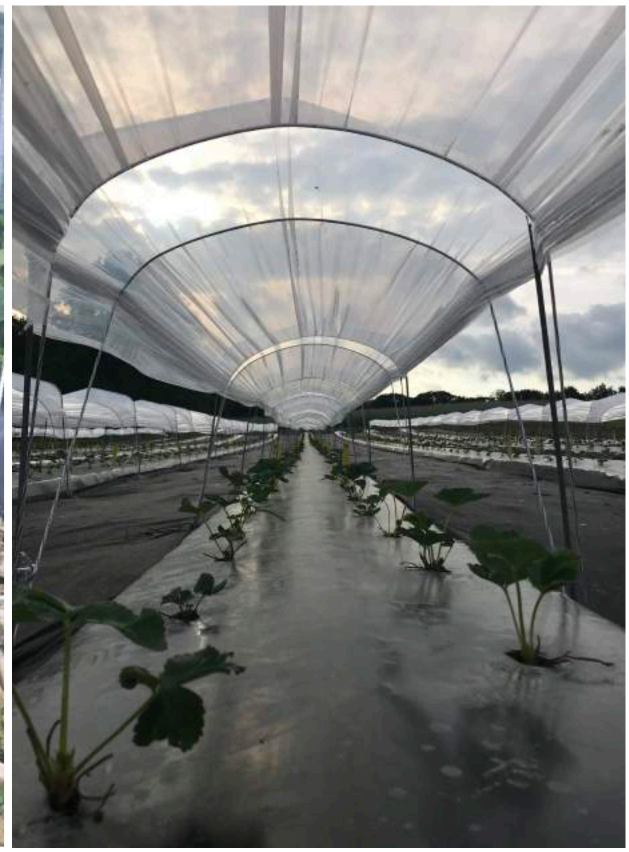
LOW TUNNEL STRAWBERRY PRODUCTION GUIDE



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I. INTRODUCTION

This guide is intended to provide an introduction to low tunnel systems and to share construction and management tips for low tunnel strawberry production. Information pertains to the use of low tunnels during spring, summer, and fall months. There are other important considerations for low tunnels installed for winter protection in cold regions with snowfall likely; see Using Low Tunnels for Overwintering Crops: Lessons Learned for more information on this topic.

Benefits of Low Tunnels

Plastic covered low tunnels are well-suited to protect fruit during the long growing season of day-neutral strawberry varieties, but may also be useful in protecting the short and valuable June-bearing (short-day) crop. Research conducted in Minnesota, Maryland, and the Northeast shows that low tunnels can have a number of positive effects on strawberry production, including:

Fig. 1: Hail experienced in southern NH, June 2017. *Photo: A. Orde*

1. ***Protecting fruit marketability***
   Low tunnels act as a barrier between plants and the environment, protecting fruit from damage caused by precipitation. The structures also offer protection from inclement weather, including hail and strong winds (Fig. 1), and have been reported to reduce sunburn on fruit.

2. ***Reduced disease incidence***
   Many plant diseases, including anthracnose fruit rot (*Colletotrichum acutatum*) and *Botrytis* (*Botrytis cinerea*) rely on high relative humidity for sporulation and rain for spore dissemination. By eliminating standing water, sporulation (especially of *Botrytis*) and disease pressure can be reduced.

3. ***Greater total yields and larger fruit size***
   In some years and locations, day-neutral strawberry plants grown under low tunnels have produced greater total marketable yields than plants grown on open beds (Lewers et al., 2017; Petran et al., 2016; Van Sterthem et al., 2017). Late season yields during the months of October and November also tend to be increased under low tunnels, especially as growing conditions deteriorate.

4. ***A higher percent of marketable fruit***

Even when marketable yields are not greater under low tunnels, plants consistently produce a higher percentage of marketable yield than plants grown on open beds (Fig. 2 and Fig. 3). Experiments conducted in at the University of New Hampshire and Cornell University have found the percentage of marketable yield is an average of 10-15% greater under low tunnels than open beds. Following rain, there is even a greater difference between low tunnels and open beds. For example, following rain on one date in October 2017, approx. 50-70% of yield was marketable under low tunnels, while less than 3% were marketable from open beds (Pritts, 2017; Orde et al., 2017).


Fig. 2 and Fig. 3: Fruit following rain in August 2016 (left) and in November 2017 (right). In both pictures, the container on the left contains fruit from open beds (no low tunnel) and the container on right contains fruit from low tunnels. *Photos: K. Orde*

5. ***Extended fruit production***

When low tunnel sides are closed, daytime maximum air and soil temperatures are greater within low tunnels than open beds (Fig. 4), this may promote growth (and flowering) during the early spring and late fall months. Research from the University of New Hampshire reports that in 2017, yield from the day-neutral variety 'Albion' was greater under low tunnels than open beds during four of the last five weeks of the season (Fig. 5). During late-season production, even though nighttime air and soil temperatures tend to be comparable to open beds (there are some exceptions), it has also been reported that low tunnels may provide some degree of frost protection.

