Cooperative Extension NRAES-88

Strawberry Production Guide

For the Northeast, Midwest, and Eastern Canada

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NRAES–88
March 1998

ISBN 0-935817-23-9

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CHAPTER 4

Production Systems

The strawberry plant is quite adaptable to a variety of growing methods. The most common method in the Northeast and Midwest, the matted row system, allows growers moderate yields of "in-season" fruit with low initial costs and moderate risk. The ribbon row system is more expensive to establish and maintain but promises higher yields of seasonal fruit than the matted row system; furthermore, it can be modified to reduce weed pressure in the planting. The annual plasticulture system produces high yields and earlier fruit and reduces harvest labor costs considerably; however, inputs are higher, and the risk of failure increases as one moves north. Dayneutral strawberries promise to extend the harvest season from five weeks to five months, but growing them is labor-intensive and off-season marketing can be challenging. Greenhouses offer growers the opportunity to produce high-quality strawberries in midwinter (figure 4-1) but require significant investments in technology and operating capital.

Which system you should choose depends on the time of year you wish to produce strawberries, the quality of

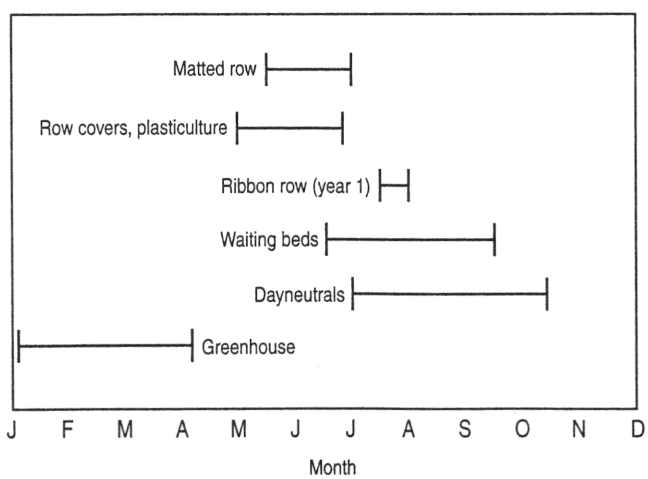

FIGURE 4-1. Production methods and seasons

the market in your area (Are consumers willing to pay top dollar for high-quality, off-season produce?), and your aversion to risk. Several options are presented in this chapter with their advantages and disadvantages. Consider each one carefully.

The Matted Row System

Synopsis

In the matted row system, strawberries are planted at wide spacings in the spring and runners fill in the gaps between plants. Fruiting occurs the year after planting, usually in June, and yields of 7,000 to 15,000 pounds per acre are typical.

This system is the most common in northern areas of the United States and Canada because it is low risk and successful. Establishment costs are low (about $3,400 per acre), because relatively few plants are needed. However, weed control is difficult, and the area between plants must be kept weed-free to allow runners to establish. Also, because rows tend to be wide and plants dense, harvesting the fruit is slow because it is less visible. Another concern with dense plantings is that disease and insect pressure can be more severe.

Details

The planting year schedule for the matted row system is summarized in table 4-1 on the following page. Before planting, soak dormant transplants (photo 4-1) in water for an hour or so. Plant the strawberries in cultivated soil, 18 to 24 inches apart within rows and 42 to 52 inches apart between rows (5,000 to 8,300 plants per acre) (figure 4-2, table 4-2, photo 4-2). A planting with many narrow rows is more productive than one with fewer wider rows.

Plant as early in the spring as the soil can be worked (April or May). If you must plant later (in June, for example), then reduce the space between plants within the row, since fewer runners will be produced. Some varieties produce more runners than others—experience will teach you how close to plant each variety in your location and soil type. Planting later than July 1 is generally not very successful, because plants do not produce as many runners, daughter plants do not produce enough leaves for flower bud production, dormant plants lose vigor after many months in storage, and the root system grows poorly when soil temperatures are too warm. There are no documented advantages to using a soluble fertilizer solution in the planting water.

TABLE 4-1. Planting year summary schedule

Activity	Approximate Timing
Plant dormant crowns	April or May
Weed control	May
Remove flowers	June or July
Fertilize	June
Position runners	July through September
Weed control	August
Fertilize	September
Weed control	November
Mulch	late November

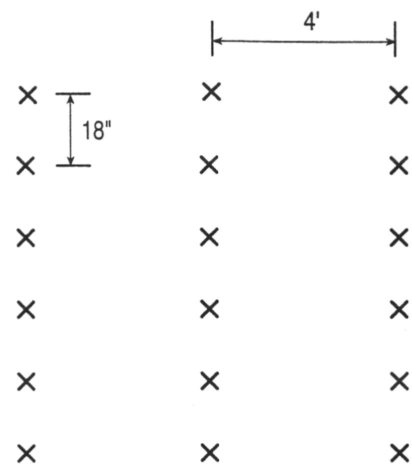

FIGURE 4-2. Spacing diagram for the matted row system

TABLE 4-2. Required plant numbers per acre for a given spacing between and within rows

Single Rows

	Spacing between Rows (feet)			
Spacing within a Row (inches)	3	3.5	4	4.5
3	58,080	49,780	43,560	38,720
6	29,040	24,890	21,780	19,360
12	14,520	12,446	10,890	9,680
18	9,680	8,300	7,260	6,454
24	7,260	6,224	5,446	4,840

Double Rows

	Spacing between Beds (feet)				
Spacing within a Single Row (inches)	4	4.5	5	5.5	6
3	87,120	77,440	69,696	63,360	58,080
6	43,560	38,720	34,848	31,816	29,040
12	21,780	19,360	17,424	15,908	14,520
18	14,520	12,908	11,616	10,606	9,680
24	10,890	9,680	8,712	7,954	7,260

Soon after planting, the crowns will produce a few leaves and flower buds will emerge. The buds were initiated during the shortened photoperiod (day length) of the previous fall, when the dormant transplants were runners.

During the planting year, remove flower trusses with scissors. Truss removal encourages runner development and adequate bed establishment and often leads to better yields the following year (photos 4-3, 4-4, and 4-5). The amount of fruit produced from first-year flowers would be of little value anyway due to the low plant density at the time. Furthermore, allowing fruit to develop and then not harvesting it would encourage disease.

Apply preemergent herbicide after the soil has settled around the roots of the plants. About four weeks after planting, fertilize the strawberries with about 30 to 40 pounds per acre actual nitrogen.

Runner plants will emerge from the crowns in the early summer. Use these to fill in the rows. To maintain easy access in the planting, limit row width to no more than 18 inches. Move runners that grow outside the 18-inch row width back into the row, or cut them off (photo 4-6).

Weed control can be especially difficult with the matted row system, since there is so much bare, cultivated soil for much of the first year. Prompt weed control is very important, because weeds will take over a strawberry bed and seriously reduce yield (photo 4-7). Frequent, regular cultivation will help control weeds and greatly increase the life of a strawberry planting. Few herbicides are available for use on strawberries. Weed pressure is greatest in June, July, and early August of the planting year; so focus control efforts then.

Irrigate plants regularly to ensure optimum growth, especially in the planting year (photo 4-8). One to 2 inches of water per week is ideal (see chapter 6 for details). By late summer, the beds should be well-filled but have no more than four to six plants per foot of row. Generally, about 30 pounds per acre nitrogen is applied in late August to early September to ensure adequate fall growth.

