A Survey of Kentucky High Tunnel Vegetable Growers: Production Challenges Faced and Strategies Used To Overcome Them

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ABSTRACT. **Kentucky vegetable growers use high tunnels (HTs) to increase profitability and resilience. Increased disease, pest, and weed pressure over time threaten these benefits. We surveyed Kentucky vegetable growers in 2024 to assess soilborne disease, plant-parasitic nematode, pest, and weed challenges they faced in HTs and the strategies used to manage them. Additionally, we assessed growers' use and willingness to use soil solarization. The results suggest that a large percentage of survey respondents are not familiar with soilborne diseases and plant-parasitic nematode problems in HTs but are aware of arthropod pest and weed problems. Common pest and weed problems faced by respondents include aphids, whiteflies, crabgrass, morning glory, and chickweed. Strategies used to address these problems include insecticides and hand weeding. Approximately 19% of respondents indicated they had used soil solarization, and those who used it were very satisfied with the results. Among those who indicated they had never used soil solarization, more than 70% indicated they were willing to try it. Among the respondents who indicated they were not willing to use solarization, a common reason was not having enough information about it. This result suggests that information providers could increase efforts to make HT vegetable growers familiar with this practice and how it can be implemented, potentially adding another strategy for pest, disease, and weed management.**

High tunnels (HTs) are relatively simple polyethylene-covered structures that are passively heated and cooled for in-ground crop production. Given that these structures typically lack active heating and cooling systems, they can provide similar benefits to greenhouses but at a lower cost (Pierre et al. 2024; Rudolph et al. 2023). The use of HTs among vegetable growers in the United States has increased because of the many benefits they provide, including season extension, improved yield and crop quality, increased profitability, and increased resilience to unfavorable weather events relative to open field production (Belasco et al. 2013; Bruce et al. 2019; Carey et al. 2009; Ernst 2020; Kaiser and Ernst 2021). Small vegetable farms, in particular, use these structures given the relatively low cost of construction and the relatively short time to recover the investment compared with greenhouses (Carey et al. 2009; Ernst 2020; Kaiser and Ernst 2021).

The increased adoption of HTs is also explained by the high investment the US Department of Agriculture Natural Resource Conservation Service (NRCS) has made in cost-share programs supporting the adoption of HTs (Pierre et al. 2024). Kentucky is the state with the highest number of HTs in the Southern United States funded through NRCS programs, including the Environmental Quality Incentives Program High Tunnel System Initiative (https://www.nrcs.usda.gov/programs-initiatives/eqip-high-tunnel-initiative), with 1311 HTs in 2020 (Pierre et al. 2024). Currently, over 1500 HTs in Kentucky are funded through the NRCS, with a production capacity of more than 260,000 m^2 (Rudolph et al. 2023).

Although HTs are nonpermanent structures, which suggests some mobility, many are built in a way that makes them stationary. Corner posts are often cemented into the ground to secure the structure from weather events (Kaiser and Ernst 2021). A survey of HT growers from Kentucky and surrounding states (i.e., Illinois, Ohio, Indiana, West Virginia, Georgia, Tennessee, and Alabama) conducted by the University of Kentucky Center for Crop Diversification in 2019 suggested that approximately 85% of the tunnels represented in this survey never moved (Ernst et al. 2020). Oftentimes, growers continuously crop the same high value crops in their tunnels (i.e., tomatoes in spring/summer, lettuce in fall/winter). This continuous cropping with very limited rotation can result in soil degradation, intensified pathogen, pest, weed population densities, and reduced yields, which could ultimately decrease HT profitability (Kaiser and Ernst 2021; Pierre et al. 2024; Rudisill et al. 2015; Rudolph et al. 2023). Results from the 2019 HT survey conducted by the University of Kentucky suggested that disease, weed, and insect pest management were the most critical challenges survey respondents faced. Common management practices used by survey respondents associated with managing these issues included crop rotation, scouting, and cover cropping. The results from this survey also suggest HT growers need assistance with information about disease, insect pest, and weed management (Ernst et al. 2020). This survey did not go in-depth about the specific diseases, plant-parasitic nematodes, arthropod pests, and weeds HT growers faced and the specific strategies they used to overcome these problems.

Soil solarization is a nonchemical strategy that has been shown to effectively manage soilborne diseases, plant-parasitic nematodes, and weeds in HTs. It uses passive solar heating of irrigated soil under a transparent plastic tarp to achieve soil temperatures detrimental to

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soilborne pests, pathogens, and weed seeds (Hanson et al. 2014; Rudolph et al. 2023). The efficacy of this management technique is dependent on both time and temperature. This production practice is particularly attractive to HT growers, given the limited number of options they have to manage soil issues, such as soilborne diseases and plant parasitic nematodes, especially when growers use organic production practices (Rudolph et al. 2023). According to the results of the University of Kentucky HT survey, approximately 44% of the respondents indicated using solarization as a management practice (Ernst et al. 2020). It is important to highlight that about three-fourths of the survey respondents were HT growers from Kentucky, and therefore, it is likely that this percentage of solarization users might capture a large percentage of Kentucky HT growers. The lack of more widespread adoption of this production practice by Kentucky HT growers, as suggested by the University of Kentucky survey results, could be related to the conflict that may exist between the best timing for implementing this practice and the timing of production in HTs. Kentucky HTs are usually occupied between March and November. The summer months (June through August), when temperatures are highest, are the best time to implement soil solarization (Rudolph et al. 2023). To our knowledge, no previous study has evaluated differences in grower and farm business characteristics of adopters and nonadopters of soil solarization. Furthermore, no study has evaluated growers' willingness to adopt soil solarization in HT production and potential barriers to adoption.

