Horticulture and Landscape Architecture



https://ag.purdue.edu/hla H0-330-W



Extension Division



HIGH TUNNELS

Authors:

Elizabeth Maynard Clinical Engagement Associate Professor of Horticulture Purdue University

Dana Hilfinger Extension Educator Agriculture and Natural Resources Central State University, Ohio

Michael O'Donnell Organic Crop Consultant Former Purdue University Extension Educator

Scheduling Fall and Winter Vegetable Production

Introduction

Winter production is one way growers get the most out of their investment in high tunnels. Producing in the "offseason" increases income and strengthens relationships with customers by maintaining contact throughout the year. It can be an opportunity to create yearround employment that reduces turnover of valuable staff. An increasing number of winter farmers markets and other direct sales venues suggests expanding demand. Customers say they appreciate how long winter-grown greens stay fresh in their refrigerator, and many love the flavor. Some reports suggest there is greater potential income per square foot with cool season crops than warm season crops. For all these reasons and more, winter production in high tunnels is a growing trend.

High tunnels are plastic-covered structures, big enough to walk in, that provide protection from wind, snow, ice and, with strategic use of row covers, from the coldest temperatures. The hardiest cool season crops can survive all winter in high tunnels. Less hardy cool season crops can be grown before and after the coldest part of the winter. In some structures, heaters provide enough warmth to prevent injury to the less hardy crops and speed growth. Compared to a fully climate-controlled greenhouse, the typical high tunnel will experience lower temperatures, often below freezing, less control over humidity and no input of carbon dioxide. For more information on high tunnels see the Indiana High Tunnel Handbook (https:// mdc.itap.purdue.edu/item.asp?Item Number=HO-296-W), and Managing the Environment (https://mdc.itap.purdue. edu/item.asp?Item Number=HO-297-W). A key factor in winter high tunnel production is the planting and harvest schedule. Several things add to the complexity. In the lower Midwest the "winter" high tunnel season runs roughly from September to May – about 9 months. During that time frame, day length, sunlight level, and temperature vary over a wide range, and sometimes widely over the course of a short time period. For about 3 months in the middle, plant growth is likely to be very slow due to low light, low temperature, or both. Compared to producing outdoors in the frost-free season, the winter production environment is more variable; that, combined with a potentially longer growing season, can compound the variation and make reliable prediction even harder. Market factors can also enhance the risk of loss due to timing of harvest. Several winter holidays and celebrations drive food markets; product that is ready a week after the big demand may have little value. The diversity of crops, and the potential for warm season and cool season crops to need space in the high tunnel at the same time further complicate crop scheduling.

This publication provides guidance on scheduling vegetable crops for winter high tunnel production. The information was developed from work on three Indiana farms, multiple farms across the state of Ohio and at Purdue Agricultural Centers, combined with existing resources on crop scheduling. Specific dates listed are recommendations for growers in the central regions of Ohio and Indiana. Producers in the north and south of the state should adjust dates accordingly by about one week.

Based on 1981-2010 normals, Indiana and Ohio include USDA hardiness zones 5b, 6a, and 6b, representing average annual extreme minimum temperatures of -15° to -10°F (zone 5b), -10° to -5°F (zone 6a) and -0° to -5°F (zone 6b). For that period the average date of the first fall frost (32°F) ranges from Oct. 4-10 to Oct. 27-Nov. 2. The average last spring frost occurs from April 3-9 to May 11-20. Latitude varies from 38° to 42° north. The information should be applicable to other regions at similar latitude with comparable minimum winter temperatures and frost dates.

Types of Winter Crops

Crops in this production system fall mainly into two groups: leafy greens and root crops. The leafy greens can be categorized further based on the harvest method and product. Crops can fall into more than one category but in a particular planting will normally fit in one. For example, lettuce can be grown as "cut and come again" greens, or harvested just once as a complete head. Planting and harvest schedules differ based on these categories.

1. Harvest method: multi-cut (also called cut-and-comeagain). Product: small leaves or sections of leaves, often called "baby-leaf" greens and packaged loose in a bag or container. Examples are mizuna, mustards, arugula, lettuce, and spinach. The plant grows as a rosette or has a short stem. Often plants are seeded very densely to create a stand of upright leaves. The crop is harvested by cutting off (mowing) all leaves at a height of an inch or two above the soil, leaving behind the growing point and developing leaves that will expand to create the next harvest. Some growers use a flexible tine rake after harvest to remove leaf residue so that dead or dying residues covering the plant do not impact subsequent regrowth and quality. The harvested product consists of leaves or leaf sections about 4 inches long.



Lettuce cut once in a tunnel will regrow and allow for additional cuttings, depending on weather and tunnel management.