Plants begin to go dormant in late fall (mid to late November). To protect crowns from extreme cold and desiccation, cover them with mulch. Three to 6 inches of straw over the plants is typical (photo 4-9). One ton of straw provides about 1 inch of cover per acre. See chapter 5 for a detailed description of mulching options and temperature control during this critical period of development.

Rake off the mulch in the early spring (March or April) and place it between the rows to provide a dry medium on which the fruit can develop (photo 4-10). Flowers are susceptible to frost during the spring; they can be protected with overhead irrigation (photo 4-11) run continuously during periods of below-freezing temperatures (chapter 5). The first fruit is usually ready for harvest about three to four weeks after full bloom.

Following harvest, renovate the beds. A renovation schedule is summarized below in table 4-3. Renovation is largely a thinning process to prevent overcrowding caused by the rooting of too many runner plants. Mow leaves off the plants (photo 4-12) to help prevent disease, aid in the penetration of miticides, and allow the application of herbicides that would otherwise burn the leaves. Do not remove leaves if the root system is unhealthy, as plants will not be able to produce another set of leaves. Likewise, do not remove leaves from fields damaged by root weevils or root rot or from fields that are under water stress.

After mowing, narrow the plant row to an 8- to 10-inch width with a disk harrow or rototiller (photos 4-13 and 4-14). Plants benefit from the addition of an inch of soil over the tops of the crowns at this time, because new roots form above older roots on the crown. Removing the side guards from a tiller is one way to throw soil over the rows mechanically. However, more than 1 inch of soil covering can be detrimental.

Fertilize and irrigate the planting to stimulate the growth of new runners that will bear fruit the following season. Apply postemergent herbicides five to seven days before mowing and preemergent herbicides immediately after tilling the beds. In autumn, mulch the beds as before. Fruiting will occur again the following spring. Beds are generally carried over for three to four fruiting years.

Table 4-3. Renovation summary schedule

Activity	Timing
Weed control	Immediately after last harvest
Leaf removal (optional)	One week after last harvest
Fertilizer application	After leaf removal
Narrowing rows	Within one day of leaf removal
Weed control	Within two days of leaf removal
Leaf sampling for analysis	When newly formed leaves expand

Organic Matted Rows

Demand for organically grown produce has been increasing significantly over the past decade. Strawberries are among the top fruits and vegetables grown organically.

All organic strawberry systems have the following five common characteristics, regardless of the location or method by which the strawberries are grown:

1. several years elapse between successive crops of strawberries
2. the production cycle is short (one to two fruiting years)
3. labor requirements are high
4. yields are lower
5. there is greater variability in yields

These characteristics mean that organic production is more expensive than conventional production. But if the price of organically grown berries is higher, then organic production can be profitable.

Organic strawberry production can be as profitable as conventional production if the price differential for fruit approaches 35 to 40%. Potential organic growers can estimate production costs by using the spreadsheets discussed in chapter 14 and examining table 14-16 (see page 131).

Organic fields are usually fruited for only two years, because it is difficult to maintain sufficiently high levels of available nitrogen from organic sources over several years. To minimize the buildup of perennial weeds and allow for manure applications, other crops such as rye, corn, or sudan grass are grown in the years the field is not planted in strawberries.

Light cultivation is used often to prevent weeds from becoming firmly established. Mulch is used in the fruiting years, and hand weeding is used when necessary.

Some of the cultural practices employed to minimize disease and insect pressure include planting in narrow rows, selecting high-yielding cultivars with disease and insect resistance, and managing the surrounding vegetation to reduce pest habitat.

Labor costs tend to be higher with organic production, but overhead and chemical costs are likely to be lower. Yields also tend to be lower—average conventional yields are about 7,000; 7,000; 4,000; and 3,000 quarts per acre in consecutive years, whereas organic yields average about 5,000; 4,000; 2,000; and 1,000 quarts per acre. To maintain higher yields, most organic growers will not fruit a field beyond the second fruiting year. Organically grown strawberries can still be profitable, though, because they can command significantly higher prices than conventionally grown berries.

The Ribbon Row System

Synopsis

The ribbon row system is an attempt to increase yield by greatly increasing initial plant densities. Fruits are harvested in the planting year; in theory, this practice allows growers to realize some early return on investment. Another difference from the matted row system is that runnering is suppressed. Weed control is easier in this system, because initial plant densities are higher. However, planting costs are also significantly higher (an additional $3,000 or more per acre) than with the matted row system, runner removal is expensive, and fruit quality in the planting year may be poor.

Details

Bed preparation for this system is the same as that for matted row culture. In most cases, however, the ribbon row is planted on a raised bed with 3-foot row centers.

Set plants in late May or early June at a 3- to 6-inch plant spacing (figure 4-3) within a single row (29,000 to 58,000 plants per acre). Mulch the alley between rows

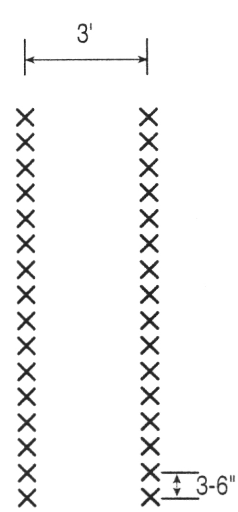

FIGURE 4-3. Spacing diagram for the ribbon row system

with straw (photo 4-15). Do not remove flowers so that runnering is suppressed. Fruit can be harvested; it can be sold at a higher price because it is produced after the normal June crop. At regular intervals, cut off any runners that are produced.

Heavily mulch the planting in late November. The plants will flower and fruit after the mulch is removed in the spring. Fruiting occurs at the normal time, but yields per acre are significantly higher than with matted rows, usually exceeding 20,000 pounds per acre (photo 4-16).

Following harvest, renovate the planting. Since raised beds require more straw for winter protection, more straw may be present in the alleyways than can be worked into the soil. Some growers remove this mulch before renovation. To renovate the beds, mow off the leaves, reshape the beds, and reapply mulch between the rows.

Since it is impossible to remove all of the runners in the second year, you can allow the ribbon rows to convert into narrow matted rows, then treat the field as a matted row planting.

There is controversy surrounding the yield superiority of these high-density systems and the benefits from first-year yields. Some argue that the cost of plants is not offset by the early yield; others contend that it is. Chapter 14 may provide some guidance in this regard.

No-Till Strawberries

You can reduce or eliminate herbicide use for the first year on lighter soils by planting a ribbon row into a mowed or killed sod. Seed rye in autumn and allow it to overwinter and flower the following spring. If the rye is cut after flowering, it will not regrow. If you desire an earlier planting, then kill the rye with a broad-spectrum postemergent herbicide. Till a narrow strip into the mowed or killed rye, and plant the ribbon row system. Lightly mulch between rows after planting. This will reduce weed pressure without a complete reliance on herbicides. This approach works best on lighter soils because it is difficult for strawberry roots to grow in uncultivated, heavy soil.

Waiting Beds

Synopsis

This system is designed to produce strawberries during the late summer without the disadvantage of the smaller fruit size that occurs with dayneutral varieties. The plants are specially treated during the first year so they grow large—they are fall-dug, then cold-stored until the following summer when they are planted into production fields. They are allowed to fruit immediately after planting, within about sixty days. This is in contrast to the matted row system, where plants are deflowered in the planting year to encourage runnering.

With waiting beds, growers can obtain fruit throughout the planting year by staggering planting dates. Waiting bed plantings revert into a matted row in subsequent years. This system works best where summer temperatures are cool (less than 80°F). Results have been variable where summer temperatures are warm (greater than 85°F).