6. ***Reduced runner emergence***

Very preliminary findings suggest that low tunnels may reduce runner emergence for some day-neutral varieties. In a one-year experiment conducted in 2017 in New Hampshire, the day-neutral varieties 'Aromas', 'Monterey' and 'San Andreas' produced significantly fewer runners per plant under low tunnels than on open beds (when grown on black plastic mulch). This experiment is being replicated for a second year at UNH in 2018. It does not appear that all varieties produce fewer runners under low tunnels, but in a plasticulture system where runner production is not desired (and removal is time consuming and costly), this response may be an additional benefit to growing some varieties under low tunnels.

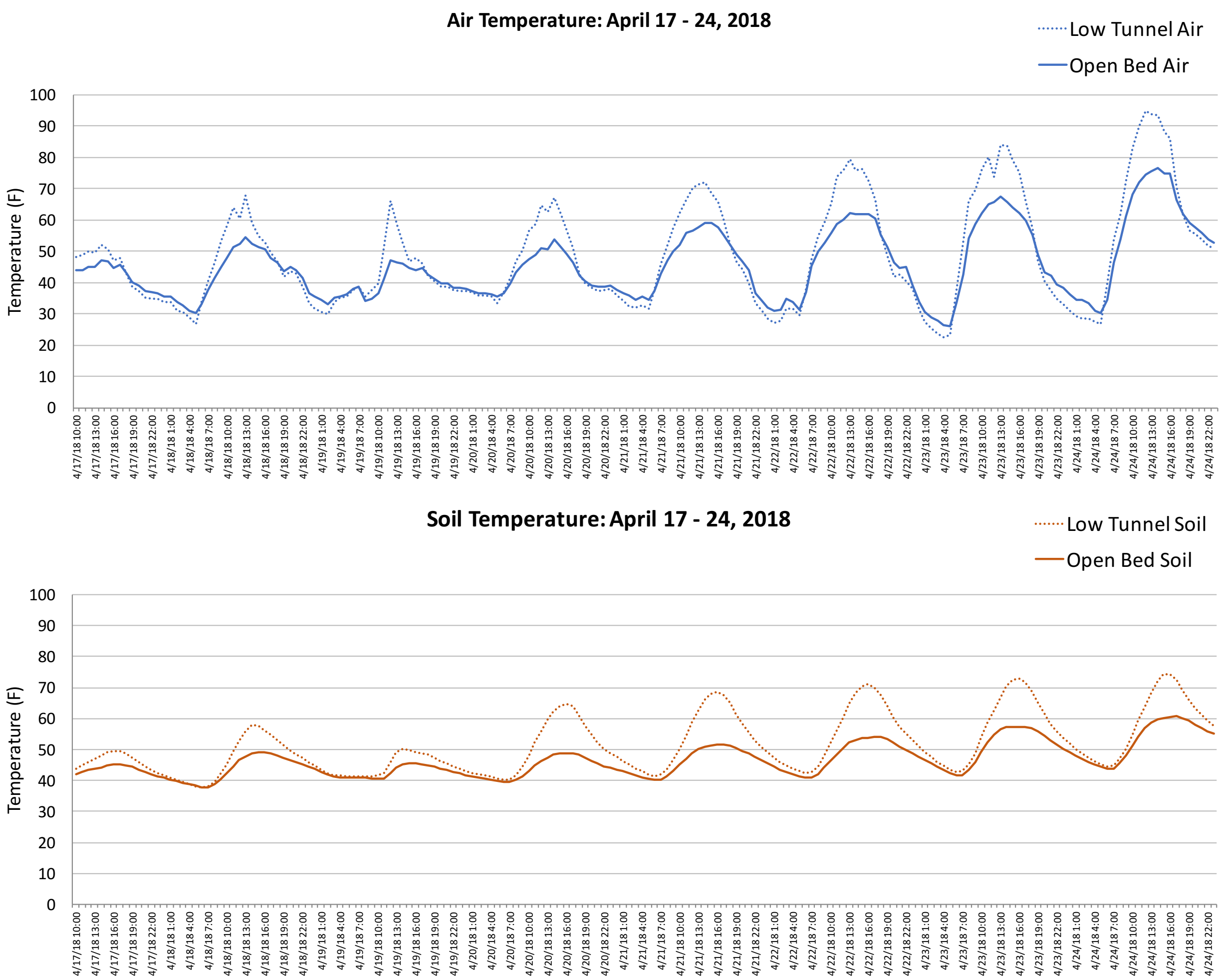

Fig. 4: Daily fluctuations in air (top graph) and soil (bottom graph) temperatures for a one-week period in April 2018. Solid lines are open beds (no low tunnel) and dotted lines are for low tunnels.