We conducted a survey of Kentucky vegetable growers between January and June of 2024 to assess production challenges they faced when growing vegetables in HTs, specifically those related to soilborne diseases, plant-parasitic nematodes, arthropod pests, and weeds, and the preferred strategies to manage those challenges. Additionally, we assessed Kentucky HT vegetable growers' use and willingness to use soil solarization as a strategy to manage soilborne diseases, plant-parasitic nematodes, and weeds in HTs. We evaluated the characteristics that differentiate growers using soil solarization from those not using it. The results presented in this study could help information providers better target the information needs of HT growers, specifically those related to the management of soilborne diseases, plant-parasitic nematodes, arthropod pests, and weeds.

Materials and methods

We conducted a survey of Kentucky vegetable growers between January and June of 2024. The survey instrument was approved by the University of Tennessee Institutional Review Board (UTK IRB-23-07688-XM). We used a mix-mode survey strategy, reaching out to potential respondents via mail with a paper version of the survey and via the Web with an online version. This strategy is used to improve response rates and reduce coverage and nonresponse error (Dillman et al. 2009). We sent the Web version of the survey on 2 Feb 2024 to individuals for whom we had e-mail addresses. We sent reminder e-mails on 13 Feb and 29 Feb 2024. The paper version of the survey was mailed on 20 Feb 2024, and reminders and follow-up surveys were sent on 1 and 15 Mar 2024, respectively, to individuals for whom we did not have e-mail addresses. We advertised the survey at the Kentucky Fruit and Vegetable Conference in Jan 2024. We provided conference attendees with a QR code they could use to complete the survey using their mobile phones. We also allowed conference attendees to fill out the paper version and deposit it anonymously in boxes we placed at a booth. Moreover, we advertised the survey through the Kentucky Vegetable Grower Association and the Center for Crop Diversification newsletters.

We targeted commercial vegetable growers who produced vegetables for sale in 2023. Although we wanted to target HT growers only, we did not have access to a contact list for Kentucky HT-specific vegetable growers. Therefore, we targeted vegetable growers producing and selling tomatoes, lettuce, and other greens, which are high-value crops that are commonly grown in HTs (Carey et al. 2009). The contact list was built using a publicly available directory from the Kentucky Proud program (https://www.kyproud.com/), which is a Kentucky Department of Agriculture state-sponsored program. We obtained contact information for 1794 Kentucky vegetable growers. According to the 2022 Census of Agriculture (US Department of Agriculture 2024), there are a total of 2173 farms growing vegetables, potatoes, and melons in Kentucky. This means we targeted approximately 83% of the total vegetable farms in Kentucky.

The Web version of the survey was sent to 393 growers for whom we had e-mail addresses. The mail (paper) version of the survey was sent to the 1401 growers for whom we had mailing addresses but not e-mail addresses. We received 316 responses for a response rate of 18%. From those 316 respondents, 253 indicated growing vegetables for sale in 2023. From those 253, 122 indicated producing vegetables for sale in HTs in 2023. We received responses from 60 of the 120 counties in Kentucky, with a high concentration of responses from Central Kentucky (Fig. 1). Survey respondents owned or were operating a total of 197 HTs.

The survey instrument was designed so that only those respondents who indicated growing vegetables in HTs completed all 32 questions. We asked respondents various questions, including the number and size of HTs they have, diseases, pests, and weed challenges they face, and management strategies they use to overcome those challenges. We also asked questions about their use and willingness to use soil solarization and the reasons for their willingness or unwillingness to use soil solarization in their HTs. Finally, we asked respondents questions about themselves and their farm businesses. The survey instrument is available in the Appendix section.

Analysis. We used independent sample t tests to evaluate differences in selected grower and farm business characteristics captured by continuous variables between respondents using and those not using soil solarization in HTs. We evaluated differences in grower and farm business characteristics captured by dichotomous variables using an equality proportion test (StataCorp 2023).

