities and the food supply chain also become more common (Orsini *et al.*, 2013; Goldstein *et al.*, 2016; Azunre, 2019; Taylor *et al.*, 2021). Urban agriculture is not a replacement for large-scale rural agriculture partly because it cannot meet caloric needs of the growing and urbanizing human population. However, urban agriculture can address nutritional deficiencies in humans by providing a local source of crops that provide important micronutrients (Weidner *et al.*, 2019). Horticultural crops, such as pulses

(Cerozi *et al.*, 2022), tubers (Richardson and Arlotta, 2023), root crops (Cerozi *et al.*, 2022), and vegetables (Song *et al.*, 2020) that are nutrient-dense, high-yielding, and easy to cultivate, are among the most suitable crops for urban production (Clinton *et al.*, 2018). Production of horticultural crops in urban areas also shifts dietary intake toward consumption of locally grown fresh foods (McCormack *et al.*, 2010), which has health benefits, such as preventing chronic disease (Boeing *et al.*, 2012). Production of horticultural crops in urban areas can also potentially have numerous social and environmental benefits, such as providing educational spaces, connecting people with the food supply chain, reducing food miles, and efficiently using natural resources (Specht *et al.*, 2014).

Kale, *Brassica oleracea* L. var. *acephala*, is one such crop well-suited to urban areas. It is grown for its high yield of edible leaves that are consumed raw or cooked and is an important staple crop for diversified market farms, community supported agriculture, and school, community, and home gardens in urban areas. Brassicaceous crops, such as kale, are a good source of mineral nutrients, antioxidant phytochemicals, secondary metabolites, and prebiotic carbohydrates (Manchali *et al.*, 2012; Chang *et al.*, 2019). Kale is higher in calcium, folate, vitamin K, riboflavin, and vitamin C than other brassicaceous crops. Furthermore, kale is a good source of vitamins (A, B1, B2, B6, C and E), folic acid and niacin, fatty acids, and essential minerals (especially K, Ca, Mg, Fe and Cu) (Jahangir *et al.*, 2009; Acikgoz, 2011; Thavarajah *et al.*, 2016). Young kale sprouts especially contain a high amount of protein and dietary fibers (Vale *et al.*, 2015).

Consumption of kale is linked to several health benefits and it has traditionally been used to treat various diseases, such as gastritis and gastric ulcer (Leonti and Casu, 2013), diabetes mellitus, rheumatism, bone weakness, ophthalmologic problems, hepatic diseases, anemia, and obesity (Lemos *et al.*, 2011; Gonçalves *et al.*, 2012; Kuerban *et al.*, 2017). Kale consumption has shown promising results in prevention of cancers of the reproductive system (Han *et al.*, 2014), gastrointestinal system, and lungs (Wu *et al.*, 2013). The strong inhibitory activities of kale extracts against glioblastoma cells and liver cancer cells, but negligible effects on the metabolites and bioactivity of normal cells, demonstrate its antiproliferative properties against tumorous cells (Gonçalves *et al.*, 2012). Furthermore, kale extracts demonstrate antigenotoxicity: properties that maintain the genetic information within a cell by preventing damage and mutations (Gonçalves *et al.*, 2012). Also, people with hypercholesterolemia who consumed 150 mL of kale juice daily for 12-weeks significantly increased their HDL-cholesterol and HDL- to LDL-cholesterol ratio and significantly reduced their LDL-cholesterol (Kim *et al.*, 2008). Kale can be considered a functional food since it may be useful for preventing different chronic degenerative diseases.

Kale is relatively easy to grow, cold hardy, and can provide a steady supply of fresh greens for most of the year if practices for extended season and winter production in temperate climates are identified. Extended season and winter production rely, in part, on protective structures (e.g., low tunnels, high tunnels) that trap solar radiation as heat in air, soil, and water. These structures are common in urban temperate climates and may provide a suitable environment for crop growth when temperatures are otherwise too low (Lamont, 2009). Protective structures act to reduce the frequency and duration of freezing temperatures that would otherwise kill crops. Exposure to freezing temperatures can cause marginal necrosis on kale leaves and temperatures between -14° to -30°C can kill the plant. Protective structures not only serve to reduce the frequency and duration of freezing temperatures but should also optimize the daily duration of temperatures above the threshold for growth. The optimal temperature range for kale growth is 16°-21°C, but growth is possible above 4.4°C (Andrews and Coop, 2011).