Details

Obtain the special plants needed for waiting beds from a nursery, or produce them yourself. (Few nurseries produce waiting bed plants.) In the first year, transplant the runner plants into beds, separating them from each other by at least a foot. Remove all flowers and runners, and fertilize and irrigate the plants well to encourage growth. After flower bud initiation in autumn, dig up the plants, wash them, and cold store them at 30° to 32°F. When these large plants are transplanted the following spring and summer, they will produce fruit in about nine weeks. For fruit production in mid-July, set the first group of plants in late May at about a 12-inch spacing. By staggering the planting dates every two or three weeks, you can obtain fruit throughout the summer and early fall.

Strawberry roots prefer cool soils, so in warmer climates transplanting plants in midsummer may not be successful. Certain varieties work better than others as waiting bed plants. Studies in Canada and the United States have shown that Jewel, Allstar, and Honeoye are the best candidates for waiting beds.

Annual Plasticulture

Synopsis

For annual plasticulture, plants are set at a high density in late summer after the day length begins to decrease and little runnering occurs. Plants produce large crowns during the fall, and they fruit in the spring. Generally, plants are set into raised beds covered with black plastic and supplied with drip irrigation. Raised beds make picking much easier, and the black plastic warms the bed so that harvest begins earlier than with straw-mulched plants in flat beds. The plants are removed after the first harvest, similar to practices in California, Florida, and North Carolina.

With annual plasticulture, pest problems such as weeds and some fungal diseases are reduced because plants are replaced each year and grown on plastic mulch. The system is expensive to implement ($5,000 to $6,000 per acre), but high returns are possible because of the high density of mother plants and because of the lower labor requirements. This system is less suitable for colder northern climates, because the fall growth period is shorter and the risk of spring frosts is greater.

Details

Varieties have been developed specifically for the annual plasticulture system, but they are not resistant to the major soil pathogens, so the soil should be fumigated each year to control diseases and weeds. Either apply the fumigant to the soil before shaping the beds, or inject the fumigant through the trickle irrigation system after shaping the beds and/or covering them with plastic. Wait twenty days after fumigating to plant.

Beds should be 8 to 10 inches high and 24 inches wide on 52- to 60-inch row centers. They should be no more than 300 feet long (photo 4-17). Incorporate 60 pounds per acre nitrogen into the beds before planting to provide about half of the plant's seasonal nitrogen needs. After shaping the beds and before applying the plastic, apply a preemergent herbicide to help suppress weeds and lay a drip irrigation line on the bed. The final step in preparing the beds is applying the black plastic mulch.

Leave the area between the raised beds bare, mulch it with straw, seed it with annual ryegrass, or treat it with an herbicide. Do not spray preemergent herbicides over the plastic, as they can run off and concentrate in the planting hole.

Set two rows of plants spaced 12 inches by 9 inches or 12 inches by 12 inches on each bed (photo 4-18). Plants are usually set in a staggered pattern with the adjacent row (figure 4-4). It may be necessary to modify a mechanical water-wheel-type transplanter to arrive at this configuration. This system requires between 15,000 and 17,500 plants per acre.

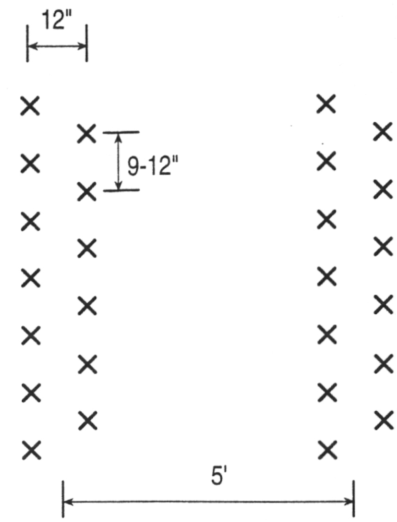

FIGURE 4-4. Spacing diagram for the annual plasticulture system

So far, the most successful variety used for annual plasticulture in the Carolinas is Chandler from California. Chandler is highly productive and large-fruited with good flavor. Sweet Charlie from Florida or newer selections such as Camarosa are being evaluated for plasticulture. In colder regions (New Jersey, Maryland, and Delaware), some of the standard matted row varieties perform as well as, if not better than, Chandler; these include Allstar, Honeoye, Jewel, Kent, Latestar, Northeaster, and Seneca.

Three types of plants are used for the annual system: dormant crowns, fresh-dug plants, or plugs, which are the preferred type (figure 4-5). Set dormant crowns in

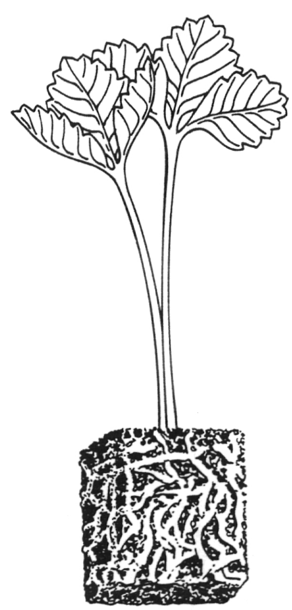

FIGURE 4-5. Plug plant

early July into a black plastic mulch that has been oversprayed with dilute white latex paint (1:8). The paint temporarily cools the surface of the mulch. Remove any flower clusters.

Fresh-dug Chandler plants are available from northern nurseries for planting in early August (in northern New Jersey and Pennsylvania), late August (in southern New Jersey and Maryland), or early September (in Virginia). Fresh-dug transplants require a significant amount of overhead and drip irrigation to get established on the very warm black plastic. You may need to water continuously for one to two weeks, and this can lead to waterlogged row middles and high water bills. For these reasons, interest in using rooted runner tips, or plugs, is growing.

Purchase plug plants directly from nurseries (although varieties are limited), or produce them on the farm. Collect runner tips in the field in July and hold them at 32°F under high humidity in plastic bags. Tips should have one or two leaves with roots less than ⅜ inch long. Place the tips into plug trays filled with potting soil in a shaded greenhouse, and keep them under intermittent mist for about seven to twelve days until rooting occurs.

For the next two weeks, water the plants regularly, then move them outside into full sun. At this point, you should be able to lift the entire plug out of the tray without the soil falling off the roots. Five weeks after planting the tips into flats, they are ready to be transplanted into the production beds. Irrigate them frequently for a few days after transplanting to ensure their survival.

The type of plant, variety, and planting date interact to influence yield; therefore, it is difficult to provide precise recommendations. Generally, plug plants can be set later than fresh-dug plants; and the colder the climate, the earlier plants need to be set. For example, Chandler is planted in Florida in mid-October; in North Carolina, early October; in Virginia, September; and in New Jersey, late August. In more northern locations, plug plants may not be available early enough for planting, and the high temperatures in July and early August make it difficult to establish either plant type. For best results, use this production method only where the growing season consists of 190 or more frost-free days.

Pay close attention to irrigation. Beds should stay moist but not wet. A small amount of nitrogen can be provided through the drip irrigation system at weekly intervals, but the amount required varies with location. In general, 30 pounds per acre nitrogen is applied in the fall. The objective is to produce a large, multi-crowned plant without runners before winter.

Plants on raised beds are more prone to cold-temperature injury than those on flat beds. A long, cool, sunny fall will encourage flower bud initiation. Row covers (photo 4-19) can be used to extend the fall growth period and to provide winter and frost protection. Row covers are essential in states north of the Carolinas. Apply them in early October, and remove them at flowering the next spring to allow for pollination.