We evaluated growers' use and willingness to use soil solarization by asking respondents to indicate whether they have used soil solarization in their HTs after providing a definition of soil solarization: "Soil solarization is a management technique that uses passive solar heating of irrigated soil under a transparent plastic tarp to achieve soil

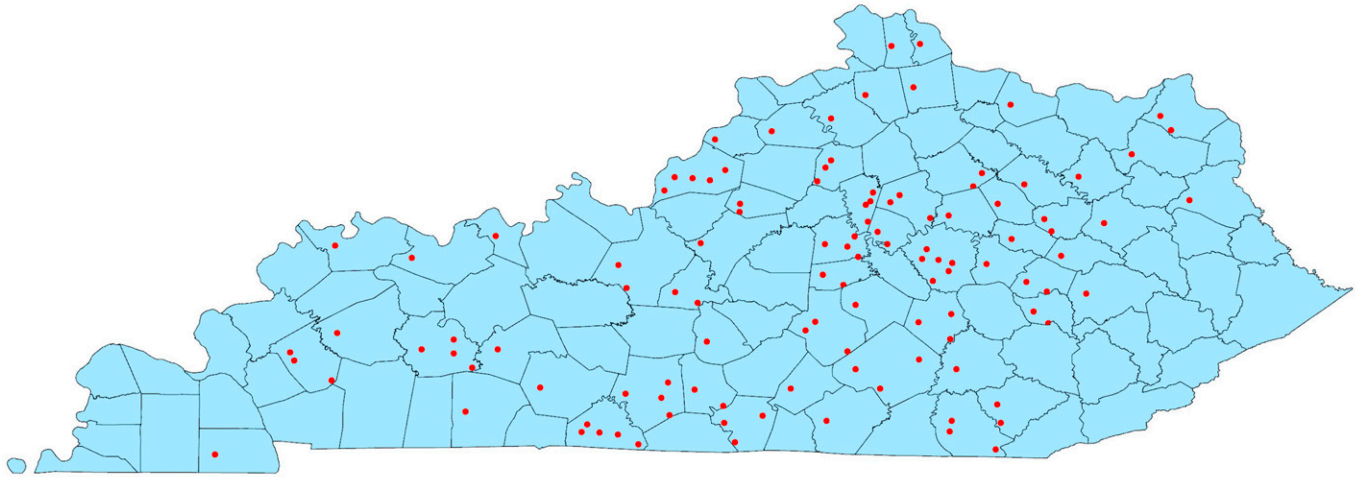

Fig. 1. Respondents to a 2024 survey of Kentucky vegetable growers who indicated producing vegetables for sale in high tunnels in 2023 based on the county where the farm is located (each dot represents one response).

temperatures detrimental to soilborne pests, pathogens, and weed seeds. Thus, soil solarization can be a nonchemical alternative to pesticide application. Sealing an entire tunnel (closing the end walls and sidewalls) during solarization has shown to be beneficial for managing diseases and pests because higher temperatures can be reached. The efficacy of this management technique is dependent on both time and temperature. Exposure to soil temperatures of 104 °F for 2 to 4 weeks will kill most organisms that thrive at moderate temperatures, which include many plant pathogens, plant-parasitic nematodes, and weed seeds. Growers would not be able to produce any crops during this period."

We then asked those who had not used soil solarization to indicate their willingness to use it if they had to seal (close the end walls and sidewalls) the HT and not grow anything for 2 to 4 weeks. We then asked respondents to explain their reasons for being willing or not willing to use it.

Results and discussion

Grower and farm business characteristics. In Table 1, we present summary statistics associated with grower and farm business characteristics of our survey respondents. Respondents were, on average, 53 years old, which is younger than the average age of 57 for growers in Kentucky (US Department of Agriculture 2024). Of our survey respondents, 62% had a bachelor's or graduate degree. Half of our survey respondents were female.

Regarding farm business characteristics, the average area in crop production in acres reported by respondents was 15.29, with a minimum of 0.01 acres and a maximum of 479 acres (Table 1). Therefore, on average, farms operated by survey respondents were smaller than the average Kentucky farm operation, which is 179 acres (US Department of Agriculture 2024). This is expected given that we were targeting vegetable farms, which tend to be smaller than row crop farms. The average number

Table 1. Summary statistics for selected grower and farm business characteristics based on data from a 2024 survey of Kentucky vegetable growers.

Characteristic	*n*	Mean	*SD*	Minimum	Maximum
Age (yr)	113	53.37	13.36	24.00	84.00
Education = 1 if bachelor's or graduate degree; 0 otherwise	115	0.62		0	1
Gender = 1 if male; 0 otherwise	115	0.50		0	1
Risk = Average score regarding grower willingness to take risk compared with other growers managing similar operations related to introducing a new practice, financial management, production, and marketing, where 1 is "much less" and 5 is "much more"	114	3.54	0.81	1	5
Farm size in acres = Acres in crop production[i]	97	15.29	59.36	0.01	479.00
Acres in vegetable production[i]	94	2.25	5.78	0.01	50.26
Gross farm revenue above \$25,000 = 1 if annual on-farm gross revenue is above \$25,000; 0 otherwise	96	0.47		0	1
Gross revenue from crops grown in HTs above \$10,000 = 1 if annual gross HT revenue is above \$10,000; 0 otherwise	100	0.33		0	1
Percentage of household income from farming = 1 if the percentage of taxable household income from farming is more than 25%; 0 otherwise	105	0.47		0	1
Use of organic or naturally grown standards = 1 if the farm operation is USDA-certified organic, Certified Naturally Grown, USDA-certified organic exempt, or following organic or naturally grown standards; 0 otherwise	113	0.39		0	1

[i] 1 acre = 0.4047 ha.