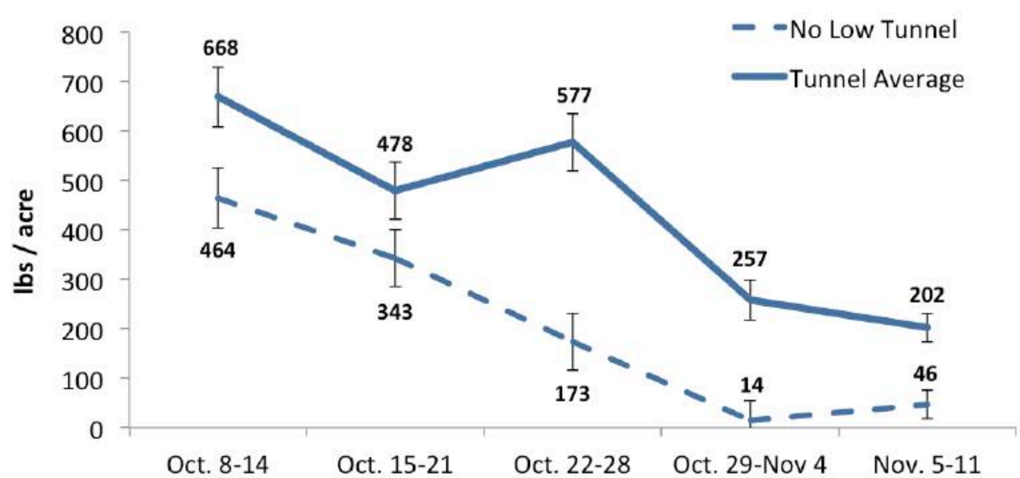

Fig. 5: Marketable yield (lbs/acre) of the day-neutral variety 'Albion' in Durham, NH during the last five weeks of the 2017 season. Plants under low tunnels produced higher marketable yields in all weeks except Oct. 15-21 ($P \leq 0.05$). Error bars are ± one SE.

How Much Management Time is Required?

Low tunnel systems are relatively easy to install but do require some degree of active management throughout the growing season. Wind and rain can trigger the need for adjustments to the system and it is important to check on tunnels to ensure plastic covers remain taut and well ventilated during summer months.

Standard Low Tunnel Components

Regardless of the low tunnel system (commercial or homemade), there are four standard components:

1. ***Hoops***: Hoops are inserted into the ground with one leg on each side of the bed to create a tunnel frame approximately 2-3' above plants. Hoops are often made of steel, but can also be created with conduit or PVC piping.

2. ***Plastic***: Agricultural plastic is used to cover the hoops to prevent water from coming in direct contact with plants and fruit. There are many options for low tunnels plastics, and films are available in a range of thicknesses and light transmission properties. Perforated plastics, which encourages airflow within tunnels, are also available.

3. ***Tie-down material:*** Twine, parachute cord, or bungee elastics is used to secure plastic to the low tunnel frame.

4. ***Anchor object:*** A stake, post, or pipe is used at both ends of the tunnel as a grounding object for the plastic cover.

II. LOW TUNNEL SYSTEM EXAMPLES

The following examples of in-ground low tunnels are presented to show the diversity of materials and approaches that can be taken, but are only a sample, as it is possible to tailor a system to your budget and needs. Commercial growers have developed completely above-ground low tunnel systems that do not affix to the ground, allowing the tunnel to be moved over different sections of the field as needed, though such systems will not be outlined in this guide.

1: Hoops & Twine

This method utilizes hoops and twine (or another tie-down material) that usually crisscrosses between hoops to hold plastic to the frame (as on a hoop house) (Fig. 6 – Fig. 7). It is necessary to include an object on each hoop that the twine can catch. For wire hoops, a rubber stopper can be inserted onto the end of the hoop (Fig. 8) but for PVC or conduit hoops, it may be necessary to install a hook onto the hoop or in the ground at the base of the hoop. Rubber stoppers can be lifted higher up on the hoop to keep plastic ventilated, but doing will make lowering sides more labor intensive and require adjustments to the twine be made. Modifications to the Hoops & Twine system include using separate pieces of twine for each hoop instead of a long piece that crisscrosses between hoops. [A detailed material list and installation instructions for this system (shown in Fig. 6) are provided by Dr. Kim Lewers of the USDA-ARS in Beltsville, MD on page 24.]

Fig. 6: Twine tied at each hoop with knot for later tightening visible.
Photo: K. Lewers

Fig. 7: Twine installed in a crisscross fashion between hoops in Lablachère, France.
Photo: http://vivacoop.pagesperso-orange.fr/fraises.html

Fig. 8: Rubber stopper used for attaching twine to hoops. The stopper is installed parallel to the ground and has a hole drilled through the middle. *Photo: K. Lewers*

2: Double Hoops

The double hoop system uses no twine. Instead, after plastic is installed on top of a first set of hoops, a second set of hoops is placed over the plastic (Fig. 9). Hoops are often made of PVC piping but other materials may work. It is important to ensure hoops provide enough tension on plastic to ensure tunnels sides do not fall and plastic remains ventilated. It may be possible to use a narrow piece of plastic, but challenges to this system have been reported; specifically, ensuring plastic is held in place and does not slide off tunnels, which has been cited as the primary issue.

Fig. 9: Double hoop system used for strawberry production in the Republic of Cyprus. *Photo: Poly Ag Corp.*

3: Commercial Low Tunnel Systems

The advantage to using a kit is that the system is ready to install and materials have been designed specifically for low tunnel use. Components often contain characteristics that make management easier, such as plastic covered hoops for the ends of rows (Fig. 10), "pegs" at the base of hoops for attaching the tie-down material (Fig. 11), and grounding stakes to keep hoops in the ground (Fig. 12). Currently there are only a limited number of commercial low tunnel systems available, but individual components can be purchased from several companies.