Mulches can also be a possibility for aiding in season extension or winter production. Organic mulch, like straw or woodchips, may have insulating properties (Richardson *et al.*, 2023) that slow the rate of heat loss in protective structures each night and slow the warming each day. Therefore, organic mulches may reduce both the frequency and duration of freezing events as well as the duration of optimal growing conditions. Black plastic mulch is known to warm soil, but it is unclear whether this material will act to buffer temperatures to the same extent as organic mulches. In northern climates where freezing temperatures are the norm, it is recommended that crops be grown on bare ground to allow a rapid buildup of heat within structures during the day (Coleman, 2009), but the influence of mulches on kale in low and high tunnels is not completely known.

Providing plants with optimal environmental conditions improves their rate of growth and yield but may also support the growth and development of weeds and insect pests that negatively affect yield. Lepidopteran eggs laid in the summer or fall will yield caterpillars feeding in an extended season crop. Aphids will continue to thrive in winter production because the same conditions that are optimal for kale growth are sufficient for aphid survival and reproduction. Aphid pest species, such as green peach aphid (*Myzus persicae* Sulzer), potato aphid (*Macrosiphum euphorbiae* Thomas), and cabbage aphid (*Brevicoryne brassicae* L.), have been reported to continue asexual reproduction at temperatures as low as 5-10°C (Barlow, 1962; Soh *et al.*, 2018).

We researched combinations of protective structures and ground covers for production of Red Russian kale through winter in an urban temperate climate. Specifically, we investigated the influence of ground cover in low tunnels at 10 urban garden sites and in low tunnels within a high tunnel at the University of the District of Columbia's Farm to ascertain the influence on the yield and nutrients of Red Russian kale, soil temperature, air temperature, weed pressure, and abundance of aphids.

Fig. 1 - Example layout for growing Red Russian kale at 10 urban garden sites in the USA. Kale is planted in a low tunnel with bare soil in the foreground, black plastic mulch in the middle ground, and straw mulch in the background.

2. Materials and Methods

Sites and production systems

Urban garden sites. We started kale seedlings on 25 September 2020 in a high tunnel at the University of the District of Columbia's 58 ha Firebird Farm (Beltsville, MD, USA) before transplanting them into 10 urban garden sites in Virginia, Maryland, and Washington, DC between 21 October through 4 November 2020. Each urban site contained three plots which were weeded and randomly assigned a ground cover treatment: bare soil, black plastic mulch, or straw mulch (Fig. 1). Each plot was approximately 3 m x 0.6 m with 8-9 kale plants spaced 0.3 m apart. We used 1.0 mil thick black plastic mulch (Dubois Agrinovation, Ontario, Canada) and applied straw to a depth of 7.6 cm. We constructed low tunnels over each plot using wire hoops (0.9 m high and 0.3 m wide) and 0.8 mil low tunnel clear plastic (Agriculture Solutions, Kingfield, ME, USA), the edges of which were secured with pins and weights. Ground cover and low tunnels were installed the same day as planting at all locations except one where the initial planting failed. Warm ambient temperatures initially required the low tunnels to be left open until 16 November 2020; at this point they were closed for the remainder of the research.

High tunnel. Red Russian kale from the same batch of seedlings used for the garden sites was transplanted 28 October 2020 into a high tunnel (30.48 m long x 9.15 m wide x 4.57 m high) covered with a 6-mil thick double-layered polyethylene film (Sun Master®, Farmtek, Dyersville, IA, USA) and located at the Firebird Farm (Fig. 2). We established four plots, each of which was 3 m by 0.9 m, in each of four parallel rows (i.e., blocks) and used a randomized complete block design to assign one of four treatments to each plot. The treatments were: 1) bare soil; 2) bare soil inside a low tunnel, 3) black plastic mulch inside a low tunnel; and 4) straw mulch inside a low tunnel. Ground cover and low tunnel treatments were set up 20 October 2020 as previously described for the urban garden sites. Each plot contained nine kale plants, spaced 0.3 meters apart. Warm ambient temperatures initially required the low tunnels to be left open until 3 December 2020, at which point they were closed until 8 March 2021.

Fig. 2 - Red Russian kale in a high tunnel in Maryland, USA. Kale was planted in one of four treatments: bare soil (no ground cover and low tunnel); bare soil + low tunnel (no ground cover and covered with a low tunnel); black plastic + low tunnel (black plastic mulch and covered with a low tunnel); straw + low tunnel (straw mulch and covered with a low tunnel). Sixteen experimental plots are arranged in four rows, with a row of non-experimental plants separating the rows into pairs.