HT = high tunnel; *SD* = standard deviation; USDA = US Department of Agriculture.

of acres in vegetable production reported by survey respondents was approximately 2.5 acres, which is smaller than the average vegetable operation in Kentucky of 3.61 acres (US Department of Agriculture 2024). This result could be explained by the fact that we were targeting HT vegetable farms, which are likely to be smaller than operations growing vegetables in the open field. One-third of our survey respondents indicated having a gross revenue from crops grown in HTs above $10,000 in 2023.

Approximately 47% of our survey respondents indicated having an annual gross on-farm revenue above $25,000. This is a larger percentage than the percentage of Kentucky farms with farm-related income above $25,000 (39%) (US Department of Agriculture 2024). This larger percentage of farms with annual gross revenue above $25,000 compared with the Ag Census data could be explained by the fact that vegetable farms, specifically those growing vegetables in HTs, are producing high-value crops, such as tomatoes and lettuce (Carey et al. 2009). Approximately 47% of survey respondents indicated having a percentage of taxable household income above 25%. Finally, 39% of our survey respondents indicated they were US Department of Agriculture (USDA)–certified organic, certified naturally grown, USDA-certified organic exempt, or that they were following organic or naturally grown standards.

As we explained in the Materials and Methods section, we specifically targeted growers of tomato, lettuce, and other greens in this survey. Approximately 90% of survey respondents indicated that they were growing tomatoes (*Solanum lycopersicum*), almost 60% indicated growing lettuce (*Lactuca sativa*), and slightly less than 44% indicated growing spinach (*Spinacia oleracea*) in their HTs (Fig. 2). Other vegetable crops grown in HTs by a large percentage of survey respondents were peppers (*C. annuum*) (67%), cucumbers (*Cucumis sativus*) (63%), carrots (*Daucus carota*) (41%), and squash (*Cucurbita pepo*) (40%).

The average number of HTs per farm operation was two, with a minimum of 1 and a maximum of 10 HTs per farm (Table 2). Approximately 62% of our survey respondents indicated having only one HT in their operation. The highest concentration of HTs by county based on survey responses was in Madison and Allen counties, with 19 and 16 HTs, respectively (Fig. 3).

The two most common sizes of HTs used by survey respondents were 30 × 96 and 30 × 72 feet, used by 34% and 33% of the survey respondents, respectively (Table 2). One-fourth of the survey respondents indicated producing crops in HTs all year. The average number of years respondents have been using HTs was 7, with a minimum of 2 months and a maximum of 29 years (Table 2). Our survey sample captured a large percentage of less experienced HT growers, with 74% of survey respondents indicating using HTs for less than 10 years.

Survey respondents used various information sources to obtain HT information. University extension and other growers were the most commonly used sources, with 82% and 81% of survey respondents using these sources, respectively (Table 2). Consultants were used by only 21% of survey respondents. Regarding the survey respondents' ratings in terms of satisfaction with the effectiveness of these sources in providing information to help resolve HT issues or improve their management, other growers were rated relatively high, with an average rating of 4.1, where 1 is unsatisfied, and 5 is satisfied. University extension and consultants had an average satisfaction rating of 3.94 and 3.87, respectively.

Soilborne disease, plant-parasitic nematode, arthropod pest, and weed challenges and management strategies. We asked respondents to indicate which soilborne diseases, plant-parasitic nematodes, arthropod pests, and weeds they have had in their HTs in the past 4 years (Table 3). When asked about soilborne diseases they have had in their HTs in the past 4 years, more than half of the respondents who answered this question indicated they did not have soilborne diseases (28%); that they did not know whether they had soilborne diseases (18%); or that they knew they had them, but they did not know which ones (19%). For those who knew they had soilborne diseases, the most common disease observed in HTs was caused by *Sclerotinia*, which was identified by nearly one-fifth of respondents. Results from a survey of Kentucky HT growers conducted in 2022 suggested diseases caused by *Sclerotinia* spp. were the top concern for Kentucky HT growers then as well (Rudolph et al. 2024).