- 2. Harvest method: Cut individual leaves from plant. Product: Entire leaves, usually full-sized for the crop, often bunched for sale. Examples are kale, spinach, mustards, Swiss chard. Individual leaves are harvested after they reach the desired size. Smaller leaves are left on the plant to grow, and the plant continues to produce new leaves for future harvests.
- Harvest method: Main stem is cut one time. Product: A "head" or stem with leaves. Examples are lettuce, bok choi, Napa cabbage (heads), spinach (stem with leaves). The entire plant is harvested by cutting the main stem near the soil. Future harvests aren't expected.



Examples of harvest methods and products for leafy greens products.

Radishes and salad turnips are the more common root crops. Carrots and beets can be grown but take longer (50 or more days to maturity) to reach a marketable stage and so may not be as profitable. Some producers find that it is more economical to grow carrots and beets in the field and store them for winter markets, and use the valuable high tunnel space for a crop that doesn't store as well – i.e., leafy greens, salad turnip and radishes.

How Planting Date Affects Harvest Date and Yield

The number of days to harvest from planting changes over the high tunnel season. As planting is delayed from early September to late September, October and November, the time to harvest increases rapidly. Examples for plantings from Indiana and Ohio are shown in **Figs. 1** and **2** and **Table 1**. As planting is delayed from January to February and March, the time to harvest decreases. For crops harvested multiple times, such as spinach or kale, delayed planting in the fall means less yield over the entire season (Figs. 3A and 4A; Table 1). For crops where each plant is harvested once, such as lettuce heads, later plantings do not reduce total yield as much (Fig. 5A; Table 1). In this example with lettuce, heads from a single planting were harvested over weeks or months. It is important to note that the longer the harvest period, the greater the chance of losing some marketable yield to disease or cold injury. On the scheduling tool that accompanies this publication, the harvest range for single harvest crops (beets, carrots, radish/specialty turnip, head lettuce and scallions) provides an estimate of the length of time during which the crop can remain in the ground and still be marketable, assuming that row cover is used on nights below 25 degrees and high tunnels are vented so as to not allow temperatures above 80°F.



Fig. 1. Days to first harvest for crops planted on various dates in high tunnels in Indiana and Ohio. A. Spinach, direct-seeded. B. Radish, direct seeded. C. Lettuce heads, transplanted. D. Kale, transplanted. E. Baby lettuce leaves or mesclun, direct-seeded. Symbols indicate location where data were collected: ▲ Eden, ▼ Goshen, ◀ Roann, and ▶ Wanatah, IN; ● Columbus, ■ Johnstown, ♦ Mansfield, and ■ Wooster, OH.



Fig. 2. First harvest date for crops planted on various dates in high tunnels in Indiana and Ohio. A. Spinach, direct-seeded. B. Radish, direct seeded. C. Lettuce heads, transplanted. D. Kale, transplanted. E. Baby lettuce leaves or mesclun, direct-seeded. Symbols indicate location where data were collected: ▲ Eden, ▼ Goshen, ◄ Roann,and ▶ Wanatah, IN; ● Columbus, ■ Johnstown, ♦ Mansfield, and ■ Wooster, OH.

Table 1. Days to first harvest and first harvest date for kale, lettuce, spinach, and radish grown in Indiana, 2016-2017, in unheated high tunnels covered with a single layer of polyethylene. Kale, lettuce, and spinach grown in Wanatah, radish in Eden. Kale harvested as 8-inch leaf blades; lettuce as heads minimum 4 inches across, spinach as 7-cm leaf blades, and radishes at a minimum 1/2-inch diameter.

	Plant Date	Days to Harvest	First Harvest Date	Relative Yield
				% of earliest plant date
	August 30	28	September 27	100
	September 15	26	October 11	67
Kalo	September 29	41	November 9	28
transplanted, 'Darkibor'	October 14	98	January 20	4
	October 28	bloomed before reaching harvest stage		0
	November 11	bloomed before reaching harvest stage		0
	August 30	30	September 29	100
	September 15	28	October 13	81
Lettuce,	October 14	48	December 1	70
transplanted, Salanova® 'Red Incised'	February 7	70	March 18	47
	February 21	56	March 18	43
	March 8	56	May 3	19
	August 31	28	September 28	100
	September 14	28	October 12	78
Spinach	September 29	35	November 3	55
direct-seeded, 'Gazelle'	October 13	47	November 29	38
	October 31	120	February 27	9
	November 11	126	March 16	9
	September 1	25	September 26	no data
	September 15	26	October 11	
Radish, direct-seeded,	October 3	35	November 7	
French Breakfast type	October 17	43	November 29	
	November 21	106	March 7	

Lettuce was direct-seeded at 1-inch spacing and harvested (thinned) by removing alternate plants, increasing space for remaining plants. Photo taken Jan. 5.