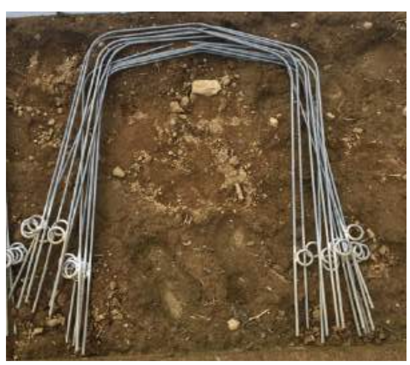

Fig. 10: Plastic covered start/end hoop (left); Fig. 11: Low tunnel hoop with peg (middle); Fig. 12: Grounding stakes for individual hoops (right). All are components of the Dubois system. *Photos: K. Orde*

III. PLASTIC SELECTION

Plastic Thickness

There are many options in low tunnel covers for strawberry production systems. For strategies for plastic management, please refer to the Plastic Management section (page 11).

Thin Plastics (1-2 mil)

Thin, lightweight plastics are pleasant to handle during installation and can be raised and lowered with ease. Such plastics are also available in a suitable width for most low tunnel systems (~8' wide), eliminating the need to cut plastic to the appropriate size prior to installation. Thin plastics can also be acquired with perforated sides to encourage airflow when sides are lowered. Depending on the hoops and how high plastic is raised on the hoops, thin plastic will often lower to the ground during rain or strong wind. While this is certainly an advantage when it comes to protecting fruit quality, labor will be required to raise sides again once the storm passes to ensure high temperatures do not negatively affect fruit set.

Disadvantages to thin plastics include a higher likelihood of developing holes or stretching. This is especially true if plastic is not installed tautly or sides are raised too high and water accumulates on the top of the tunnel. Commercial growers report replacing thin plastics annually. Partially-perforated 1.5 mil plastic has been used for two growing seasons at the University of New Hampshire, but the sides were noticeably less taut in the second year of use. Low tunnels covered by 1.5 mil film are shown in Fig. 13.

Fig. 13: Low tunnels covered with 1.5 mil plastic with perforated sides only. Perforation can be seen where the plastic meets soil. *Photo: K. Orde*

Fig. 14: Fully ventilated 6 mil plastic covered low tunnels. Sides have been rolled under and up to keep sides raised. *Photo: K. Orde*

Thick Plastics (4-6 mil)

Based on our experience, thick plastics tend to be sturdier and less likely to rip or stretch than thin plastics, and can definitely be used for multiple years. However, they also tend to be more challenging to handle and time-consuming to install, and it is often necessary to cut the plastic to the appropriate width for low tunnels (although it is possible to special order narrow rolls).

University of New Hampshire researchers found that when 6 mil plastics were used in conjunction with the Dubois low tunnel hoops and bungee elastics, sides would not remain raised by simply lifting or "scrunching" the sides up. Instead, researchers needed to roll the plastic inward and up in segments (Fig. 14). This method was very effective in ensuring good air flow and it kept plastic in place all season but made lowering plastic for each rain event too labor intensive. Therefore, if using this method, it is likely that plastic would be left ventilated and only provide overhead protection until late fall or in the event of a serious storm. Note: separate bungee elastics were attached at each hoop in this experiment. Crisscrossing the tie-down material between hoops may help alleviate this problem.

Light Modification

Transparent (or "clear") agricultural plastics transmit a high percentage of both ultra-violet (UV) and infrared (IR) solar radiation. UV light (especially UV-B) can be helpful in inhibiting some pathogens (such as powdery mildew), but for *Botrytis cinerea*, blocking UV radiation can reduce fungal sporulation. Additionally, because some insect pests cannot navigate in environments lacking UV light, reduced pest damage has been reported for UV-absent environments (Papaioannou et al., 2012). On the other end of the visible spectrum, IR wavelengths are heat generating. Closed protective structures covered by plastics that block or reduce the transmission of IR wavelengths tends to have a lower daily maximum air temperature than tunnels covered by transparent plastics that allow a high percentage of IR light transmission.

Effects of Low Tunnel & Mulch Color on Temperature

A study at the University of New Hampshire monitored air and soil temperatures under low tunnels covered with both 6 mil UV-blocking and IR-limiting, 6 mil UV and IR-transparent, and 1.5 mil transparent commercial plastics. Researchers report that during the summer months when the sides of low tunnels are raised (ventilated), air temperatures are the same under low tunnels as open beds. However, once low tunnel sides are closed in the fall, daily maximum air temperatures are increased within closed tunnels. The highest temperatures recorded were under transparent films, which were often 40°F warmer than open beds. Maximum temperatures under an IR-limiting plastic (6 mil) was cooler than transparent films (especially when covering white plastic mulch) but still warmer than open beds.