Regarding plant-parasitic nematodes, survey respondents indicated they had in their HTs in the past four years, almost all indicated they did not have nematodes (40%), did not know if they had nematodes (38%), or knew they had nematodes but did not

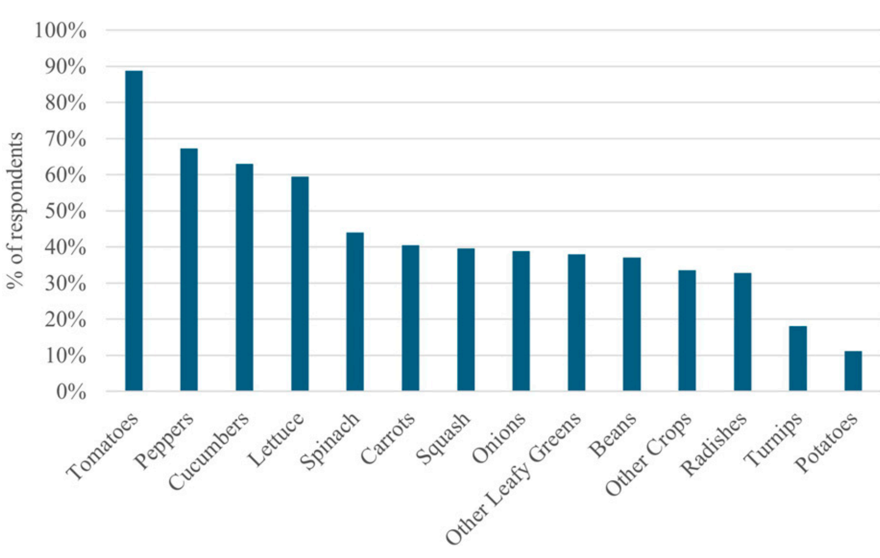

Fig. 2. Percentage of specific crops grown in high tunnels in the past 4 years by respondents to a 2024 survey of Kentucky vegetable growers, including tomato (*S. lycopersicum*), pepper (*Capsicum annuum*), cucumber (*C. sativus*), lettuce (*L. sativa*), spinach (*S. oleracea*), carrot (*D. carota*), squash (*C. pepo*), onions (*Allium cepa*), other leafy greens [e.g., kale (*Brassica oleracea* var. *acephala*), mustard (*Brassica juncea*)], green bean (*Phaseolus vulgaris*), radish (*Raphanus sativus*), turnip (*Brassica rapa*), and potato (*Solanum tuberosum*).

Table 2. **Summary statistics about the use of high tunnels (HTs), including the number of HTs per farm, sizes of HTs, number of years using HTs, use of HTs all year, sources of information used to get HT information, and rating of satisfaction with information sources based on data from a 2024 survey of Kentucky vegetable growers.**

Statistics	*n*	Mean	*SD*	Minimum	Maximum
High tunnel use					
No. of HTs = Number of HTs under production in 2023	115	1.71	1.41	1	10
HT_14 × 30 = 1 if owned a HT of size 14 × 30; 0 otherwise	118	0.03		0	1
HT_15 × 60 = 1 if owned a HT of size 15 × 60; 0 otherwise	118	0.03		0	1
HT_30 × 72 = 1 if owned a HT of size 30 × 72; 0 otherwise	118	0.33		0	1
HT_30 × 96 = 1 if owned a HT of size 30 × 96; 0 otherwise	118	0.34		0	1
HT_Other = 1 if owned HTs of other sizes; 0 otherwise	118	0.38		0	1
Years using HTs = Number of years using HTs	116	6.55	4.82	0.2	29
All_year = 1 if crops are grown all year in HTs	117	0.25		0	1
Information sources and ratings of information sources for HT information					
Extension = 1 if used university extension as an information source	109	0.82		0	1
Extension rating = 1 if unsatisfied and 5 if satisfied with effectiveness in providing information that helped solve HT problems or improve HT management	87	3.94	1.20	1	5
Consultants = 1 if used consultants as an information source	109	0.21		0	1
Consultant rating = 1 if unsatisfied and 5 if satisfied with effectiveness in providing information that helped solve HT problems or improve HT management	23	3.87	1.22	1	5
Other growers = 1 if used other growers as an information source	109	0.81		0	1
Other growers rating = 1 if unsatisfied and 5 if satisfied with effectiveness in providing information that helped solve HT problems or improve HT management	82	4.07	0.97	1	5

SD = standard deviation.

know what kind (17%). HT growers might not be aware of plant-parasitic nematode issues in their HTs, such as root-knot nematode (*Meloidogyne* spp.) until they pull plants at the end of the season and see the roots, and even then, they might not know what the issue is (Bajek and Rudolph 2023). Those survey respondents who indicated not having nematode issues might not be aware they have them. Results from a soil survey of Kentucky HTs conducted between 2019 and 2022 show that plant-parasitic nematodes are an increasing issue, with 71 of the 105 farms from where HT soil samples were collected testing positive for root-knot nematode (Bajek et al. 2023).

When asked about arthropod pests they have had in their HTs in the past 4 years, 77% of survey respondents indicated they have had aphids, and over one-third indicated they have had whiteflies in their HTs. This result is not surprising given that HTs provide ideal environments for whiteflies and aphids (Kaiser and Ernst 2021). Finally, when asked about weeds they have had in their HTs in the past 4 years, over 40% of respondents indicated they have had crabgrass (*Digitaria* spp.), and over 30% indicated they have had morning glory (*Ipomoea purpurea*) and chickweed [*Stellaria media* (L.) Vill.].