Planted Sept. 29 Thinned Nov. 3 & 17

Planted Oct. 13 Thinned Dec. 7 Planted Oct. 27 Thinned Dec. 20

Pictures of three different lettuce plantings in a single-layer high tunnel in January.

Once a crop has accumulated enough growth, growers can plan for steady harvests on a weekly or biweekly schedule, until the accumulated growth is used up and new growth is too slow to keep pace with harvests. **Figs. 3B, 4B,** and **5B** illustrate yield from regular harvests for kale, spinach, and lettuce heads at a research farm. On each harvest date, all marketable leaves of kale and spinach were harvested. In this example, very little kale was harvested from January through mid-February. To be able to harvest over that period, more leaves could have been left on the kale plants during fall harvests. Instead of picking every leaf with a blade at least 8 inches long on each harvest date, some leaves could have been left on the plant to be picked later.



Figure 3. Yield of 'Darkibor' kale grown in unheated high tunnels at a research farm, Wanatah, IN. Seedlings were transplanted 9 inches apart in rows 8 inches apart. On each harvest date all leaves with blades longer than 8 inches were harvested. A: Total yield from regular harvests through mid-March for kale transplanted on four dates.

B: Yield versus harvest date for kale transplanted on Aug. 30.

In the case of spinach (**Fig. 4B**), the biweekly harvests in December and January produced less than the weekly harvests earlier in the fall. This trend is similar to that seen for many multi-cut leafy greens (e.g., mesclun): the plants take longer to regrow in the coldest and darkest periods. The amount available for harvest from a single planting will decrease each week under these conditions.

In the case of lettuce (**Fig. 5B**), one head was cut at each harvest and so the yield on each harvest date reflects the size of the heads. August and September plantings produced large heads before they became unmarketable due to cold weather. The mid-October planting produced small heads through the winter and then larger heads in spring. Heads from the February and March plantings did not get as large as those from the fall plantings. These effects on harvest date and yield are due to changes in day length, intensity of sunlight, and temperature that occur with the change in seasons. As a general rule, when the daily light integral (DLI) inside is less than 10 mol/m2/day and/or average temperature inside the tunnel is below 35-40°F, crops grow slowly, if at all. In Indiana and Ohio these conditions prevail from mid-November until the end of January. As light and temperature increase so does crop growth. Fig. 6 shows average DLI outside and in a double-poly tunnel, and average daily temperature outside and at crop level in high and low tunnels during the fall-spring. For more information on environmental conditions, see Purdue University's publication on Managing the High Tunnel Environment (https://mdc.itap.purdue.edu/item. asp?Item Number=HO-297-W).



Figure 4. *Yield of 'Gazelle' spinach grown in unheated high tunnels at a research farm, Wanatah, IN. Seeds were planted 1 inch apart in rows spaced 4 inches apart. On each harvest date all leaves with blades longer than 2.75 inches were harvested. A: Total yield from regular harvests through mid-March for spinach seeded on six dates.*

B: Yield versus harvest date for spinach seeded on Aug. 31.



Figure 5. Yield of Salanova® 'Red Incised' lettuce grown in unheated high tunnels at a research farm, Wanatah, IN. Seedlings were transplanted 6 inches apart. Harvest for each planting date began when heads reached minimum marketable size (approximately 4 inches diameter). A single head was harvested at each harvest date. Yield is reported as the weight of trimmed marketable heads harvested divided by the total area harvested for each planting date. Harvest for September and October plantings of lettuce ended when heads became unmarketable in January due to disease or cold injury; for November planting in mid-April when the entire planted area had been harvested; and for February and March plantings in May. Harvest of lettuce from October and spring plantings could have continued longer. The movable tunnel was moved off the harvest area on 4/12/2017.

A: Total yield for lettuce transplanted on six dates.

B: Yield on each harvest date for lettuce transplanted on six dates. One head harvested on each date.



Figure 6. *A:* Daily light integral outside and inside a double-poly high tunnel. B: Average monthly temperature outside and inside heated, unheated, and low tunnels. Roann, Indiana, 2016-2017.

Planting Date Scheduling Tool

This guide provides transplant seeding, planting and harvest date ranges for crops often grown during the fall, winter and early spring months in high tunnels. All of these crops are generally able to withstand freezing nighttime temperatures and have lower temperature thresholds for plant growth (36-40°F). Recommendations are for Zone 6a (see General Notes on adjustments) in Ohio and Indiana and assume crops are planted in a single-layer high tunnel or hoophouse (see note about adjustments for double-layer tunnels).