Soil temperatures under white plastic mulch were cooler than black plastic mulch during both the summer and fall months, regardless of plastic properties. The presence of low tunnels did, however, increase daily maximum soil temperatures compared with open beds. Nighttime soil temperatures in the fall were slightly increased (by 2-5°F) under 6 mil plastic and for 1.5 mil plastic covering low tunnels on black mulch (but not 1.5 mil covering white mulch).

IV. PLASTIC MANAGEMENT

If low tunnel sides are lowered for rain or wind, it is important they be raised once weather clears to ensure high temperatures do not negatively affect fruit set. Another important consideration is how water will be shed off tunnels. If plastic is raised too high on the hoops, rain water may pool and stretch plastic or compromise the tunnel structure. The following are examples of plastic management strategies used by growers and researchers throughout the region. See Ventilation (page 16) for tips on preventing water accumulation.

1: Overhead Cover

This method provides overhead protection to plants at all times. If using thick plastic, sides can remain raised during rain events, though this will only provide moderate protection to fruit (Fig. 15). If the overhead cover technique is coupled with thin plastics, sides can very easily be manually lowered for rain. In fact, thin plastics often lower on their own from the weight of the water on the tunnel, necessitating labor to re-ventilate tunnels after the storm has passed. It is important to remember that to keep rain completely off of fruit and plants, it is necessary to close the low tunnel sides. Fig. 16 illustrates how thin plastic tend to drop and thick plastics (with sides rolled up) stay ventilated during precipitation.

Fig. 15*:* Thick 6 mil plastics rolled under and up in segments. *Photo: K. Orde*

Fig. 16: A low tunnel covered with thin 1.5 mil plastic that automatically closed during a rain event (left). A tunnel covered with a thick / heavyweight 6mil plastic (right). *Photo: K. Orde*

2: One Side Lowered

Using this approach, one side of the tunnel is lowered to the ground (often, the side of prevailing wind) and the other is left raised (Fig. 17 and Fig. 18). There are several advantages to this strategy: if the location is windy, lowering the side towards the prevailing wind protects plants from wind while ensuring good air flow. Perhaps the most significant advantage is that only one side of the tunnel needs to be lowered during a significant rain event, reducing time and labor input for management.

Fig. 17 (left): Plastic lowered on one side without overhead cover. *Photo: M. Pritts*
Fig. 18 (right): Plastic lowered on one side as well as overhead cover. *Photo: M. Pritts*

3: Ridge

When using this method, plastic is lifted up to the ridge of the tunnel (Fig. 19 and Fig. 20). This approach essentially eliminates the need to actively manage plastic *except* for during periods of precipitation when both sides are lowered. This may be a good strategy for producers who do not have the ability to check on the tunnels frequently, but are willing to deploy labor to lower sides periodically. However, sides must be quickly lowered when it does rain in order to reap the benefits of the low tunnels.

Fig. 19 and Fig. 20: Ridge method of plastic management. *Photos: B. Poling (left) and K. Orde (right)*

V. TIPS FOR SUCCESS

We highly recommend constructing at least one complete tunnel before installing individual components for multiple tunnels so that modifications to spacing, anchoring, etc. can be made as problems are identified. The following are some key tips for the successful installation and management of low tunnels.

Hoops

- Hoops can be placed in the field anytime but are bothersome to navigate when planting by hand and would completely prevent mechanical transplanting. Thus, we recommend waiting to install until after planting.
- A hoop distance of 5’ is recommended by commercial manufacturers. While this may seem close and it is tempting to increase this distance, doing so makes it more challenging to keep plastic in place.
- To prevent the terminal hoop from collapsing inward, install the last hoop at each end of the tunnel at a 60° angle (facing away from the tunnel).

Anchor Object

- Anchoring plastic to sturdy anchor posts at the ends of each row is a critical step in the installation process. Commercial growers have reported collapsed tunnels from poorly installed anchors. Hollow steel pipes measuring 1¼” x 24” have worked well at the University of New Hampshire (Fig. 21). T-posts have been used successfully elsewhere, but wooden stakes should be used with caution, as our experience suggests they may rot and break by late season (Fig. 22).
- Install the anchor object deeply into the ground, as the stability is more important than the length of stake above ground.
- If plastic is being wrapped directly around the anchor object, install the anchor object at a 45° angle to prevent plastic from sliding off (Fig. 21).


Fig. 21 and Fig. 22: (Left) Hollow steel anchor pipe. (Right) A wooden tomato stake used as the anchor object. While readily available, they may break under the tension from the tunnels. *Photos: K. Orde*

Plastic Covers

- ✧ If plastic is purchased in a large roll it may need to be cut to the correct width for low tunnels. The exact measurements will depend on the low tunnels hoops being used, but 8' wide is the standard width of commercially available low tunnel plastics.
- ✧ Take caution not to damage thin plastics during the cutting or installation process. Dragging plastic over rocks, stakes, etc. can compromise the film enough that it can (and will) split once the plastic is installed over hoops and there is tension on it.
- ✧ If plastic is being attached directly to the anchor object at the ends of rows, factor in a few extra feet of plastic for each end of the tunnel.