By spring, flowers have been initiated. They will develop over the next several months. Soluble calcium nitrate has proven to be a good nitrogen source during this period. Apply it weekly at 3½ pounds per acre nitrogen for a total of eight weeks. Bear in mind that excessive nitrogen reduces the flavor of Chandler and produces tall, lush plants that are more prone to disease.

Using row covers, black plastic, and raised beds accelerates flowering by up to three weeks. Be prepared for frost protection with overhead irrigation (see chapters 5 and 6). Preventing frost injury is perhaps the most significant challenge with the annual plasticulture system. Also, because plants green up very early in the spring, growers have reported a considerable amount of deer damage then as well as in late fall. To keep row middles clean for harvest, manage the alleyways with cultivation, heavy mulching with straw, or a contact herbicide.

With plasticulture, the weather is generally cool during ripening, so flowering occurs over an extended period. Bees may be necessary to facilitate pollination (see chapter 8). Berries may require harvesting only twice per week in the cooler weather. Harvest efficiency is much improved with the raised bed plasticulture system, because fruits are large, exposed, and off the ground. This is the major advantage of the plasticulture system.

In most cases, growers remove the plants after harvest and transplant warm-season vegetables into the planting holes to reuse the plastic mulch. Some growers hold the strawberry crop over for a second year. If you choose to hold the crop over, reduce vegetative growth as much as possible, because the plants will already have sufficient branch crowns. Mowing leaves and reducing water and nutrients will slow vegetative growth and help maintain berry size until the following year.

Dayneutral Strawberries

Synopsis

Dayneutral strawberries offer growers the opportunity to produce fruit during late summer and fall of the planting year. Extending the strawberry season from five weeks to five months, dayneutrals provide new marketing possibilities, especially for supermarkets and roadside stands.

Dayneutral strawberry production is much more resource-intensive than standard June-bearing strawberry production, and it may not be compatible with diversified farm operations because of the attention the strawberries demand throughout the season. However, the price for off-season fruit can be twice that of in-season fruit, and the quality of available varieties is high. Fruit size is small, so harvesting is labor-intensive. A major challenge is controlling tarnished plant bug during summer.

First-year yields of dayneutrals can be as high as second-year yields from standard June-bearing strawberries. Yields between 12,000 and 20,000 pounds per acre are common. Unfortunately, because of the small fruit size, some of the crop may not be marketable. Dayneutrals are sold in pint containers—in quart containers, they appear small.

The cost of producing dayneutrals is approximately $1 per pint, or about $18,000 per acre—two-thirds of which is for labor. It may take as many as ten people to harvest an acre of dayneutrals during late August and early September.

Details

Dayneutrals produce fruit in the planting year, beginning as soon as ten weeks after planting. First-year production peaks in late August and early September, but plants continue to bear fruit until frost.

Many growers remove the planting after frost, essentially treating the strawberries as annuals. Others retain their plants for a second year. The production cycle is different in the second year, with a large June crop and a smaller August crop (figure 4-6). Economic analyses show that both annual and perennial systems are economically viable and provide equivalent returns. (For more information, see the *Dayneutral Strawberry Production Guide;* for ordering information, see page 161.) With the perennial system, the savings in plant costs are balanced by lower prices in June and additional overwintering costs.

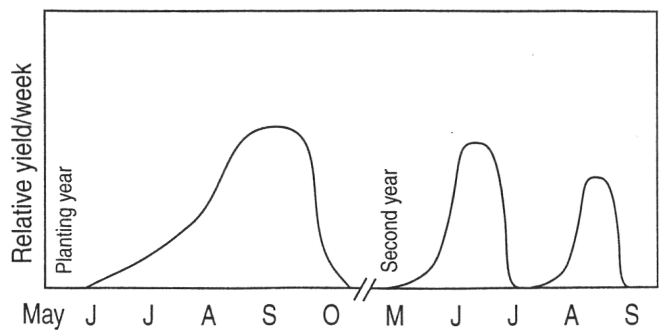

FIGURE 4-6. Production cycle of dayneutral strawberries

Tribute and Tristar are currently the best dayneutral varieties for the Northeast, although all of the California varieties will grow in the annual system. The California varieties tend to have better size, while the eastern varieties tend to have better flavor and color and are resistant to soil diseases. Tristar has a better shape and flavor than its sibling, Tribute; but Tribute seems to be more productive under most conditions. Both are susceptible to late summer foliar diseases such as mildew and leaf spot.

Site preparation is essentially the same as for standard strawberries; refer to chapter 2 for details. If possible, band slow-release fertilizer in the bed just below the root zone of transplants. The amount and composition of the fertilizer depend on soil test results but should include about 30 pounds per acre nitrogen.

A plasticulture system is best for dayneutral production. Set dormant plants on raised beds covered with black plastic that overlays trickle irrigation (photo 4-20). Use white plastic where summer temperatures are warm (photo 4-21). Beds should be at least 8 inches high and 12 inches wide, with at least 3 feet between beds.

Some growers apply an herbicide to the tops of the beds before planting to prevent weeds from growing through the planting hole. Straw mulch applied over the alleyways will help prevent weed seed germination and provide a pleasant surface for walking and kneeling. Flatbed production is possible if weeds are controlled by mulching the entire field with straw immediately after planting (photo 4-22).

Dayneutral strawberries produce fewer runners than standard varieties, especially when fruiting (photo 4-23), so planting density must be high. Highest yields occur when plants are set in staggered double rows, with row centers about 9 inches apart and plants about 9 inches apart within rows (figure 4-7). It may be impossible to plant at this spacing using a mechanical transplanter without filling in by hand. Plant no later than mid-May. If you can plant earlier, then increase the spacing between plants.

Remove flowers for two to six weeks after planting, depending on plant vigor. Plants that are allowed to produce fruit immediately after planting may become stunted. Allow flowers to remain on the plants as soon the plants seem well established. Remove runners regularly, since the optimal plant density has already been established and runners cannot root through the mulch.

Dayneutrals have very shallow root systems, so they must be given what might seem like excessive water and nutrients. Irrometers are good indicators of soil moisture status. Deliver nutrients to the plants through the trickle irrigation system. Provide 7 pounds per acre nitrogen at weekly intervals during the growing season. Dayneutrals have a high demand for potassium, calcium, and boron. Provide supplemental boron and calcium in foliar applications.

Dayneutrals fruit during the hottest time of the year, so many growers use overhead irrigation to cool the plants in the early afternoon when temperatures exceed 85°F. Keeping the irrigation time short (for example, irrigating for fifteen minutes out of each hour) will allow water to evaporate before a disease infection period can occur.

Pests

The biggest challenge for dayneutral strawberry growers is controlling the tarnished plant bug (TPB) (see chapter 8 and photos 8-1 through 8-3). TPB populations increase during the summer and are at high levels when dayneutrals flower and fruit. Strawberry flowers are a preferred food for the TPB, so damage can be very high, sometimes approaching 100%. Control is difficult because few options are effective, other than repeatedly applying insecticide. Since plants are continuously flowering, select insecticides carefully and apply them at a time when bees will not be affected. Late-evening applications of short-residual materials are the best choice. As many as two applications per week may be required in midsummer. Days-to-harvest restrictions can present scheduling problems for pickers, so you may want to divide the field into sections and treat the sections at different times. This way, at least a portion of the planting will be available for harvest at any one time.