Respondents indicated using various strategies to manage disease, pests, weeds, and/or plant-parasitic nematodes (Table 4). The most popular strategy for managing weeds was hand weeding, which was used by 95% of the survey respondents who answered questions about management strategies used in HTs. Respondents who indicated using this practice indicated being, on average, moderately satisfied

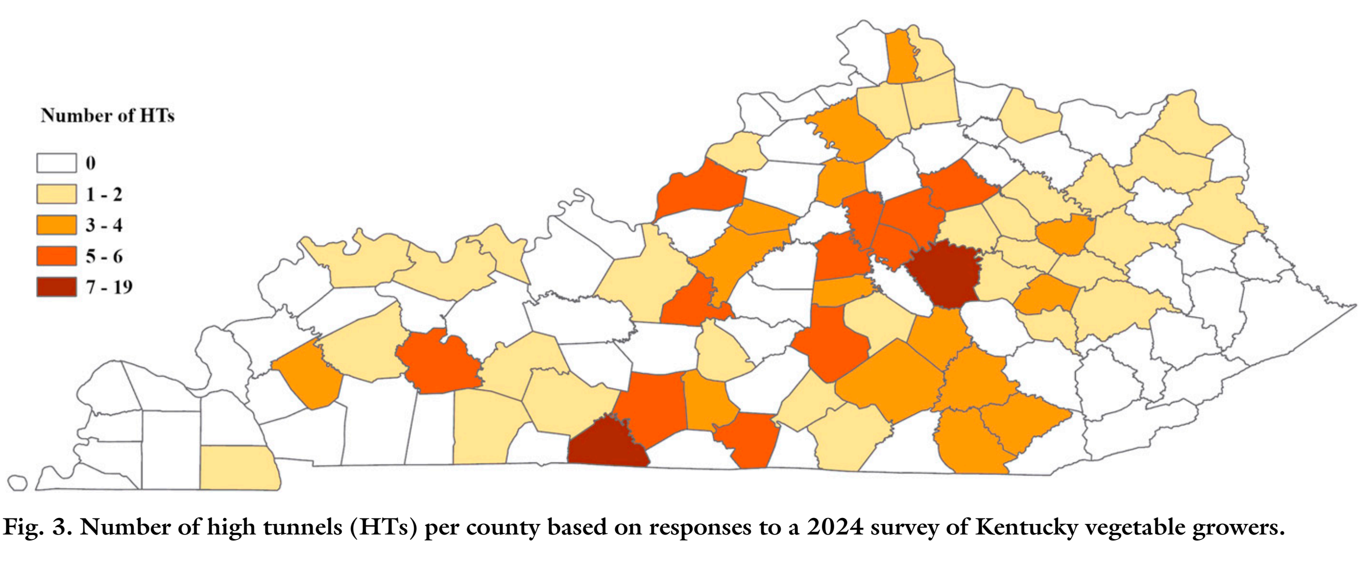

Fig. 3. Number of high tunnels (HTs) per county based on responses to a 2024 survey of Kentucky vegetable growers.

Table 3. Respondents' perceptions and observations of production challenges faced in high tunnels in the past 4 years, including soilborne diseases, plant-parasitic nematodes, arthropod pests, and weed problems based on data from a 2024 survey of Kentucky vegetable growers.

Challenges	N	Respondents who have had this issue (%)
Soilborne diseases		
I have not had soilborne disease issues	120	27.50
I know I have a disease issue, but I do not know what kind	120	19.17
I do not know if I have had soilborne disease issues	120	18.33
Sclerotinia	120	17.50
Southern blight	120	13.33
Root rot	120	10.00
Plant-parasitic nematodes		
I have not had nematode problems	120	40.00
I do not know if I have had nematode problems	120	37.50
I have nematodes, but I do not know what kinds	120	16.67
Arthropod pests		
Aphids	120	76.67
Whiteflies	120	34.17
Spider mites	120	26.67
Thrips	120	11.67
Weeds		
Crabgrass	120	41.67
Morning glory	120	33.33
Chickweed	120	31.67
Johnson grass	120	29.17
Pigweed	120	22.50

with its effectiveness in managing weeds (3.63, on a 5-point Likert scale, where 1 is unsatisfied, and 5 is satisfied).

Over half of the survey respondents used or had used insecticides to manage pests. On average, users of this strategy were moderately satisfied (3.79) with the effectiveness of this practice. Fungicides were used by approximately 38% of survey respondents. Users of this practice were moderately satisfied with its effectiveness in managing diseases (3.55). Solarization was used or had been used by more than 19% of the survey respondents. Those respondents who indicated using this practice rated it the highest among the management practice options provided in terms of satisfaction (4.13) with the effectiveness in managing pests, weeds, and/or diseases. This result is consistent with previous studies suggesting that soil solarization alone or in combination with other management practices, such as grafting, is effective in managing disease and plant-parasitic nematodes in Kentucky HTs (Rudolph et al. 2023, 2024).

Table 4. Management practices used in high tunnels to handle weeds, pests, diseases, and/or plant-parasitic nematodes, and satisfaction ratings in terms of effectiveness with each management practice based on data from a 2024 survey of Kentucky vegetable growers.