Securing Plastic

- ✧ Once plastic has been laid over hoops, it needs to be secured to the anchor pipe. Zip ties (>12") are a quick and effective way to attach plastic around the anchoring object, and a small tensioner or ratchet at both ends of the low tunnel can be useful for removing slack lengthwise in the plastic (Fig. 23 – Fig. 25). We suggest leaving several feet of twine/cording between the tensioner/ratchet and the plastic, so that the slack can be taken in throughout the season (Fig. 25).
- ✧ Possibly the <u>most important step</u> is tight installation of the tie-down material (twine, bungee elastics, etc.) at each hoop. The tie-down material removes slack in the plastic and keeps it taut, preventing water from accumulating on top of the tunnels. Tight installation will also prevent plastic from being blown off the hoops. A good rule of thumb is that each hoop should look like a small "wave" (Fig. 26). [Note: avoid sisal which may fall apart.]

Fig. 23: Zip ties, tensioner, and parachute cord used for attaching plastic. *Photo: K. Orde*

Fig. 24: Tensioner installed on a wooden tomato stake. *Photo: K. Orde*

✧ It is helpful to have a plan for tightening the tie-down material once or twice throughout the growing season. Bungee elastics, especially, will stretch and loosen as the season progresses. Methods for tightening the tie-down material include wrapping the bungee around the rubber stopper (Fig. 8, page 8) or around the peg at the bottom of the low tunnel (if the hoop contains a peg). Slack in the line can also be pulled and a new knot tied. Parachute cord or twine can be untied, tightened, and retied.

Fig. 25: Anchor pipe attached to 1.5 mil plastic using tensioner and parachute cord. *Photo: K. Orde*

Fig. 26**:** Bungees installed to create a "wave" at each hoop. *Photo: K. Orde*

Fig. 27: Accumulated water on 1.5 mil plastic. Water accumulation can be prevented by ensuring the bungee elastics are very tight and the plastic has not been lifted too high on the tunnel hoops (where it cannot drop as water accumulates). *Photo: K. Orde*

Ventilation

- For thin plastics in their first year of use, low tunnels sides typically remain ventilated when plastic is lifted or "scrunched" up. If plastic is used for more than one year, it may become unevenly stretched and need to be lifted higher on the hoop to keep it ventilated.
- The height in which the plastic is lifted on low tunnels (especially straight-sided hoops) will affect the tunnels ability to shed water during rain events. If plastic is raised above the eave of the hoop (Fig. 28), water tends to accumulate on the top of the tunnel and can stretch plastic (Fig. 27, previous page). Alternatively, if plastic is raised to just below the eave (Fig. 28), plastic will mostly lower automatically before too much water accumulates, preventing excessive pooling which may stretch plastic.
- For thick plastics, rolling plastic under and up in 3-4" segments is a very effective strategy to keep tunnels ventilated. However, it is important to note that it is very labor intensive and time consuming to lower sides once they have been rolled.
- If tunnel sides tend to perpetually fall, this is an indication plastic is not secured tightly enough lengthwise and/or that the tie-down material is not tight enough at each hoop.
- When low tunnel sides are lowered for rain or early/late in the growing season, water does not accumulate on tunnels (Fig. 29 and Fig. 30).

Fig. 28: Plastic "scrunched" to above (left) and below (right) the eave of the hoop. *Photo: K. Orde*

Fig. 29 and Fig. 30: 1.5 mil perforated plastic lifted for harvest (left) and closed for late season production (right). *Photo: K. Orde*

Grounding Stakes

- ✧ Grounding stakes are intended to hold low tunnel hoops in place during strong wind or storms. They are easy to install (even plentiful rocks have not obstructed installation) and we have found them be very effective in keeping tunnels in place during storms.
- ✧ If using the Dubois hoops, it is advantageous to be able to slightly lift one side of the hoop throughout the season so the tie-down material can be wrapped around the peg at the base of hoops to tighten it. Since it is very difficult to lift hoops out of the ground without removing the grounding stake, we suggest installing only one stake per hoop, alternating sides so that both sides of the tunnel are secured. If using a homemade wire, PVC, or conduit hoop, rebar (bent into a hook) can be inserted into the ground as an anchor for the tie-down material.
- ✧ For easiest removal of grounding stakes, install them perpendicular (straight) into the ground, as opposed to at an angle (Fig. 31).

Fig. 31: Grounding stake installed vertically (left) and at an angle (right) onto the peg at the base of the low tunnel hoop. *Photo: K. Orde*

VI. WINTER PROTECTION

Intact low tunnels have been overwintered in Maryland and trials are underway at Cornell University in New York, but we do not currently have recommendations for overwintering intact low tunnels in northern New England. Not only is snow load likely to stress tunnel components in the Northeast, but low tunnels alone will not provide protection from cold winter temperatures. Straw or row cover need to be used during the winter to ensure there is not significant plant loss.

If low tunnels are used in a June-bearing production system, we suggest they be fully assembled prior to bloom and disassembled at the end of the fruiting period. For day-neutrals, we recommend using low tunnels to carry fruit production into the late fall months, but when it is time to protect plants for winter, there are several options for preparing low tunnels for winter.