Environmental data and plant yield

We measured air temperatures hourly in all plots at garden sites and in the high tunnel using HOBO® Pendant MX 2201 Data Loggers (Onset, Bourne, MA, USA). They were initially placed flat and 7.62 cm above the ground upon planting kale. If plants in any plot grew large enough to cover the data logger, all sensors at that site were then raised to 33 cm (garden sites) or 40.6 cm (high tunnel) above the ground. We also measured soil temperature in each plot hourly using HOBO® Pendant MX 2201 Data Loggers or, in two cases, a HOBO MX2303 Two External Temperature Sensors Data Logger (Onset, Bourne, MA, USA). Data loggers were buried 7.62 cm below the surface of the soil upon planting. Data from all loggers were downloaded weekly.

We began collecting weed mass biweekly starting 26 November 2020. Weed mass was measured by removing all weeds from a plot, shaking dirt from the roots, and weighing the total fresh mass. We scouted for all insect pests bi-weekly from 10 December 2020 to 17 March 2021, but aphids were the only pest regularly present. To measure the abundance of aphids, we removed the leaf with the most aphids from each plant that had more than five aphids present, stored them in a freezer, and then counted the aphids under a dissecting microscope. After leaves were removed, we treated all plants at a site using 59 ml Triple Action Neem Oil (Southern Agricultural Insecticides, Inc., Boone, NC, USA) per 3.8 l water to reduce pest infestations.

Biweekly harvest began on or after 10 December 2020 when at least three plants per plot had one or more leaf blades 20.3 cm long. Individual leaves 20.3 cm or longer were cut 5 to 7.6 cm from the stalk of the plant and all fresh mass from a plot was weighed. Final harvest was 17 March 2021.

Nutrient analysis

Due to low yield of kale in garden sites, nutrient analysis could only be conducted with samples from the high tunnel. Approximately 12 fully developed leaves from each of three subsamples within a treatment were shipped on ice to Waypoint Analytical (Leola, PA) to quantify mineral content, including calcium (%), magnesium (%), nitrogen (%), phosphorous (%), potassium (%), sodium (%), sulfur (%), boron (ppm), copper (ppm), iron (ppm), manganese (ppm), and zinc (ppm) using the United States Environmental Protection Agency (US EPA) SW-846 method and American Oil Chemists' Society (AOCS) Official Method Ba 4e-93 for nitrogen. Amounts are reported on a dry matter basis. Additionally, we noticed a distinct difference in texture between kale plants in bare soil with no low tunnel versus all other treatments which had a low tunnel, which we suspected was due to fiber content. So, we harvested approximately 100 g of fresh kale leaves per subsample in the two bare soil treatments (with and without a low tunnel) and mailed them on ice to Eurofins Microbiology Laboratories (Lancaster, PA). Eurofins Microbiology Laboratories analyzed total dietary fiber using the Association of Official Analytical Chemists (AOAC) method 991.43. The percent content of fiber is reported on a fresh matter basis. Leaves harvested for all nutrient analysis were included in our measurements of total yield.

Data analysis

In all analyses, the plot is the replicate and the individual kale plants are subsamples. We used the mean yield per plant, plot, and month in a mixed model, (PROC GLIMMIX; SAS Institute, 2020) to determine whether yield differed among the three ground cover treatments at garden sites, with mean air and soil temperatures as covariates, treatment as a fixed effect, and site as a random effect. We also used separate mixed models (PROC GLIMMIX; SAS Institute, 2020) to determine whether weed mass and the number of aphids per plant differed among the three treatments at garden sites, with treatment as a fixed effect and site as a random effect.

We used the mean yield per plant, plot, and month in a mixed model, (PROC GLIMMIX; SAS Institute, 2020) to determine whether yield differed among the four ground cover treatments in the high tunnel experiment, with mean air and soil temperature as covariates and treatment as a fixed effect. Differences in weeds and most nutrients, except fiber, across treatments in the high tunnel experiment were also analyzed with separate general linear models (PROC GLM; SAS Institute, 2020). We used a negative binomial model (PROC GENMOD; SAS Institute, 2020) to determine whether the total number of aphids differed among the four treatments. This analysis differs from the aphids at garden sites because the number of plants in each plot was variable, but the number of plants in each plot in the high tunnel was the same, allowing for a count model to be used. Differences in dietary fiber between bare soil plots with and without a low tunnel were compared with a t-test. We used base-10 log transformations prior to some analyses to meet assumptions of normality but means for non-transformed data are presented in the results. We used means separation tests for all analyses to determine which means differed (P<0.05).