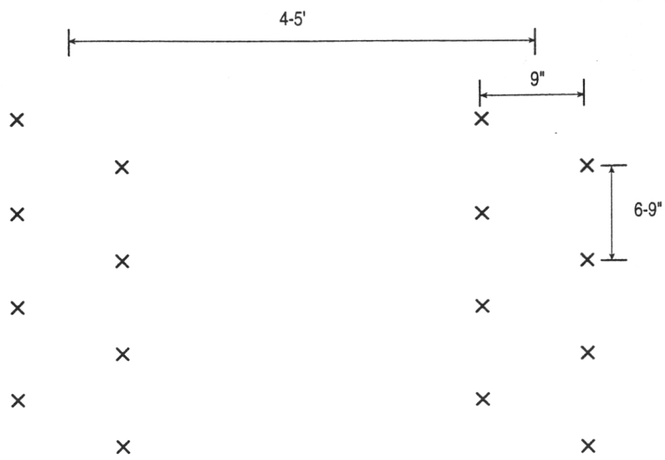

FIGURE 4-7. Spacing diagram for dayneutrals

Planting on raised beds creates a more favorable microclimate for flower drying, so gray mold incidence is less of a problem on raised beds than it is on flat beds or in matted row plantings. However, the continuous presence of fruit provides high levels of inoculum should a period of rainy weather occur and the disease becomes established. Sanitation is the most important cultural practice for controlling gray mold in dayneutrals. Do not allow pickers to handle moldy berries. Moldy berries should be picked separately by a designated worker.

Anthracnose causes a large, black, circular spot on the berry, rendering it unmarketable. This pathogen is usually not a problem for standard varieties in the Northeast, because it requires warm temperatures to grow. However, plasticulture provides an ideal environment for its growth and spread. Spores spread via scattering raindrops, which are more likely to occur on the plastic beds. Fungicides specific for gray mold are not effective against anthracnose fruit rot. Obtaining clean nursery stock is the best way to prevent this disease.

Leaf spot and powdery mildew can infect plantings in late summer, just when dayneutral production is at its peak. Because of days-to-harvest restrictions on fungicides, little can be done to prevent these diseases, except to maintain an environment in which leaves dry quickly.

Weeds are a major problem for dayneutral strawberry growers. Because plants are continuously flowering and since herbicides have long days-to-harvest restrictions, non-chemical methods of weed management are the only option. Mulching is crucial, as is prompt removal of problem weeds. Eliminate perennial weeds before planting; many can penetrate plastic mulch.

Harvest

Dayneutrals develop their most intense flavor after they turn completely red. Avoid harvesting them too early. Two harvests per week may be necessary during the summer; but in late summer and early fall, once a week may be sufficient. Since dayneutrals are not likely to be sold in a pick-your-own scenario, use good postharvest handling practices (see chapter 12).

Overwintering and Second-Year Production

Most growers treat dayneutrals as annuals and remove the planting after harvest. Overwinter dayneutrals only if you have a need for more strawberries in June. Dayneutrals produce a large crop of medium-sized berries simultaneously with the regular June crop. Prices will be lower then than in the summer and fall, and the smaller berries may be more difficult to sell.

Do not renovate second-year fruiting beds. Unlike standard strawberries, dayneutrals do not respond well to renovation practices like mowing leaves after harvest.

Dayneutrals planted on raised beds should be mulched with straw in late November more heavily than those on flat beds. Plants on raised beds are more susceptible to winter injury.

The June crop of the second year can be as large as the previous year's crop. The second summer crop will be somewhat smaller. In climates with long growing seasons, a small crop can be harvested in the fall.

Dayneutrals tend to produce many crowns; so by the end of the second year, each plant can have five to ten crowns. Fruit from multi-crowned plants is usually smaller than that from plants with fewer crowns. The accumulation of weeds and pests is large enough by the end of the second year that it is not economical to carry plants over for a third year.

Special Problems

Dayneutrals may revert to a standard habit (vigorous plants that runner prolifically and produce no flowers) if temperatures are too high for too long. Evaporative cooling and planting through white plastic can help prevent this occurrence. However, in cooler climates, white plastic may be too cool for good growth in spring. For unknown reasons, some plants seem to revert to a standard habit without experiencing heat stress. This may be a consequence of the propagation process.

Late in the season, berries may become excessively firm or crack. No one knows what causes this physiological condition, but it may be related to water regulation.

Plastic Tunnels and Greenhouses

Synopsis

Growers in temperate climates are limited by their inability to produce fruits and vegetables on a year-round basis. Not only is their growing season short, but day lengths during their growing season are long, and many crop plants initiate flowers and fruit only when day lengths are short and temperatures are cool. This puts growers in temperate climates at a competitive disadvantage with growers from other areas who can supply the fresh market more consistently.

Strawberries can be grown in controlled, high-technology environments for off-season production. Controlled environment systems range from vertical outdoor systems (photo 4-24) to plastic tunnels over raised beds in the field (photo 4-25) to peat bag or pot culture in greenhouses (photo 4-26). The objective is to produce a very high-quality fruit for a niche market. Strawberries are expensive to produce by these means, and growers who use high-tech systems cannot compete with growers in Florida or California on the basis of price. Rather, the high quality of the product is the selling point.

Controlled environments offer growers the opportunity to produce strawberries throughout the year, because temperature and day length can be regulated. The relatively stable environment of a greenhouse is also conducive to biological pest control, which reduces the need for large amounts of pesticide. Furthermore, nutrients and water can be recirculated in a closed system, so little waste is introduced into the environment.

Strawberries have been grown in greenhouses for many years, especially in northern Europe and Japan. High tunnels have been used in Italy and Spain to extend the growing season. A Cornell University extension bulletin written by Liberty Hyde Bailey in 1897 discusses forcing strawberries in greenhouses. Bailey states that "the attempt was so successful that the methods which were employed in raising the crop are here detailed." In his research, Bailey rooted strawberries in pots outdoors. The potted plants were kept in a cold frame, then moved into a heated greenhouse in intervals beginning in late December. Flowers were pollinated by hand, and the first crop was harvested from May 6 through May 16. Each plant produced an average of six large berries, or 1 quart per 3 square feet of bench space. Interestingly, the price these berries sold for in 1897, $2 per quart, is approximately the same as the seasonal price today.

Details

Many options are available to growers interested in winter fruit production.

Plastic Tunnels

Placing temporary plastic tunnels over production fields can accelerate harvest by one month in northern climates. This works particularly well with the varieties Chandler and Sweet Charlie in the plasticulture system. Follow the steps for the plasticulture system, except in early October, place clear plastic on hoops over the beds to create a plastic tunnel. If excessive heat builds up inside the tunnels, roll up the sides. When temperatures are very low, install row covers over the plants under the tunnels. In some cases, bees are needed to facilitate pollination in spring, since flowering occurs up to one month earlier than normal. These systems have been tried in New England with some success.

Day Length–Sensitive (June-Bearing) Varieties in Greenhouses

Waiting-bed plants or plugs (described in an earlier section) can be cold-stored at 28°F for up to eight months and then transplanted into a greenhouse. Transplanting begins in late December. By staggering planting dates, a long harvest season can be realized.

Set dormant crowns into 6-inch pots in May or June, and allow them to grow outdoors until early November. Remove runners and flowers at regular intervals. Then store the plants in a cold room at about 28° to 30°F for another month. Ten weeks before fruit is desired, move them into the greenhouse. Plug plants can be used in a similar manner.

A major advantage of using day length–sensitive varieties is that pest pressure is low because plants are cycled through the greenhouse every twelve to fourteen weeks. Yields of 12 ounces per square foot during a three-week fruiting period are reasonable.