Low Tunnel Plastic

Low tunnel plastic can be removed from tunnels or left in the field over the winter. Detaching plastic from the anchor pipes is quick and easy, and storing the film inside during the winter ensures it is clean and undamaged the following spring. We suggest cutting the zip ties that connect the ratchet/tensioner (and plastic) to the anchor object at the ends of rows, rolling the plastic up, and labeling it with the row number for fast setup the following spring.

It is also possible to slide the low tunnel plastic to one side of the hoops and leave it in the field over the winter. This has been reported to be a successful approach in some cases, but researchers at Penn State have noted that plastic becomes dirty and foggy the next spring, and may require cleaning.

Hoops, Grounding Stakes, Anchor Pipes

Regardless of the approach taken with the low tunnel plastic, leaving other tunnel components in the field over the winter makes for a quick setup in the spring (Fig. 32 – Fig. 37). There is added wear and tear associated with leaving materials outside during the winter months, but if the plan is to re-construct the low tunnels the following year, time and labor will be saved by having the hoops, ground stakes, and anchor pipes already installed and ready to attach the plastic to. Additionally, preliminary research suggests low tunnels may be useful for hastening growth and flowering in the spring (both for short-day and day-neutral plants).

Mulching Method

When hoops remain in the field during the winter, it may be easier to use straw mulch than row cover for winter protection. Row cover has been used within hoops, but this would require a narrow piece of row cover be applied over plants and secured on both sides of the bed, all within the tunnel frame.

Fig. 32: December 2017 - Strawberry plants mulched with straw. Plastic was removed but other low tunnel components remain in the field. *Photo: K. Orde*

Fig. 33: December 2017 – Hoops are visible following first snow. *Photo: K. Orde*

Fig. 34: April 3, 2018 – Day-neutral strawberry plants after straw mulch was removed the following spring. *Photo: K. Orde*

Fig. 35: April 3, 2018 - Low tunnels re-constructed over plants following the removal of mulch. *Photo: K. Orde*

Fig. May 28, 2018 – first fruit harvested from day-neutral plants in the second year of fruit production. *Photo: K. Orde*

Fig. June 1, 2018 – 'Seascape' fruit under low tunnels. *Photo: K. Orde*

VII. DAY-NEUTRAL STRAWBERRIES

For years, June-bearing (short-day) strawberry varieties have been the dominant plant-type grown in the Northeast. June-bearers initiate flowers under short-day conditions in the late fall and produce fruit for a short 4-6 week period the following year, from about mid-June to early July. While this “strawberry season” is met with enthusiasm by both consumers and producers, the short fruiting period prevents regional growers from satisfying (and profiting from) strong consumer demand for local strawberries beyond this period. Additionally, poor weather during these few weeks can cause significant damage to the marketability of the crop and be devastating for commercial growers.

In other regions of the United States and throughout the world, day-neutral varieties have been widely adopted to fill gaps in production. Unlike June-bearers, day-neutral strawberry plants have the ability to produce flowers (and fruit) continuously through spring, summer, and fall months, mostly independent of day-length. Some commercial growers reported low yields and small fruit size from several of the earliest day-neutral varieties released in the 1980’s and understandably, may feel apprehensive to try day-neutrals again. However, a new generation of cultivars has been available since the late 2000’s and several cultivars consistently produce high annual yields (>15,000 lbs/acre) and a large fruit size in colder climates, including the Upper Midwest and northeastern regions of the US.

If planted early spring (late-April) in a plasticulture system (raised beds, plastic mulch, and drip irrigation), these day-neutral varieties will begin fruiting within 10 weeks and continue producing fruit into November (Fig. 38 – Fig. 40). Fruit production lasts approximately four continuous months (July-November) in the year of planting, peaking in September in New Hampshire. Plants can then be mulched and over-wintered, and will fruit again in the spring of the second year. Following second year spring production, day-neutral plants are often discarded, but some growers do keep them in production through the summer and fall months of the second year.

Combining day-neutral cultivars with existing June-bearing production can effectively extend the strawberry production season to a minimum of six months in the Northeast. To achieve high yields and season long production, runners must be removed bi-weekly or monthly, and plants fertilized weekly through the drip irrigation system, typically at a rate of 5 lbs nitrogen per acre. Variety performance, including winter survival rates are currently being investigated at the University of New Hampshire and Cornell University. Varieties appear to differ in yield, production patterns, and winter survival. ‘Albion’ is currently recommended for its reliable moderate-high yields and excellent flavor.

Fig. 38: ‘Aromas’ fruit on October 6, 2017 in Durham, NH. *Photo. K. Orde*

Fig. 39: 'Albion' fruit on October 10, 2016 in Durham, NH. *Photo: K. Orde*

Fig. 40: 'Albion' fruit on November 20, 2016 in Durham, NH. *Photo: K. Orde*

VIII. ECONOMICS

The yield (and financial) advantage afforded by low tunnels is likely to depend on a number of factors, especially the frequency of precipitation and other storm events, location, and the health and productivity of the planting. Depending on these factors, the inclusion of low tunnels may or may not increase yields, but low tunnels consistently increase the percent marketable yield of the plants beneath them, prevent water damage on fruit, reduce disease pressure, and may decrease runner emergence. We suggest low tunnels serve as a form of crop insurance with the capacity to "save" a crop that may otherwise be lost during poor or inclement weather.

