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Midwest Strawberry Production Guide

THE OHIO STATE UNIVERSITY
EXTENSION

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Contents

Introduction

The *Midwest Strawberry Production Guide* is a completely revised edition and is produced for the Midwest strawberry industry. The selection of color prints and sections on management, economics, plasticulture production, and marketing represent an improvement in information to encourage the future success of the industry.

The use of this guide is a must for the interested grower who is starting in the business or who is already established. This strawberry guide is based on many research and Extension publications as well as the research and demonstration plots that have been developed over the past several years. Growers and researchers have supported this research. Thus, this bulletin is dedicated to those who were willing to invest in the future of strawberry production in the Midwest.

Chapter 1
Business Management

Decision Making

Prior to planting, the strawberry grower must make some major decisions as to the site, soil type, cultivar, acres to be planted, plant spacing, equipment, marketing, and long-term dollar investment. These decisions will have a lasting effect on his or her success in later years. The return on investment will depend on management of the planting.

The relative efficiency of farm size should be considered. Small plantings of two to three acres are suggested for getting started. If certain annual crops are already being produced, your present equipment may be adaptable to strawberry production without additional expense.

Larger plantings may require an investment in specialized equipment, such as planters and irrigation. Large acreages, however, require more hired labor and supervision. Commitments to other crops and development of markets are important considerations for scheduling your time and investment.

Limiting Factors

The management of strawberry production does have limiting factors in terms of climate, site, soil, spacing, cultivar, and money. An operation will proceed at the rate imposed by the most limiting of these factors. The management of weeds, insects, diseases, irrigation, and fertilizer is not fixed. These factors can be controlled when timely measures are taken. Many useful guides, such as spray bulletins, production manuals, economic reports, and soil and leaf testing, are available to answer management questions. Useful references will be suggested throughout this publication.

Strawberry production, like any complex enterprise, will have problems that require action. A systematic approach to problem solving is preferable to meeting problems haphazardly. Before taking action to correct problems, a grower should consider the possible results of his or her actions. A grower must develop realistic prioritized goals. Look at alternative actions and/or alternative crops as to investment in labor, capital, and land.

Record Keeping

As appropriate software is developed, growers will increasingly turn to the computer for aid in decision-making. Computers are capable of storing accurate and up-to-date weather and financial data. Information, such as temperature, humidity, wind speed, and evaporation, can be automatically accumulated into a computer, and the timely application of pesticides, mulches, and irrigation can be predicted.

Because strawberry production involves a large investment over a long term, more financial record keeping will be essential for grower analysis as well as for a database to obtain a loan from financial institutions. Keep records for each block (unit) of strawberries. A block should be plants of the same age and cultivar. Thus, a 2005 planting of Allstar is a block, and a 2006 Allstar planting is another block.

Chapter 2
Production

Nature of the Strawberry Plant

The strawberry plant is a perennial that produces leaves, stolons (runners), flowers, and roots in patterns determined by its genetic makeup (Figure 2-1). Each year leaves and roots arise at higher points on the crown. Thus, the plant tends to grow out of the ground and develops poor root-soil contact with age.

The root system is shallow, with 80 to 90 percent in the top 6 inches of clay and 50 percent in the top 6 inches of well-drained sandy loam soils (Figure 2-2). A primary root normally lives for one year. The plant will initiate new roots at succeedingly higher levels on the crown and, when exposed to cold or drought, may die while younger plants live.

Fertility, water supply, and aeration at soil depths greater than 6 inches are of major concern. Placing 1 inch of soil over the plant bed after harvest will enhance new root formation and make plants less vulnerable to cold and drought. The use of raised beds and renovation for Midwest conditions is discussed later in this publication.