Table 1 - Mean yield per plant of Red Russian kale, mass of weeds, and number of aphids per plant across three treatments at 10 urban garden sites in Virginia, Maryland, and Washington, DC from October 2020 to March 2021. The sample size for each measurement equals the number of garden sites (10)

Variable	Ground cover treatment		
	Bare soil	Black plastic	Straw mulch
Crop yield (g)	14.1 (30.9)	9.8 (25.6)	5.1 (16.6)
Weeds (g)	313 (349) a	68.6 (59) b	7.0 (8.8) c
No. aphids per plant	48.4 (72.2)	19.7 (20.5)	23.0 (49.1)

Each urban site included three plots with a ground cover treatment: bare soil, black plastic mulch, or straw mulch. Means with different letters within rows are different (P<0.05). Standard deviations are provided in parentheses.

3. Results

Garden sites

The amount of kale harvested from garden sites was extremely low and did not differ across ground cover treatments ($F_{2,106}$ = 0.24, P = 0.78) (Table 1). However, yield was higher when mean air ($F_{1,106}$ = 20.1, P<0.01) and soil temperature $F_{1,106}$ = 16.6, P<0.01) were higher. The mean marketable yield/plant/treatment generally decreased over time from a maximum of 37.5 g in December to 11.4 g, 3.7 g, and 4.0 g in January, February, and March, respectively. Ground cover treatments influenced weed mass, with the greatest mass manually removed from plots with bare ground, a lesser amount from plots with straw, and nearly none from plots with black plastic mulch ($F_{2,18}$ = 58.1, P < 0.01) (Table 1). The number of aphids per plant did not vary across treatments ($F_{2,18}$= 0.95, P = 0.40) (Table 1).

High tunnel

Kale yield varied across treatments ($F_{3,58}$ = 4.1, P = 0.01), with the greatest yield from plots with straw and plastic mulch and the least yield from plots with bare soil and no low tunnel (Table 2). Yield was also greater when mean air ($F_{1,58}$ = 20.2, P < 0.01) and soil temperature ($F_{1,58}$ = 31.9, P < 0.01) were higher, and this was influenced by treatments. Specifically, mean air temperature was 19.1°C in plots with straw

Table 2 - Mean yield per plant of Red Russian kale, mass of weeds, and total number of aphids across four treatments in a high tunnel in Maryland from October 2020 to March 2021. There were four plots per treatment

Variable	Treatment			
	Bare soil	Bare soil + low tunnel	Black plastic + low tunnel	Straw + low tunnel
Crop yield (g)	917 (830) b	1334 (632) ab	1384 (709) a	1390 (577) a
Weeds (g)	141 (189) b	142 (96) b	2.8 (4.3) b	65 (110) ab
No. aphids	231 (285)	118 (141)	66 (90)	65 (121)

Each plots within the high tunnel was assigned one of four treatments: bare soil (no ground cover and low tunnel); bare soil + low tunnel (no ground cover and covered with a low tunnel); black plastic + low tunnel (black plastic mulch and covered with a low tunnel); straw + low tunnel (straw mulch and covered with a low tunnel). Means with different letters within rows are different (P<0.05). Standard deviations are provided in parentheses.

mulch, 18.5°C in plots with plastic mulch, and only 15.6°C in plots with bare soil and no low tunnel. Mean soil temperature was 12.2°C in plots with straw mulch, 12.5°C in plots with plastic mulch, and only 10.9°C in plots with bare soil and no low tunnel.

Ground cover treatments influenced weed mass with the greatest mass manually removed from plots with bare soil (with or without a low tunnel) and nearly none from plots with black plastic mulch ($F_{3,12}$ = 7.6, P<0.01). However, the total number of aphids did not differ across treatments (F_3 = 1.75, P = 0.63) (Table 2).

Analysis of 12 plant elements in the high tunnel experiment revealed that B, Ca, Fe, K, Mg, Mn, N, Na, P, and Zn showed no variation across treatments (all P-values > 0.07). However, Cu was highest in plants in straw mulch and lowest in those grown in bare soil without a low tunnel (Table 3). Plants in all treatments with a low tunnel exhibited higher S compared to those without a low tunnel (Table 3). Furthermore, plants grown in bare soil under a low tunnel displayed greater dietary fiber compared to those in bare soil without a low tunnel (Table 3).