A common approach to growing cold-tolerant crops in unheated high tunnels during the fall-spring in Northern climates is to plant beds in the late summer/early fall so that plants are mature by end of November, at the latest, at which point plant growth slows considerably until early February. Crops can then be harvested from November-February, using the tunnel as a "living refrigerator" and picking as needed. Considerable regrowth will begin again starting in February, at which point harvesting can either continue for leafy greens or new crops can be planted for early spring harvests.

Each line of the chart represents the projected harvest timeframe for a crop, given the corresponding planting and seeding timeframe. Harvest timeframes end at dates when we have observed that most of the crop is no longer marketable. This could be due to crops bolting (kale, collards, Swiss chard, spinach, carrots) or because multiple freezes decrease quality (radishes, lettuce, beets, mustard). Note that delaying planting by a week in the fall can result in delays in harvest of much more than one week, while planting earlier in the late winter doesn't necessarily result in earlier harvests.

This information is based on the "normal" days to maturity listed for each crop – i.e., the time from seeding to harvest under ideal temperature conditions. This information is provided as a guide for your decisionmaking, understanding that there can be differences in days to maturity depending on variety that will require adjustment from these harvest intervals.

Crop-Specific Notes

Baby greens: Certain crops in this list are more tolerant of freezing temperatures and will maintain quality through multiple freezing events better than others. These include: bok choy, tat soi and kale. Denser seeding rates can also result in the quality of the crop to decline more rapidly than less-dense seedings.

Spinach: Late summer plantings are best transplanted, as high temperatures in early September can inhibit germination.

Swiss Chard: Growth of chard slows down substantially in January, so may not be able to harvest during that month.

General Notes

Planting Dates are recommended for Zone 6a, and should be adjusted roughly one week back for Zone 5b and one week forward for Zone 6b. You may also find variation within your specific location, particularly due to differences in relative cloud cover.

TP=Transplant; DS=Direct Seed

This plan is for single-layer tunnels. For double-layered tunnels, planting dates could be delayed by as much as a week in fall, and crops could be started a week earlier in winter for spring harvests.

There is limited information on planting dates for high tunnels with supplemental heat. Based on a few on-farm records for tunnels with supplemental heat, crops could be planted up to one month later in the fall and one month earlier in the late winter.

Transplant seeding date recommendations assume transplants are grown at temperatures ideal or nearideal temperatures for plant growth.

All harvest ranges assume that the grower would use at least medium-weight row cover over beds within the tunnel when nighttime temperatures drop below 25°F and double layer cover if nighttime temperatures drop below 10°F.

For single-harvest crops (beets, carrots, radish/ specialty turnip, head lettuce and scallions), the harvest range provides an estimate of the length of time in which the crop can remain in the ground and still be marketable, assuming that row cover is used according to the above guidelines and high tunnels are vented so as to not allow temperatures above 80°F.

For multiple-harvest crops (all others), the harvest range provides an estimate of the length of time in which you can harvest where most of the crop is marketable.

The information in this chart is based on Ohio and Purdue on-farm records and Rural Action and Green Edge Gardens' "Season Creation Handbook" (funded through North Central SARE).

-	
	Transplant seeding date range
	Date range to plant transplants in beds
	Date range to direct seed beds
	Typical Harvest Window
	Likely Harvest Window (if milder winter)

HO-330-W HIGH TUNNELS - Scheduling Fall and Winter Vegetable Production

Plant	Ideal Soil	"Normal"	Month												
	Required for Germination	Maturity	July	August	Sept	Oct	Nov	Dec	Jan	Feb	March	April	May	June	
Baby Greens (Bok Choi, Tat Soi, Mizuna, Kale, Arugula, Mustards)	41-90	DS: 25 days													
Baby Greens (Lettuce, Swiss Chard, Beet Greens)	40-85	DS: 35 days													
Beets	59-80	DS: 50 days TP: 35 days													
Carrots	50-90	DS: 70 days													
Kale and Collards		TP: 50 days													
Head Lettuce		TP: 40 days													
Leeks		TP: 80 davs				}		, ,	} 				{	; ;	
Mustard (full- size)		TP: 45 days													
Peas	50-86	DS: 60 days				 									
Radish/Salad Turnips	50-95	DS: 30 days													
Scallions	60-85	TP: 45 days DS: 60 days													
Spinach	50-85	TP:20 days DS: 30 days													
Swiss Chard		TP: 40 days													

Fillable Scheduling Tool

Use this chart to keep track of your own planting and harvesting dates within your high tunnel.

Crop	Location		Ju	ly		ļ	Aug	ust	t		Se	pt			0	ct	
Ex. Lacinato Kale	HT1 - Beds 1-3	}							ΤР							н	
																	_

List the crops that you are growing and mark when you plant and then when you harvest. See example below, where we used "TP" to indicate when transplanted, "H" to indicate first harvest and "LH" to note last harvest.