Day Length–Insensitive (Dayneutral) Varieties in Greenhouses

Dayneutral culture is an alternative to the waiting-bed system that does not require a special nursery for transplants. Obtain dormant dayneutral runner plants from commercial nurseries in late autumn and plant them directly into the greenhouse. Because dayneutral strawberry plants are unresponsive to day length, they will continuously flower and fruit even under long photoperiods (photo 4-27). The fruiting season for individual plants can be several months long as opposed to several weeks.

Dayneutral strawberries also provide an opportunity to use electrical power during off-peak hours. Using supplemental lighting in the greenhouse at night will allow the plants to grow rapidly. The extended photoperiod will not inhibit flower bud initiation if the temperature remains below 85°F.

Dayneutral strawberry plants should be planted into soilless media and deflowered for two weeks to allow for good establishment. Derunner the plants periodically, although runnering lessens when plants begin to bear fruit. Water the plants between one and three times a day, as needed. Mature plants use between 2 and 4 quarts of water per month, depending on the season. Plants grow better when irrigation water is warm (75°F).

Tristar produces high yields of very flavorful fruit, ranging from 7 to 10 ounces per square foot per month, with an average of 0.3 ounce per berry. Other dayneutral varieties, especially Irvine from California, have performed well in trials in Quebec.

Greenhouse Management

Light quantity and quality, temperature, nutrition, pests, and pollination must all be controlled in a greenhouse environment. Refer to *Greenhouse Engineering*, NRAES–33, for detailed information on greenhouse basics (see page 160 for a description of the book and page 158 for ordering information).

Lighting/Heating

Because the weather is cloudy for much of the winter in the Northeast and eastern Canada, supplemental lighting is necessary. Provide about 150 $\mu mol/m^2s$ of PAR (photosynthetically active radiation). Lower lighting costs significantly by providing supplemental light only at night, when off-peak electricity can be used.

Strawberries thrive at lower temperatures than most plants. Heating the greenhouse should be necessary only at night. The heat from the lamps is usually enough to provide high enough temperatures. Use a 75°F/55°F day/night temperature cycle.

Vertical Hydroponic Systems

Some growers have shown interest in vertical systems for strawberry production. This system is productive on an area basis because of the large number of plants that the system can accommodate. Also, harvesting can be done from a standing position, and fruit is clean because it never contacts soil.

Care must be taken to ensure that waterborne pathogens do not occur, because water is recirculated throughout the entire system. Similarly, nutrient levels in the water must be monitored closely because they will tend to concentrate as water evaporates.

Vertical systems have been used outdoors in the Northeast (photo 4-24). In the greenhouse in winter months, light levels are generally too low in the Northeast to make vertical systems feasible, even with supplemental lighting.

Fertilization/Irrigation/Growing Media

The composition of the soil mix depends on the type of irrigation system in use. Most mixes are a combination of peat, perlite, and vermiculite. Increase the percentage of perlite to facilitate drainage. Adjust the growing media to pH 6.5 with lime, and add a slow-release fertilizer and micronutrients. An alternative to using soil mixes is to purchase peat bags and plant directly into them. Peat bags (photo 4-28) are popular in Europe. Pure hydroponic systems are rare.

Fertigation, or applying fertilizer through the irrigation system, is a practical way to deliver nitrogen and other major nutrients to greenhouse-grown strawberries. Two stock solutions should be kept for this purpose. Stock #1 is prepared by dissolving 615 grams of calcium nitrate and 130 grams of ammonium nitrate in 10 gallons of water. Stock #2 is prepared by dissolving 1,230 grams of a soluble, commercial 5-11-26 fertilizer in 10 gallons of water. The fertilizer delivery system should include a proportioner that adds both stock solutions in equal proportions, diluting each to a ratio of one part fertilizer to fifty parts water before delivering it to the plants. Using this ratio, the proportioner will deliver a solution of 100 parts per million (ppm) nitrogen to the plants.

A conductivity bridge can be used to determine the electrical conductivity (EC) of the fertilizer solution at 100 ppm nitrogen; this EC reading can then be used as a standard for maintaining the fertilizer concentration of the irrigation water.

If you do not have a proportioner and elect to mix the fertilizer solution directly, you can make a 100 ppm nitrogen solution by mixing 2.46 grams per gallon 5-11-26 fertilizer, 0.26 grams per gallon ammonium nitrate, and 1.23 grams per gallon calcium nitrate. This solution provides 88 ppm nitrogen as NO_3–N and 12 ppm nitrogen as NH_4–N. In either case, the solution should be kept at pH 6.5. Add phosphoric acid if the solution is too alkaline or potassium hydroxide if it is too acidic.

Maintain the application rate at 100 ppm nitrogen while plants are vegetative; once flowering begins, reduce the overall rate to 50 ppm (change the proportioner to 1:100). When iron deficiency is indicated by leaf analysis, alleviate it by applying an iron chelate fertilizer through the irrigation system; do this independent of the standard solution to prevent precipitation. Use leaf analyses to monitor nutrient levels.

Pollination

Some type of assistance is required to move pollen from the anthers to the stigma on the strawberry flower. Commercially available hives of bumble bees (photo 4-29) provide remarkable pollination for strawberry plants. They are recommended over honey bees or hand pollination in the greenhouse.

Pest Management

One advantage of greenhouse production is that there are no weeds. However, the controlled climate is ideal for arthropods and fungal pests. The following pests can be encountered when growing strawberries in greenhouses: shore flies, fungus gnats, whiteflies, two-spotted spider mites, aphids, thrips, powdery mildew, and gray mold. If you use bees in the greenhouse, then pesticide use is not a good idea. Use the following strategies to manage pests.

Prevent gray mold by harvesting the berries frequently. Burning sulfur in the greenhouse at night or using foliar bicarbonate sprays will suppress powdery mildew. Separate soil from the flowers and fruit at planting with paper or plastic barriers or collars; this will prevent insect larvae in the soil mix from burrowing into the ripening fruit and will reduce the incidence of gray mold on the fruit. Once plants are established, use blue and yellow sticky cards over the plants to monitor insect movement. Release *Geolaelaps, Orius,* or *Amblyseius cucumeris* at the first sign of thrips; use lacewing larvae and *Aphidoletes* midge for aphids; and release *Phytoseiulus persimilis* for mites.

For biological control agents to work effectively, the target pest must be present and greenhouse conditions must be favorable. It is important to release agents at the first sign of a pest, before an outbreak occurs. Scouting for pests is important, because populations can increase rapidly under the favorable greenhouse conditions.

Root diseases can become a serious problem with a recirculating irrigation system. Ensure that plant material is disease-free prior to planting. Ultraviolet sterilizers are available to disinfect recirculating water upon its return to the reservoir.

Economics

Producing off-season strawberries is expensive—the break-even price may be as high as $3.00 per pint. However, a small but significant number of consumers are willing to pay top dollar for a fresh berry picked at the peak of ripeness and delivered to the store within a few hours.

FROST PROTECTION FOR SMALL FRUIT CROPS

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Historically, the first recorded efforts at frost protection were by ancient grape growers who burned their pruning waste to prevent freeze damage to their grape vines. Early man eventually found that one of his best methods of frost protection was good site location. If at all possible, this is the first and most important step for frost or freeze protection of a small fruit crop.