Practice	N	Respondents using practice (%)	Rating (where 1 = unsatisfied with effectiveness to 5 = satisfied with effectiveness)
Hand weeding	108	95.37	3.63
Insecticides	108	54.63	3.79
Fungicides	108	37.96	3.55
Solarization	108	18.52	4.13
Herbicides	108	16.67	3.67
Nematicides	108	2.78	3.00
Other – Use of groundcovers	108	13.89	4.25

Herbicides and nematicides were used by only approximately 17% and 3% of the survey respondents, respectively. Both practices had moderate to low ratings in terms of satisfaction with their effectiveness in managing weeds and nematodes. It is important to clarify that the herbicides available to be applied in HTs in Kentucky are limited because the Kentucky Department of Agriculture considers HTs as greenhouses. There are limitations in the chemicals that can be applied inside these structures (Bajek and Rudolph 2023; Gauthier et al. 2024). It is possible that respondents who indicated that they were using herbicides were applying them to the perimeter of the HTs. Nematicides had the lowest rating in terms of satisfaction with effectiveness in managing nematode problems (3.00). Nematicides are a costly option for managing plant-parasitic nematodes. Therefore, small-scale HT growers might not be able to afford this management practice (Bajek and Rudolph 2023). Furthermore, similar to herbicides, the availability of nematicides approved to be applied in Kentucky HTs may be limited, given restrictions related to the chemicals that can be applied in HTs in Kentucky (Bajek and Rudolph 2023; Gauthier et al. 2024).

Finally, we asked respondents to list other management strategies they have used to manage diseases, pests, weeds, and/or plant-parasitic nematodes aside from the ones discussed above. Approximately 14% of the survey respondents indicated using groundcovers, including landscape fabric, plastic mulch, and natural mulches. Those respondents who indicated using any type of groundcover rated this strategy high (4.25) in terms of effectiveness in handling diseases, pests, or weeds. Other strategies mentioned by a small percentage of survey respondents included beneficial insects, cover crops, grafting, tilling, and insect netting.

Differences in grower and farm business characteristics between those using and those not using soil solarization. Responses in this section are related to the survey question, "Do you currently use, or have you used soil solarization in your high tunnels in the past 4 years?" This question (see Appendix, survey instrument Question 13) is different from the one we used to assess the use of different management practices in HTs:

"Rate your satisfaction with the following management practices. First, mark whether you have used the management practice, then indicate your satisfaction" (see Appendix, survey instrument Question 17). This second question asked respondents to indicate whether they have used solarization at any point in time, not specifically within the past 4 years. The number of observations associated with Questions 13 and 17 were different (n = 119 vs. n = 108). There were three respondents who indicated they had used soil solarization in Question 17 but indicated they had not used soil solarization in the past 4 years (Question 13).

Approximately 18% of the respondents indicated that they were currently using or had used soil solarization in their HTs in the past 4 years. On average, survey respondents who indicated that they use or have used soil solarization in the past 4 years were younger (P = 0.0157 for the age comparison), had more experience using HTs (P = 0.0794 for the years using HTs comparison), and were more likely to take risks compared with their peers (P = 0.0950 for the willingness to take risk comparison) (Table 5).

Previous studies suggest that younger Kentucky growers have more positive attitudes toward sustainable practices compared with older growers (Mishra et al. 2018). Older growers have shorter planning horizons and may be less willing to change their production practices. A larger percentage of our survey respondents who indicated they used or had used soil solarization were also using organic and naturally grown production standards and produced crops all year in their HTs (P = 0.000 for the use of organic and naturally grown production standards comparison, and P = 0.0039 for use of HTs to produce crops all year comparison). These results are not surprising given that soil solarization is a nonchemical alternative to managing soilborne diseases, pests, and weeds and therefore might be more compatible with organic or other sustainable practices (Rudolph et al. 2023). Also, HT growers producing crops year-round may have more flexibility in stopping production for a couple of weeks to implement soil solarization, especially in those months (April to October) when soil solarization could be most effective in handling diseases in Kentucky HTs (Rudolph et al. 2023).

Table 5. Selected variable means for respondents who are using or have used soil solarization and those who have not used soil solarization in the past 4 years and statistical significance of mean differences.

Characteristics and sources	Use solarization or have used solarization in the past 4 years	Do not or have not used solarization in the past 4 years
Farm and farmer characteristics		
Age	47.68**	54.81
Education	0.65^{ns}	0.62
Gender	0.40^{ns}	0.52
Risk	3.75*	3.49
Farm size acres	5.49^{ns}	17.59
Acres in vegetable production	1.36^{ns}	2.47
Gross farm revenue above $25,000	0.50^{ns}	0.46
Gross revenue from crops grown in HT above $10k	0.33^{ns}	0.32
Percentage of household income from farming	0.50^{ns}	0.45
Use of organic and naturally grown production standards	0.80***	0.30
No. of HTs	1.95^{ns}	1.63
Years growing in HTs	7.91*	6.27
Year-round production	0.48***	0.20
Information sources		
Extension	0.85^{ns}	0.81
Extension rating	4.47**	3.83
Consultants	0.10*	0.24
Consultant rating	4.00^{ns}	3.86
Other growers	0.80^{ns}	0.81
Other growers rating	3.86^{ns}	4.10

ns, *, **, *** Nonsignificant or significant at $P \leq$ 0.10, 0.05, or 0.01, respectively.
HT = high tunnel.