						[Мо	ntł	1										 				 					
	No	JV			D	ec			Ja	in			Fe	зb			Ma	rch		Ар	ril		Ma	ay		Jui	ne	
																			LH									
	$\left - \right $		\vdash	\vdash	\square		\vdash	\square	-	\square	$\left - \right $	[]		$\left - \right $		\square											\square	
<u> </u>	\vdash	<u> </u>	\vdash	\vdash			-	\vdash	\vdash	\vdash	$\left - \right $	$\left - \right $	\square	\vdash	$\left - \right $	$\left - \right $						\neg						-
	\vdash	\vdash	\vdash	\vdash	\vdash	\vdash		\vdash	\vdash	\vdash	\vdash	$\left - \right $	\vdash	\vdash	\vdash	$\left - \right $						-					\square	
	\square	<u> </u>	\vdash	\square	<u> </u>	<u> </u>	<u> </u> _'	<u> '</u>	<u> '</u>	\square	\square	\square	\square	\square	\square	$\left - \right $											\square	<u> </u>
		<u> </u>	\square	\square	\square	\square	<u> </u> _'	\square	\square	\square																		
				\square								\square^{\dagger}																
							\vdash																				\square	
	\vdash	-	\vdash	\vdash	\square	-	\vdash	\vdash	\vdash	\vdash	\vdash	$\left - \right $	-	\vdash	$\left - \right $							\neg						
	\vdash	-	\vdash	\vdash	\vdash	\vdash		\vdash	\vdash	\vdash	\vdash	$\left - \right $	\vdash	\vdash	\vdash	\square						-					\square	
	\square	-	\vdash	\vdash	-	\vdash		\vdash	\vdash	\square	\square	\square	\vdash	\square	\square	$\left - \right $											$\left - \right $	<u> </u>
	\square	<u> </u>	\vdash	\square	<u> </u>	<u> </u>	<u> </u> _'	<u> '</u>	<u> '</u>	\square	\square		\vdash	\square	\square	\square												<u> </u>
		<u> </u>	\square				<u> </u> '																					<u> </u>
		[_'	$\left[\right]$				[_'	[_]	[_]																			í _
																												1
							\vdash					\square^{\dagger}			\square^{\dagger}													
	\vdash		\vdash	\vdash			\vdash	\vdash	\vdash	\vdash	$\left - \right $		\square	\vdash	$\left - \right $	$\left - \right $						\neg						
	\vdash	-	\vdash	\vdash	-	-		-	-	\vdash	\vdash	$\left - \right $	\vdash	\vdash	\vdash	\square						-					\square	
	\square		\vdash	\square	\vdash		<u> -</u> '	\vdash	\vdash	\square	\square	\square	\square	\square	\square	\square								—		_	\square	-
		<u> </u>			\square	\square	<u> </u> _'					\square																<u> </u>

Planting Dates for Crops Harvested October - February

Generally accepted guidelines suggest that crops to be harvested before about February should be planted early enough that they are at least three-quarters grown by the time daylength falls to 10 hours, which is November 10-17 in Indiana and Ohio and other locations at latitude 38° to 42°. Depending on the crop, that means planting from September to mid-October. The planting date scheduling tool included in this publication is based on information collected from regional farms and is discussed further below in "Fine Tuning your Crop Schedule."

Planting Dates for Crops Harvested February - May

Fall Plantings

For crops that will not be harvested until February or later, fall plantings should be planted early enough to get the crop established before extreme cold. Mid-November is a suggested cutoff date for a hardy crop like spinach. Note, however, that for most crops, planting after mid-October results in a significant decrease in yield over the life of the crop (**Table 1**).

If maximum yield over the entire winter harvest season is the goal, early planting is clearly the way to go. Early plantings are in the ground for a longer period of time, are harvested for a longer period of time, and so there is more yield potential. In addition, the higher temperatures and longer day length in the early planting period mean they grow more quickly: a week of growth in early September adds more to the plant than a week of growth in early October. To help in deciding whether to remove a summer crop in the high tunnel in order to plant spinach, it can be helpful to think of the potential profit for each week of high tunnel use. For instance, if tomatoes are in the tunnel in September, what is the potential profit from those for the first two weeks - and how does that compare to the potential profit from planting spinach the first of September versus the 15th?



A bed of spinach harvested from a tunnel in early April in Columbus, Ohio.

If a heater is used to keep the high tunnel above 28°F or so, the planting schedule can be adjusted. The risk of crop loss to freezing is low, so harvest of less hardy crops (e.g., lettuce) can be planned throughout the winter using successive plantings or multi-cut harvesting. Crop growth will be faster, so the time to first harvest will be reduced, and the time between subsequent harvests can be reduced. The result will be a higher yield over the same time period, but the profitability will depend on heating costs, environmental conditions and the sales price of the produce. Low light will still keep crop growth slow.