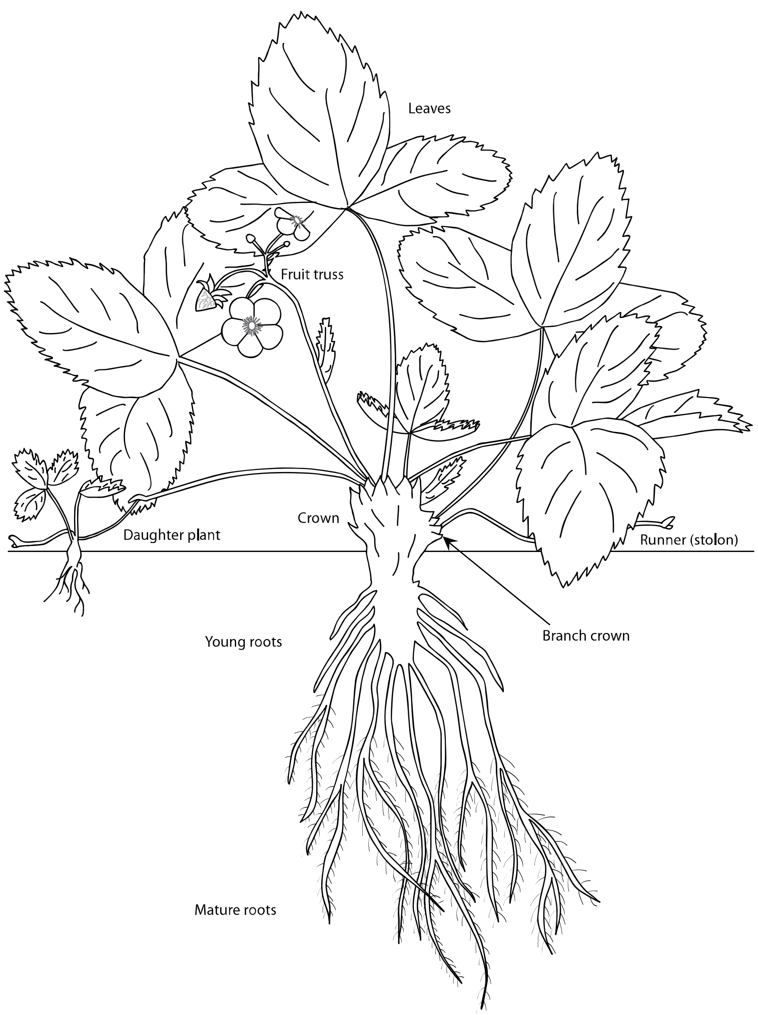

Figure 2-1. Mature strawberry plant at flowering with stolons. Courtesy of The Pennsylvania State University.

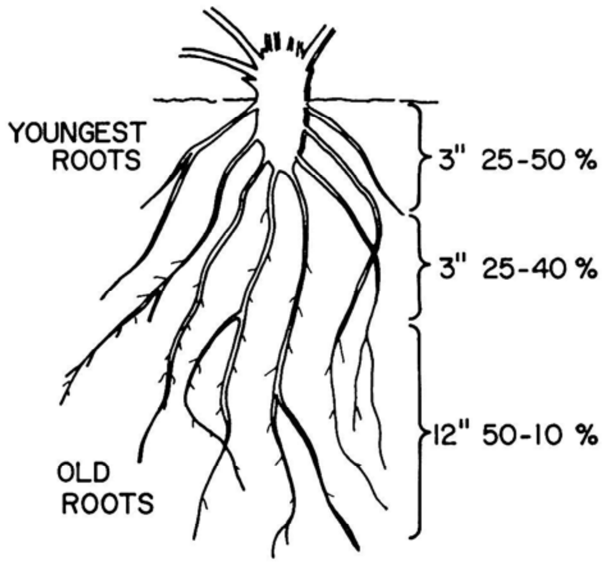

Figure 2-2. Root distribution of mature strawberry plant.

Cultivars can be separated into three plant types based on their response to the hours of sunlight per day (photoperiod). These are June bearers, everbearers, and day-neutrals. The June-bearing strawberry is a popular type for commercial production in the Midwest and will produce one crop each year. Everbearers are long-day plants and initiate flowers when days exceed 12 hours of light; they produce two main crops. Day-neutral strawberries are insensitive to daylength and will produce fruit from spring through fall.

Selecting Site and Soil

Strawberry plants grow and produce satisfactorily in a wide range of soil types, from sandy to clay loams. They are not particularly sensitive to soil reaction (pH); however, they produce best on sandy-loam soils with a pH of 5.8 to 6.5. If soil reaction is unknown, the grower should submit a soil test. Best yields are obtained when strawberries are grown on deep, fertile soil that is well supplied with organic matter. Important factors to consider in site selection are internal soil water drainage and freedom from frost.