In terms of the use of information sources, a lower percentage of soil solarization users used crop consultants as an information source compared with solarization nonusers (P = 0.0874 for the use of crop consultants' comparison). Those users of soil solarization rated, on average, university extension (P = 0.0240 for university extension rating comparison) higher in terms of satisfaction with the effectiveness in providing information to solve issues in or improve their management of HTs compared with those not using soil solarization.

Willingness to use soil solarization. Among respondents who had never implemented soil solarization in their HTs, over 70% indicated that they were willing to use soil solarization (Table 6). Among the most popular reasons for their willingness to use soil solarization was to use more environmentally friendly management practices in their HTs (selected by over 55% of respondents who indicated they were willing to use soil solarization). These respondents also indicated that soil solarization could be cheaper and more effective in handling weeds, soilborne diseases, and pests (selected by nearly 59% of respondents who indicated they were willing to use soil solarization) (Table 6).

Among those who indicated not being willing to use solarization, the most common reasons were not having enough information about the practice (31%) and being satisfied with their current management practices (42%) (Table 6). Over a quarter of respondents who indicated that they were not willing to use soil solarization indicated that taking their HTs out of production for a couple of weeks would negatively affect the economic viability of their farm business.

Conclusions

We conducted a survey of Kentucky HT vegetable growers in 2024 to evaluate the soilborne disease, plant-parasitic nematodes, arthropod pest, and weed challenges these growers faced and the strategies they used to overcome them. We were particularly

Table 6. Percentage of respondents who were willing to use soil solarization and reasons for willing and not willing to implement solarization in their high tunnels.

Responses	*N*	Respondents (%)
Answered yes to the question: "Would you be willing to use soil solarization in your high tunnels if you have to seal (close the end walls and sidewalls) the high tunnel and not grow anything for 2 to 4 weeks?"	97	71.13
Reasons for being willing to use soil solarization		
I'm not satisfied with the effectiveness of the practices I'm currently using.	68	23.53
I'm interested in using more environmentally friendly practices in my high tunnels.	68	55.88
I think soil solarization might be cheaper and more effective in managing weeds, pests, diseases, and/or nematodes in my high tunnels.	68	58.82
Reasons for being unwilling to use soil solarization		
I do not have enough information about soil solarization.	26	30.77
Taking my high tunnel out of production for a couple of weeks will have a negative impact on the economic viability of my farm.	26	26.92
I'm happy with the effectiveness and cost of the practices I'm currently using in my high tunnels.	26	42.31

interested in evaluating Kentucky HT growers' use of and willingness to use soil solarization.

The results from this study suggest that a large percentage of survey respondents were not aware of the presence of soilborne diseases and plant-parasitic nematode problems in their HTs, or if they were aware, they did not know the specific soilborne diseases or plant-parasitic nematodes they had. A lack of awareness and understanding of these problems may affect HT growers' ability to make informed decisions about best management practices. For example, survey results suggested that 42% of those respondents who indicated that they were not willing to use soil solarization were satisfied with their current practices. Nonetheless, these same respondents may be those who were not aware of the soilborne disease and plant-parasitic nematode issues in their HTs. This is an opportunity for information providers to highlight existing resources and educational offerings for growers and county agents that will help them identify soilborne diseases and plant-parasitic nematodes. For example, the University of Kentucky has a Plant Disease Diagnostic Laboratory that offers free diagnostic services to anyone in Kentucky. There are also many extension publications that provide information and guidance on how to identify and manage common vegetable diseases and pests in Kentucky. Proper identification can help growers make informed decisions about the best management practices to use in their HTs.

Another finding from this study that is relevant for information providers is that 31% of those respondents who were not willing to use soil solarization indicated they needed more information about this practice to make an informed adoption decision. Although soil solarization is not a new management method, many Kentucky growers may be unfamiliar with it and may prefer regionally specific information on the efficacy of soil solarization. Presenting research-based information in a variety of formats, such as oral presentations at grower conferences and field days, an extension fact sheet, and video tutorials, will help growers better understand whether soil solarization is a good management method for their farm. The fact that 27% of respondents who were not willing to use solarization thought the adoption of this practice would be detrimental to the economic viability of the farm suggests additional information about the economics of soil solarization in HTs is needed. Although previous studies have evaluated the economics of soil solarization in open-field vegetable production (Hasing et al. 2004), no studies have evaluated the economics of soil solarization in HTs. Future research should focus on the evaluation of the economic viability of adopting soil solarization in HTs.

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