Late Winter and Early Spring Plantings

Even though some fall-planted crops can be harvested into early spring, there are advantages to making additional plantings after the first of the year. Crops planted then provide fresh, new growth for late winter and early spring harvests, without as much potential for reduced quality or yield due to the accumulation of disease, pest, or nutritional disorders that can occur with overwintered crops. Less hardy crops that would not survive the winter can do very well planted at this time.

Schedule seeding and transplanting for mid-February to mid-March. Planting before mid-February generally doesn't lead to earlier harvest. Direct seed in the high tunnel when soil temperatures are warm enough that seeds will germinate – soil temperatures can be tested using a soil thermometer inserted to the seeding depth. If seeded while the soil is still too cold, seeds will germinate when the temperature increases, but the grower has less control over the timing of the crop. Plant 3- to 4-week-old transplants in the high tunnel beginning in mid-February, as light levels and temperature are increasing. For crops harvested within a month or so of planting, successive plantings a few weeks apart can be used to maintain a consistent supply of high-quality product.

To make the most of the tunnel's space, some growers intercrop cold-hardy crops with summer crops within the same bed: low-growing cold-hardy crops, such as mesclun mix or radishes, are seeded on the outside of the beds as early as February, and then summer-harvested crops, like tomatoes or cucumbers, are planted down the middle of the beds beginning in April. This method utilizes the bed space for spring harvest, while still allowing for an early summer crop planting.

Whether for fall, late winter, or early spring, these planting date recommendations all assume that soil nutrients are adequate for growth. Insufficient soil nutrients (particularly nitrogen) can result in lower crop yields and slower growth, both of which can hamper an otherwise well-scheduled tunnel crop plan. For new plantings in cool soils when biological activity is low, using more readily available sources of nitrogen can help ensure that enough nitrogen is available for early growth. Take care to avoid excess nitrogen, which can result in more favorable conditions for certain pests. Monitoring and managing soil nutrient levels, via amendments and crop rotation, is particularly important in tunnels because one bed will have multiple successions of crops.

Planning for Late Winter Flowering

Most cool season crops are harvested during the vegetative stage of growth. Once they start to develop flowers, the product quality declines and soon the crop leaves are not marketable. This must be considered in planning a schedule. Most of these crops are triggered to flower by environmental conditions. Many in the mustard family, as well as beets, carrots, and onions, switch from producing leaves to flowers after growth at cool temperatures. Once the switch has occurred at the microscopic level, the growth of the flower stalk occurs more quickly at higher temperatures. On overwintered crops in this group, flowers often begin to open in March. Late winter and early spring plantings of leafy crops in the mustard family can be triggered to bloom while they are still small. If you plan to let them grow beyond the baby stage, become familiar with the flowering behavior of specific crops and varieties before committing to a large planting.

For some producers, flowering is an opportunity to harvest a new product. For them, kale stalks with buds are readily marketed as a vegetable similar to broccoli raab.



An example of Koji greens bolting inside a tunnel in March.

The same could possibly be done with similar crops. Whether flowering stalks are harvested or not, it is important to plan for an end to harvest of the leaves once flowering occurs.

Spinach and lettuce harvest is also curtailed by flowering. Spinach leaves become more arrow-head shaped as long days trigger flowering, although the flower stalk does not appear until May or June. For lettuce, the combination of long days and high temperature trigger flowering. As the stem lengthens, smaller leaves develop, and with high temperature bitterness increases.

Varieties within a type of crop vary in the duration and degree of cool temperatures or the daylength required to trigger flowering. As winter high tunnel production increases, information about these characteristics will probably be more readily available. When planning for spring harvests, look for varieties that are slow to bolt.

Fine-Tuning Your Crop Schedule

Included in this publication is a guide for scheduling crop plantings according to the desired harvest window. Planting recommendations in the guide factor in soil temperature requirements for germination and minimum temperature requirements for growth. The guide also factors in hardiness of different fall-planted crops to determine an estimated harvest window during the winter months. The less hardy crops are more likely to be seriously injured when temperatures drop into the low 20s or below. Hardiness varies depending on the conditions under which the crop is grown – crops that develop under cold temperatures can withstand colder temperatures.