A complete low tunnel system (steel hopes, plastic, bungee elastics, grounding pipes, etc.) requires an initial investment of approximately $20,000 per acre. Hoops and grounding stakes can be re-used for many years and plastic will need to be replaced periodically. Gross revenue at the reported rate of $2.90/lb would range from $43,500/acre (based on 15,000 lbs/acre) to $58,000 (based on 20,000 lbs/acre). For direct market sales, revenue could reach $80,000 lbs/acre (based on 20,000 lbs/acre).

Low tunnels may create an even more significant financial return during years with exceptional weather events. For example, in 2013 researchers at the University of Minnesota reported substantial yield increases under low tunnels following hail (8,500 lbs per acre higher under low tunnels), which would result in $27,917 additional revenue per acre under low tunnels than open beds (based on the reported rate of $2.90/lb; USDA NASS, 2016). If yields were to double under low tunnels, as they have in Pennsylvania, the result would be an additional $9,570 in revenue per acre. Lastly, if yields did not increase under low tunnels (as has been observed in New Hampshire and Minnesota in 2016, a drought year), low tunnels are still apt to decrease unmarketable yield and may decrease runner emergence, reducing labor required for the removal of fruit and runners. Under all these circumstances, revenue potential for a plasticulture strawberry system is great enough to cover the initial purchase cost of a low tunnels system.

IX. ADDITIONAL RESOURCES

Extending Local Strawberry Production Using Day-neutral Cultivars and Low Tunnel Technology
By Marvin Pritts and Laura McDermott, Cornell Cooperative Extension
http://hort.cornell.edu/fruit/pdfs/low-tunnel-strawberries.pdf

Strawberry Production Season Extension Using Low Tunnels
By Kim Lewers, USDA-ARS Beltsville, MD
http://www.hort.cornell.edu/expo/proceedings/2013/Berries/Berries Lewers Low Tunnels.pdf

USDA-SCRI Sponsored TunnelBerries
https://www.tunnelberries.org/

Season-long Strawberry Production with Everbearers
By Willy Lantz, Harry Swartz, Kathleen Demchak and Sherry Frick
http://www.sare.org/Learning-Center/SARE-Project-Products/Northeast-SARE-Project-Products/Season-Long-Strawberry-Production-with-Everbearers-for-Northeastern-Producers

Dayneutral Strawberry Production Guide
By Marvin Pritts & Adam Dale
https://ecommons.cornell.edu/bitstream/handle/1813/3275/Dayneutral Strawberry Production Guide.pdf;jsessionid=A262BC9C332E0FD21B57FC84707FB903?sequence=2

Using Low Tunnels for Overwintering Crops: Lessons Learned
By Becky Sideman, University of New Hampshire
https://extension.unh.edu/resources/files/Resource004419_Rep6301.pdf

Hoops & Twine - **Materials and Installation Instructions**
Courtesy of Kim Lewers, USDA-ARS Beltsville, MD

Materials:

- 1/4” stainless steel wire, cut into 12’ pieces
  (in Maryland, 1/4” has withstood the weight of ice during inclement weather better than 3/16”)
- Black polyethylene plastic water pipe 1” in diameter cut to 6” long. To use as “stoppers”. Each 6” stopper needs a 7/32” hole drilled through the center of the stopper (perpendicular; see Photo 4)
- Polypropylene baling twine (avoid sisal twine, it may fall apart)
- T-post/anchor stake for tunnel ends
- Plastic for covering tunnels. Up to 12’ wide will work for hoops this size

Construction:

- A stopper is pushed onto the 12’ piece of wire, 2’ from the end of both sides. This will become the low tunnel hoop.
- Hoops are installed in the ground every 4-5’ deep enough so the stopper rests just above the ground. There is no need to pre-bend the wire.
- One piece of twine is run down the entire length of the tunnel before plastic covering is installed, winding around the ridge of each hoop. This acts as a purlin/ridgepole.
- Next, individual 20’ pieces of bailing twine are cut and attached to each low tunnel hoop. Loops of 20’ twine are hooked under one stopper, lifted over the long piece of twine acting as the purlin, and hooked under the stopper on the opposite side of the tunnel (see Photo 3). Be sure to tie twine in a way that allows for later tightening.
- Lay plastic cover on the ground the length of tunnel. Attach plastic to the T-posts at both ends.
- Next, simply unhook the twine from under the stopper on that side of the tunnel, lift over the sheet, and re-hook it to the stopper under the sheet. This step loosely attaches the plastic to the hoop, preventing it from blowing around while it is being lifted over tunnels, and essentially allows one person to setup the tunnel.
- The plastic can now be pulled up onto the tunnel, one hoop at a time.
- Once plastic is covering tunnels, twine should be tightened just to the point where there is no excess. Next, stoppers can be twisted 180° and twine looped under each side of the stopper. Repeat this step on both sides of the tunnel.
- Giving the twine a hard pull to snug up the loops, and a second knot.
- Lastly, tie each loop to its neighbor at the top of the tunnel. This step keeps the “hoop in the loop.”

X. REFERENCES

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