The site selected should slope to provide for good air drainage away from the site (i.e., to lower elevations). Most spring freezes are radiant freezes which occur on clear cloudless nights when there is little or no wind. After sunset, heat is lost from the soil and plants and radiates back to the sky. The air is chilled and the cold air, being heavier than the warm air, flows down and pools or collects in the lower area (frost pockets). Often the temperature will be 4 to 5°F lower in these frosty areas compared to that on higher surrounding areas. Note, too, that areas surrounded by a continuous timberline of higher trees can also form a frost pocket, even though the site is elevated or has a slight slope because the "high walls" of the tree line prevent the free flow of cold air off the site.

Critical temperatures

There is no one temperature at which frost damage occurs uniformly. With most small fruit plants, damage due to freezes and frost increases after bud break in the spring until flowering or fruit set. The damage thresholds also vary with the type of crop.

Strawberries. Table 1 shows the critical temperatures associated with frost and freeze damage. The duration of temperature for damage can be 20 minutes to 2 hours depending on wind, humidity, and cultivar.

Table 1. Critical air temperatures for damage to strawberry buds, flowers and fruit.

Buds Emerge	Buds Closed	Flowers Open	Small Green Fruit
10°F	22-27°F	30°F	28°F

Source: Funt, R., et al. (1985)

Grapes. Table 2 shows that at different stages of plant development, a difference of only 2^{o}F in the ambient air temperature can be enough to kill half the buds and shoots.

Table 2. Critical air temperatures for damage to grape buds and shoots.

Damage Level	Dormant buds enlarged	Dormant buds swollen	Shoot burst	First leaf	Second leaf
50% killed	6.8^{o}F	25.9^{o}F	28.0^{o}F	28.4^{o}F	28.9^{o}F
None killed	--	--	30.2^{o}F	30.2^{o}F	30.2^{o}F

Source: Wolf, Poling (1995) Mid-Atlantic Wine Grower's Guide

Brambles. Red, purple and black raspberries can tolerate low winter temperatures to about-20^{o}F, -10^{o}F and -5^{o}F, respectively, while black berries can tolerate only about 0^{o} F. These temperatures are estimates only and assume that the plants are fully dormant at the time of exposure. Low temperatures can occur when the bramble plant is no longer fully dormant. Red raspberries can break dormancy after 800 to 1,600 hours of temperatures below 40^{o}F, which may occur well before our usual winter season is over in Maryland. Blackberries can break dormancy after only 300-600 hours of temperatures below 40^{o}F which explains why cold injury to these plants is much more common in this area. Some cold damage in blackberries may not be apparent until after fruit set when a damaged vascular tissues cannot deliver the water required and plants appear to wilt and die quickly.

Whenever temperatures warm after the cold temperature requirement has been met, the plant begins to lose its dormancy and, thus, its tolerance to cold temperatures. Winter injury is frequently the result of fluctuating winter temperatures, rather than absolute low temperatures. This fluctuation occurs more toward the later winter to early spring time when solar radiation on clear days can raise the internal temperatures of the canes several degrees higher than ambient air temperatures. when the sunset and air temperatures become colder still, the "overheated" canes can be severely stressed by the rapid *change* in temperature, not necessarily a very low temperature. For this reason, summer-fruiting cultivars should be planted on north -facing slopes, if possible, to minimize exposure to the heating effect of direct winter sunlight. South and southwest-facing slopes are the worst locations.

Blueberries. When blueberries are in full bloom, the flowers can be injured by temperatures slightly below freezing (30^{o}F). The exact temperature that damages flowers depends on the rate of temperature change, wind speed, humidity, sugar content of nectar, flower orientation, etc. Under certain conditions, open blueberry flowers can tolerate temperatures as low as 23^{o}F. The earliest-flowering varieties are most susceptible to frost injury, so avoid planting these on frost prone sites.

Types of freezes

Radiative freezes are the most common that we can experience in the spring. They occur on calm, clear nights, when we have no cloud cover. Heat is lost or radiated from the earth's surface to the sky above out to outer space. They usually occur a day or two after the passage of a cold front.

Advective freezes are represented by the classic "Alberta clipper", a cold front with lots of cold air and wind. They have also been called windborne freezes. This type of freeze is the hardest to protect against. It is characterized by cold, dry winds and, in many cases, the dew point is below freezing. They are large cold air masses with strong winds. Many times the best strategy is to do nothing when we are confronted by a severe advective freeze situation.

Environmental factors affecting frost protection efforts

Air temperature information to be used for initiating or stopping frost control practices should be determined at the crop level on the site to be protected. A temperature report from an instrument at eye level one quarter mile or more from the site is not comparable to measurements made within a few inches of the ground in the strawberry foliar canopy.

Wind speeds of more than a few miles per hour can make frost protection harder, especially if it is an advective or frontal type freeze.

Dew point is the temperature at which water in the air (humidity) condenses to form dew. When the air temperature falls below freezing, frost forms instead of dew and the potential for damage increases.

Soil moisture is an important component of frost protection since a moist soil well retain the heat of the day better than a dry soil. It will radiate this captured heat back to the environment over a longer period of time as it has more heat to radiate back than dry soil.

Ground cover. A bare, undisturbed moist soil with no ground cover can give you 2 to 3^{0} F of increased temperature versus a sod or grass covered soil.

Surrounding terrain and air drainage. Cold air will collect and drain to the lowest spot to which it can travel unimpeded. Obstructions at the bottom of a slope such as a timberline can cause the cold air flowing down the slope to "dam up", producing a frost pocket along the wooded border.

Air temperature inversions occur when cold air is trapped near the soil surface and the crop below warmer air above.

Environmental modifications for frost control

The best site location for frost protection and environmental modification is a site downwind or closely surrounded by a large body of water. In Maryland, sites that are within a few miles east of the Chesapeake Bay or necks that jut out into the Bay have a natural environmental modifier. In the fall and early winter, the water stays warmer than the surrounding land, making the winters less severe. In the late winter and the early spring, the water is colder than the surrounding land which delays early bud development on sensitive crops so that the incidence of damaging frosts is reduced. Bloom is not as early as it is further inland and the temperature variation between the daily minimum and maximum temperatures is not as great. A site with some elevation will help too, as cold air drains away to the lowest point if unimpeded.

Selection of the correct elevation is important, especially in the more mountainous areas of western Maryland. The crop should be planted above the spring freeze line and below the winter freeze line. Below the spring line, cold settling air may kill open blooms. Above the winter freeze line, low winter temperatures can injure or kill trees. Southern slopes are generally warmer than those facing north.

Methods for frost protection

Heating or burning may require burning permits issued by local jurisdiction. It is the oldest method for frost protection, but is not practical for very low growing small fruit crops like strawberries. In general lots of small fires are better than one large one and it will take twice as many heaters or small fires on border rows as for interior rows.

Wind machines are useful when a temperature inversion occurs in that the air mixing they cause pulls down the warm air from above to replace the colder air trapped near the soil surface. They only work if a temperature inversion occurs and there is no wind as with radiant type freezes.

Two systems have the most potential for frost and freeze protection in strawberries: row covers and sprinkler irrigation. Frost protection has become more critical with the advent of annual "plasticulture" for strawberry production in Maryland. The rise of black polyethylene covered beds and floating row covers for winter protections leads to spring blooms coming as much as two or three weeks earlier than the normal June matted row production. This is not to say that frost protection isn't needed for June matted row production, but only to emphasize that active efforts at frost protection are a must for strawberries grown using plasticulture to obtain good yields for an earlier, and more profitable, spring fruit market.