Good production cannot be expected without adequate soil drainage during the entire year. The strawberry cannot tolerate standing water. Tile drainage systems should be considered if land is poorly drained. Raised beds that are eight inches high and two to three feet wide have been recommended and should be maintained over the life of the planting. Because strawberries bloom very early in the spring, plantings should not be located in frost pockets. Where air drainage is limited, the crop may be lost to late spring frosts, which can kill the flower. Frost control measures may need to be considered.

Strawberries require cultivation, so avoid planting on steep slopes. Plantings on 10 to 15 percent slopes are likely to erode, with some plants being buried and others washed out of the soil. If sloping sites must be used, run rows across the slope or on the contour and use a wide row width.

Avoid areas that have been used recently to grow tomatoes, potatoes, or sod. Such sites are likely to contain disease and insect pests that may attack plants. Likewise, sites that are heavily infested with sedge, nutgrass, quackgrass, Johnson grass, and thistles should be avoided or treated prior to planting to destroy these chronic weeds.

Ideally, the site should be selected the year before it is to be planted. Early site selection allows proper preparation of the soil, including weed control, fertility, and pH adjustments and elimination of other potential problems. Selection of a suitable site is the first step toward success with strawberries.

Cultivar Selection

Selection of the best possible cultivar is vital to the success of any strawberry enterprise, whether or not it is a large commercial planting. No cultural practice can overcome the handicap imposed by poor selection of cultivars. Cultivar performance is strongly influenced by local soil and climate conditions, and a cultivar that may be highly satisfactory in one area of the country may be of little value in another.

Most growers would be wise to test cultivars, even recommended ones, on a limited scale before making extensive plantings. In this way, the grower can determine, with minimal financial risk, how a cultivar performs under his/her own growing and marketing conditions. Commercially available strawberry cultivars are self-fruitful (do not require cross pollination) and will produce full crops when planted alone. Most growers, however, plant several cultivars in order to extend the harvest season.

Cultivars have been developed that are resistant to the most important root, leaf, and fruit diseases; however, each cultivar is different in fruit size, color, and firmness. The major decision as to cultivar selection must deal with fruit quality and resistance to disease for maximum economic yield. Each cultivar will require different cultural methods in regard to pests, herbicide sensitivity, soil and weather conditions.

Cultivars can be separated into three plant types based on their response to the hours of sunlight per day (photoperiod). These are June bearers, everbearers, and day-neutrals. Tables 2-1, 2-2, 2-3, and 2-4 (see pages 14-18) list important characteristics of strawberry cultivars adapted to Midwest growing conditions.

The annual plasticulture system of strawberry production has gained much attention in the Midwest since 2000. Fruit ripening can be in early May and continue over several weeks. Growers should investigate promising methods, costs, and higher levels of management than current production systems. (See Chapter 10, *Plasticulture in the Midwest.)*

Many new cultivars are patented, which requires that the propagator own a license before growing patented cultivars. Growers need to be aware of the legal aspects of patented cultivars.

June-Bearing Cultivars

The June-bearing strawberry is the most popular type for commercial production in the Midwest and will produce one crop each year. These strawberries are typically planted in the spring (April 15 to May 15). Newly set plants are deblossomed to encourage more growth and stolen (runner) production for the popular matted-row system of culture.

Stolons are produced under the long sunny days of June and July. At the same time and at the second node, a daughter plant begins and sets roots. Dry soil conditions, recently applied herbicides, or high winds retard daughter plant establishment. Poor establishment of daughter plants will result in reduced fruit yield the following year.

Growers can increase fruit potential for high yields by timely planting, irrigation, and proper fertilization to increase leaf area early in the season. Flower buds are initiated when daylength shortens in the autumn (less than 10 hours light per day). In addition to triggering flower bud formation, short daylength and cool autumn temperatures induce the production of branch crowns and trigger the onset of dormancy.