Factors specific to each farm will influence crop scheduling. The local microclimate makes a difference. Locations in a valley with early frost and cooler average temperature may require earlier planting dates in later summer; tunnels in urban environments may stay a few degrees warmer than comparable tunnels in rural environments. Soil composition, bulk density and color can also affect growth rate in a tunnel - a heavier clay soil will take longer to warm up in the spring, for example, resulting in slower growth. The structure matters: in a small high tunnel with less air mass or volume that cools down more quickly, less hardy crops will probably be injured or killed earlier than in a larger and well-insulated structure. A high tunnel covered with double poly stays warmer than one covered with single poly (but light intensity is reduced), and if minimal heat is provided, the average temperature is even higher. Less cold injury and faster crop growth require adjusting the production schedule.



Materials such as row cover or heaters (bottom right and left, respectively) are two ways to speed up growth and protect crops during the coldest months. Movable high tunnels (top right) allow farmers to be able to still seed a crop early enough for a plentiful winter harvest, while still growing a summer crop in the tunnel. A movable tunnel could be moved off the summer crop beds and over the winter crop in October or early November.

On most farms, the critical time period for planting/ seeding is from late August through mid-October. During this period crops will be seeded or transplanted into tunnels for late fall and winter harvest. Plant earlier for a shorter time to harvest and higher potential yield. Crops requiring more days to maturity should be planted early in this window. Crops requiring fewer days to maturity, or those harvested at a "baby" stage, can be planted later during this period.

Planting fall crops in late August requires a trade-off with warm season crops (e.g., tomatoes) that could still be harvested if left to grow in the tunnel: the summer and winter crops compete for the same space. When designing a planting schedule, it is important to consider the potential revenue from winter harvested crops versus revenue from one or two more months of summer crop harvest. Equally important is how the crops fit into the overall marketing plan. The "competition" for space between summer and fall crops can be reduced with the use of movable tunnels. With these structures, winter-harvest crops can be planted outside while the summer crops are still in the tunnel, and the tunnel can be moved over the winter crops later in the fall, allowing several more weeks of harvest from the summer crops. Another approach some farmers use to accommodate both summer and winter crops is to grow transplants for crops that are often direct-seeded, such as spinach and baby-leaf greens. The transplants can be put in the tunnel later than direct-seeded crops and yet be harvested on

the same (or even earlier) date. This practice has become more common with the introduction of the paper-pot transplanter, which significantly reduces the labor required for transplanting tightly spaced crops.

Your own records are an invaluable tool for continually refining and improving your crop schedule. Included in this publication is a fillable form for keeping track of actual seeding, transplanting and harvest dates by crop. Note when a crop is damaged or becomes unmarketable due to low temperatures, bolting, or other conditions. A simple way to make records during daily work is to assign a wooden stake to each planting, and use a marker to write key dates and notes on the stake. When the crop is finished, the stake can be collected (or photographed) and the information transferred into a more permanent and more easily referenced system - maybe a spreadsheet, text document, or notebook. Along with the crop records, keep records of temperature and weather conditions. During the planning process for subsequent crop schedules, use this information to adjust planting and harvest dates and to compare outcomes with other growers in your region and network.

Winter high tunnel production is a system where there is a lot of innovation and experimentation on farms, and an increasing amount of research. Learn and stay informed by connecting with trustworthy sources of information – in person, online and in print.

An example of using a stake at the head of the bed to keep records on the crop grown, when it was seeded and transplanted, and how much was harvested out of the bed by date.

Winter Growing Scenarios

Scenario #1 (Year-round Spinach Harvest)

A farmer sells baby spinach to a local restaurant during the regular growing season and was asked if they would be able to supply the restaurant with spinach year-round. They have one 30x96' single-layer high tunnel with eight beds and plan to use a single layer of medium-weight row cover at night when temperatures are forecasted to be below 20°F. The farm is able to reliably harvest spinach in the field until the first week of November in the fall; their earliest field harvest in the spring is the first week of May. They need to be harvesting spinach in their tunnel from November to April, roughly 26 weeks. The restaurant pays the farmer \$7/lb for baby spinach.

They plan to direct seed spinach and have to harvest 1/2 bed of spinach each week (20 lb), conservatively, to fill their restaurant order, using a greens harvester. They anticipate being able to get a second cutting off of beds, but don't anticipate additional cuttings, given the restaurant's quality standards. Their past records on winter spinach harvesting helped them determine the amount of time between first and second harvests – roughly one month for earlier plantings and longer for later plantings. After the second harvest, they planned to turn over the beds for an early spring crop.



Gold indicates dates to direct seed spinach for desired harvest, shown in orange.