Row covers. Floating row covers of 0.6 oz or heavier rating can give 2 or 3°F protection in a frost situation. Heavier covers such as 1/8-inch nursery foam can provide more protection, but are not readily available or economical for strawberries in most situations. At the Wye Research and Education Center, we have been able to get as much as 11^{0}F protection using nursery foam covers in the fall of the year for day neutral varieties and use it exclusively as our frost protection option.

Sprinkler irrigation for frost protection has been used successfully from Canada to Florida. It works best on low growing crops. This option needs to be approached carefully, however, because it is a two edged sword. Used properly, irrigation can save a crop, but when it is not used properly the crop injury level can be more than if it were not used at all. The real danger here is when conditions such as those associated with advective freezes develop and evaporative cooling occurs at crop level.

Why does sprinkler irrigation work for frost protection? When water changes from a liquid to a solid (i.e., a freeze), it gives off heat at the rate of 144/BTU per pound. The flip side is that when ice melts to form a liquid, it takes up heat. For this reason, ***once irrigation is started for frost protection, do not stop it until all the ice is gone or damage from evaporative cooling can occur.*** Enough water must be applied uniformly over the entire area to be protected so that the heat of fusion overcomes or offsets evaporative as well as radiative and convective heat losses to maintain the temperature near 32^{0}F, the melting point of ice (or freezing point of water). Plant tissue will not be damaged at 32^{0}F because of dissolved substances in the cell walls reduce the tissue freezing point to slightly below 32^{0}F. As long as a film of water is over the ice which encases the stem and flowers, we can protect against frost damage. Evaporative cooling and environmental conditions such as high wind and low dew point decrease the effort of irrigation for frost protection and may cause more damage than might have occurred by doing nothing.

Frost protection using irrigation works only if the system is already set up and fully functional prior to the event. It should be tested to insure it works and that you have an adequate supply of water. One acre-inch of water equals 27,154 gallons. To protect a 10 acre block with solid set sprinklers using 0.2 inches per hour, then 54,308 gallons of water are needed for each hour of operation or 270,000 gallons over a five hour protection period. The system not only needs to be started *before* the critical temperatures for frost damage are reached, but *before* ice freezing in the pump or lines can be a problem. Do not shut off the system if there is any chance water will freeze in the pump. The temperature at the pump or water source is good to know.

Most overhead frost protection sprinkler systems are designed to deliver 0.1 to 0.2 acre-inches of water per hour and are useful for radiant freeze or frost protection when wind speeds are light and temperatures are not below the mid-twenties. Table 3 provides a guide for determining the application rates for frost protection at various temperature and wind speed levels.

Table 3. Application rate of water recommended for cold protection under different wind and temperature conditions [2]

Minimum Temperature Expected	Wind speed in miles per hour			
	0 to 1	2 to 4	5 to 8	10 to 14
	Application rate (acre inches of water per hour)			
27°F	0.10	0.10	0.10	0.10
26°F	0.10	0.10	0.14	
24°F	0.10	0.16	0.30	0.40
22°F	0.12	0.24	0.50	
20°F	0.20	0.30	0.60	0.80
18°F	0.20	0.40	0.70	1.00

[2]Extension Circular 287, Florida Agricultural Extension Service by Gerber and Martsolf.

If the dew point is below freezing, irrigation must be started sooner at a higher temperature (i.e., *before* freezing occurs). According to Sprinkle Irrigation 5th edition, a common recommendation is to start the system when the temperature at plant level falls to 34°F. Under conditions with wind or low humidity, it is possible to form ice when the air temperature is several degrees above the freezing point because of evaporative cooling. When these high evaporative cooling conditions (wind+low humidity) exist, the droplets reaching the plant could be super cooled (i.e., below 32°F) and some injury could occur to the plants when the system is first started. Because of this, it is suggested that the wet bulb temperature is a better indication of when the irrigation system should be turned on.

The assumption is made that the wet bulb temperature is equal to the critical plant temperature. It is necessary to use dew point temperatures as the indicator of moisture in the air instead of wet bulb or relative humidity, because these two change with the air temperature The suggested starting air temperatures should provide 2 to 3°F safety for starting up the system to keep the wet bulb above the critical plant temperature. See Table 4 for suggested starting air temperatures for various critical plant temperatures and dew points. You can also see Table 5 for approximate dew point temperatures calculated for air temperatures.

Table 4. Recommended temperatures for starting cold protection irrigation with various critical plant damage temperatures and dew points.

Critical Temperature (Wet Bulb)		Dew Point		Suggested Starting Air Temperature	
°F	°C	°F	°C	°F	°C
32	0	32	0	34	1.1
32	0	31	-0.6	35	1.6
32	0	29	-1.7	36	2.2
32	0	29	-2.2	37	2.8
32	0	26	-3.3	38	3.3
32	0	24	-4.4	40	4.4
32	0	22	-5.6	41	5.0
32	0	20	-6.7	42	5.6
32	0	18	-7.9	43	6.1
30	-1.1	30	-1.1	32	0.0
30	-1.1	29	-1.7	33	0.6
30	-1.1	27	-2.8	34	1.1
30	-1.1	25	-3.8	35	1.6
30	-1.1	24	-4.4	37	2.8
30	-1.1	22	-5.6	38	3.3
30	-1.1	20	-6.7	39	3.9
30	-1.1	17	-8.3	40	4.4

Source: Sprinkler Irrigation, 5th edition

Table 5. Approximate dew point temperatures calculated from air temperature and relative humidity values.[2]

Dry Bulb Temperature	Percent Relative Humidity			
	25%	50%	75%	100%
20°F	-8°F	6°F	14°F	20°F
25°F	-4°F	10°F	19°F	25°F
30°F	2°F	15°F	24°F	30°F
35°F	5°F	20°F	28°F	35°F
40°F	9°F	24°F	33°F	40°F
45°F	13°F	28°F	38°F	45°F
50°F	17°F	32°F	42°F	50°F

[2] Adapted from G.E.S. Handbook No. 1, Cooperative Extension Service, University of Georgia by Myers.

Additional cautions for frost/freeze protection

- Overhead irrigation for frost protection is a sensitive procedure that can result in major damage to the plants if not handled properly.
- Do not attempt irrigation unless you have confidence in the dependability and volume of your water system.
- If there is less than 10 percent bloom, the "risks" associated with irrigation may outweigh the benefits.
- Once watering begins, it should not be stopped until all ice is gone or damage from evaporative cooling can occur.
- For windy conditions (10 mph), move main water supply lines closer (from 60 to 40 foot centers) and increase the volume of heads (from 0.15 to 0.25+ inches per hour). When wind speeds exceed 10 mph, the risks for crop damage from evaporative cooling due to inadequate water supply or even distribution of the water may outweigh the potential benefits.
- Irrigation can be applied directly over row covers used for frost protection. Here again, water needs to be applied until the ice melts off and then as soon as possible after the frost/freeze the covers need to be removed to allow for pollination and drying.

REFERENCES

Funt, R., et al. (1985)

Wolf, Polins, *Mid-Atlantic Wine Grower's Guide* (1995) Raleigh, Department of Agricultural Communications, 1995.

Extension Circular 287, Florida Agricultural Extension Service by Gerber and Martsolf

Sprinkler Irrigation, Fifth Edition, Arlington, The Irrigation Association,1983.

NRAES #35, Bramble Production Guide, Northeast Regional Agricultural Engineering Service, Ithaca, 1989.

NRAES #55, Highland Blueberry Production Guide, Northeast Regional Agricultural Engineering Service, Ithaca, 1989.

EB 242, 1998-99 Maryland Commercial Small Fruit Production Guide, University of Maryland Extension Bulletin, College Park, 1998.