4. Discussion and Conclusions

One potential benefit of urban agriculture is the possibility of producing local, nutritious foods year-round, such as Red Russian kale. However, winter production in unheated structures such as low and high tunnels in temperate environments relies on capturing sufficient solar radiation to support crop production. Heat generated within these structures during daylight will dissipate from those structures at night. Heat storage and the rate of dissipation are influenced by environmental conditions outside of the tunnel and the size and construction of the protected structures. For example, secondary covers within a high tunnel may increase the amount of time plants experience optimal growing temperatures during colder months and modulate extreme temperatures (Borrelli *et al.*, 2013; Drost *et al.*, 2017). Small tunnels with a single layer of plastic will experience faster heat loss than larger tunnels with multiple layers of plastic. Insulating ground covers may act to slow down heat loss below- and above-ground (Bhardwaj, 2013). In our study straw and black plastic ground covers combined with low tunnels were not sufficient to produce a viable yield of Red Russian kale at 10 garden sites. Yield at these garden sites was higher when air temperature and soil temperature were higher, but these temperatures were likely influenced by geographic location because the ground covers were not associated with differential yield. Outside temperature around the low tunnels was likely too cold, and the area within the tunnels too small, to increase or retain sufficient heat for crop production. However, cultivating kale in a high tunnel resulted in good yields, especially when paired with a low tunnel and either plastic or straw mulch; this combination led to the highest air and soil temperatures. Our results should not be taken to mean that low tunnels alone cannot be used to produce kale or that a high tunnel is necessary. These systems may vary in their effectiveness under other environmental conditions or if made from other materials. Also, other varieties of kale may perform better in these systems than Red Russian kale because different varieties, cultivars, and genotypes of a plant species respond differently to cultivation methods and environmental conditions (Yoder and Davis, 2020; Richardson and Arlotta, 2021, 2022; Richardson *et al.*, 2022).

Mineral absorption in plants is known to be influenced directly or indirectly by air and soil tempera-

Table 3 - Mean content of nutrients that differed in Red Russian kale across four treatments in a high tunnel in Maryland from October 2020 to March 2021. There were four plots per treatment

Nutrient	Treatment				P
	Bare soil	Bare soil + low tunnel	Black plastic + low tunnel	Straw + low tunnel	
Copper (ppm)	9.8 b	11.4 ab	10.7 ab	11.7 a	0.02
Sulfur (%)	0.88 b	1.24 a	1.23 a	1.16 a	<0.01
Dietary fiber (%)	4.4 a	3.4 b	NA	NA	<0.01

Each plot within the high tunnel was assigned one of four treatments: bare soil (no ground cover and low tunnel); bare soil + low tunnel (no ground cover and covered with a low tunnel); black plastic + low tunnel (black plastic mulch and covered with a low tunnel); straw + low tunnel (straw mulch and covered with a low tunnel). Means with different letters within rows are different (p<0.05).

ture (Tachibana, 1982; Inthichack *et al.*, 2013). Given this understanding, we expected to observe variation in mineral content among the different treatments. However, our results indicate that the use of low tunnels and ground covers in the high tunnel did not influence mineral content, except for copper and sulfur, which were lower in plots without a low tunnel or ground cover than some other treatments. Although yield and mineral content, to an extent, were improved with low tunnels and ground cover in the high tunnel, dietary fiber was higher when no low tunnel or ground cover was used. This may help urban farmers grow kale for instances in which maximizing dietary fiber is a priority. However, it is important to consider that these plants were also much smaller in structure and yielded less, which could potentially affect profitability.

Beyond the influence on the Red Russian kale, the ground covers also had an impact on weed growth. As expected, the use of plastic and straw mulch suppressed weed growth. Contrary to our expectations, we did not find evidence that these ground covers in combination with low tunnels increased the abundance of insect pests. Insect pests were observed in all treatments in garden sites and the high tunnel. It is likely the presence of insect pests in all treatments can be attributed to the warmer air temperature fostered by the low and high tunnels alone, rather than the addition of ground covers.

In conclusion, our work demonstrates that Red Russian kale, a highly nutritious, desired, and appropriate crop for urban systems can be grown in temperate regions throughout the winter using specific combinations of tunnels and ground covers. These findings open opportunities for year-round cultivation of this crop in urban systems. Future research could continue to build upon our findings to elucidate the best methods that maximize yield and nutrients while not significantly contributing to increased abundance of insect pests.

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