They developed the following schedule, using the golden squares in the spinach section of the planting chart to determine direct seeding dates for different harvests (cutout above):

Bed	Planting Date	First Harvest	Second Harvest
1	9/15	12/19 (½ bed) 12/26 (½ bed)	
2	9/20	11/22 (½ bed) 1/29 (½ bed)	1/2 (½ bed) 1/9 (½ bed)
3	10/1	2/15 (½ bed) 2/22 (½ bed)	
4	10/8	1/16 (½ bed) 1/23 (½ bed)	2/29 (½ bed) 3/6 (½ bed)
5	10/8	1/30 (½ bed) 2/7 (½ bed)	3/13 (½ bed) 3/20 (½ bed)
6	10/8	January harvest b	backup
7	2/10	4/1 (½ bed) 4/8 (½ bed)	4/29 (½ bed) 4/8 (½ bed)
8	2/28	4/15 (½ bed) 4/22 (½ bed)	

Beds seeded in mid-October may reach marketable size prior to when they were going to be harvested, but cold temperatures and slow growth preserve the crop's quality and marketability in the bed while it awaits

> harvest. This farmer opted to plant an extra "insurance" bed for January harvest, in case particularly cold temperatures slow regrowth, or delay initial harvest of other beds. If they get more spinach than needed, they can sell surplus through their online store. Having a heater would reduce time to harvest, shorten the time regrowth interval between harvests and overall provide more reliability of harvests

in the event of extreme conditions. A double layer tunnel would provide some of the same benefits, but to a lesser degree.

Revenue:

20 lb/week of spinach*26 weeks = 520 lb spinach total *\$7/lb = \$3,640

Total: \$3,640

Scenario #2 (Winter Kale)

A farmer has been asked to provide green curly kale for a co-op's 140-member winter CSA from December through mid-March (14 weeks). Each CSA member would receive 1 bunch (\sim ³/₄ lb) of kale each week, meaning the farm needs 140 bunches/week. They have one 30x96' double layer high tunnel with 8 beds and plan to use a single layer of medium-weight row cover at night when temperatures are forecasted to be below 20°F. The co-op pays the farmer \$2.50/bunch.

In this case, the planting schedule is relatively straightforward. The kale is seeded in trays for transplant in mid-August and transplanted into all beds in the tunnel on 9/15. The farmer decided to transplant the kale a little earlier than necessary for a December harvest so that the kale could develop more harvestable leaves prior to the initial harvest. The double-layered tunnel should also shorten the regrowth interval slightly, compared to a single-layered tunnel.

_		Month														
Plant	July	August	Sept	Oct	Nov	Dec	Jan	Feb	March							
Kale and Collards																

During the month of December, the farmer harvested four beds of kale per week at a rate of roughly 2-3 leaves/plant in order to get 140 bunches (about 8-10 leaves/bunch). Through the end of January, they alternated harvests each week between the first four beds and the second set of four beds. Regrowth was slow in January, so in the end of January and for the first two weeks of February, they took only 1-2 leaves/ plant (meaning they were harvesting from all beds each week). By the end of February, growth was picking back up, and they resumed harvesting 4 beds/week at the rate of 2-3 leaves/plant. By their last harvest in the second week of March, the kale was beginning to show signs of bolting (elongating stem, smaller leaves) and they took their final harvest on March 10, taking all bunch-able leaves. They were also able to sell one additional harvest of the budding stalks of kale (sometimes called "kale raab") through the CSA before removing the plants on March 17.

Revenue:

140 bunches/week*14 weeks = 1,960 bunches *\$2.50/bunch = \$4,900

140 bundles of kale raab*1 week*\$3/bundle = \$420 Total: \$5,320



purdue.edu/extension

Photo Credits

All photos in this guide are provided by the authors unless otherwise indicated in the caption.

Acknowledgments

We thank Ben Hartman, Clay Bottom Farm; Nathan Fingerle, River Ridge Farm; and David Robb, Eden Prairie, for their collaboration in recording crop and environmental information on their farms over two winters as part of the SARE Partnership project mentioned below. Erin Bluhm managed crops and collected data for research at Wanatah, Indiana. We are grateful to reviewers Chris Adair, Stephen Dienger, Wenjing Guan, Ben Hartman, George Mertz, David Robb, and Logan Walter for helpful comments and suggestions that have improved the publication. This material is based on work that was supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, under award number 2014-38640-22156 to the University of Minnesota, through the North Central Region SARE

> program under project number ONC15-008; and by the U.S. Department of Agriculture with the Indiana State Department of Agriculture under award number 15SCBGPIN0032.

Disclaimer

Reference in this publication to any specific commercial product, process, or service, of the use of any trade, firm, or corporation name is for general informational purposes only and does not constitute an endorsement, recommendation, or certification of any kind by Purdue Extension, Central State University, the U.S. Government, or the State of Indiana. Individuals using such products assume responsibility for their use in accordance with current directions of the manufacturer. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government, the State of Indiana or any agency thereof.

> Find out more at THE EDUCATION STORE edustore.purdue.edu



An Equal Access/Equal Opportunity University