In the Midwest, fruit ripens from late May to early July, depending on the cultivar. Many of the newer June-bearing cultivars are resistant to red stele root rot, a fungus disease. (See Chapters 5 and 6 on disease and insect problems for detailed information on red stele.) Red-stele-resistant cultivars can be grown successfully on soils in which the disease-causing fungus is present. Non-resistant cultivars should not be planted in soil suspected of having the red stele fungus. Resistant cultivars often have sufficient merit to warrant planting, even though red stele is not a problem.

Day-Neutral Cultivars

Day-neutral strawberries produce fruit from spring through fall, with several peaks throughout the season because they are insensitive to daylength and will flower and runner continuously if temperatures remain above 35° and below 80°F. A temperature above approximately 70°F will not allow flower bud formation. This may account for some field observations that day-neutrals have poor flower production from mid-summer to early fall. Daughter plants flower the first season, often without rooting.

Fruit size is correlated with soil temperature and can be increased by cooling the soil in the root area with mulches, shading, or irrigation, such as trickle irrigation. Fruit size tends to be 7 to 11 grams per berry, compared to "Guardian" (June bearer), which is 10 to 13 grams per berry. However, in mid-summer, berry size is very small (4 to 5 grams) if plants are subjected to hot, dry conditions.

Day-neutral cultivars do not runner as profusely as June-bearers; therefore, they require a completely different cultural system. Plants can be set out in mid April to early May. All flowers should be removed until mid July of the planting year so the plant can put energy into vegetative growth.

Weed control is a problem with day-neutral strawberries. Since they are more sensitive to herbicides than June-bearers, and since herbicides vary in their preharvest interval (PHI), chemical control is virtually eliminated. Weeds will need to be cultivated by hand.

Tristar and Tribute, two older red-stele-resistant day-neutral cultivars have been available since 1982. Fruit size has been medium, and flavor has been good. These cultivars bear fruit three times per season, nearly four to six weeks apart, or June 1 to 10, July 10 to 15, and August 15 to 20 in Ohio. They may bear an additional crop before frost. For high yields, they should be spaced 10 inches or closer in the row.

- Tristar bears an early crop and is smaller than Tribute. It is resistant to Verticillium wilt.
- Tribute is slightly later in cropping than Tristar, but berry size is larger. It is similar in cropping pattern to Tristar but only tolerant, not resistant, to Verticillium wilt.

Renovation techniques and cultural practices for day neutrals have not been fully explored in all climatic conditions. However, the use of close spacing (plants 8 to 10 inches apart), raised beds, drip irrigation, and black and white plastic mulch (black on the bottom side, white on the top side) appear to be valuable cultural techniques. See Chapter 10, *Plasticulture in the Midwest.*

Everbearer Cultivars

Everbearers are long-day plants, which initiate flowers when days exceed 12 hours of light. They produce two main crops, but yields are less than a single crop from a June-bearer. They produce few runners and tend to form multiple crowns.

Table 2-1. Listing of Red Stele-Resistant, June-Bearing Strawberry Cultivars Currently Grown or for Trial in the Midwest, USA, 2005.

Earliglow [MD 2350 (Fairland x Midland) x MD 2713] is an early-blooming and early-ripening cultivar with excellent flavor and color. Berry size is small (10 gm), and yields can be low.
Annapolis [(Micmac x Raritan) x Earliglow] is a major cultivar in Canada, the Midwest, and the northeastern United States; it has firm berries of good size (12 gm) and good flavor. It runners freely.
Northeaster (MDUS 4380 x Holiday) is a medium-sized berry (12 gm) that is firm and has good flavor and aroma. Adapted to heavy soils. Does not have favorable grower or customer acceptance.
Sable K90-1 (Veestar x Cavendish) is larger and more productive than Veestar; berries are bright, attractive, and have a very good flavor. Less firm than Annapolis. Plant runners freely. Lacks size and firmness. Flowers open early.
Cavendish (Glooscop x Annapolis) is a medium-sized berry (14 gm) with good flavor and firmness. Plants are productive, but susceptible to leaf spot. May ripen unevenly in warm seasons. Not recommended in Missouri. Patented.
Brunswick K90-12 (Cavendish x Honeoye) ripens with Honeoye and produces attractive, medium-sized, firm berries that can be larger than Honeoye but smaller than Cavendish. May have good winter hardiness. Performance best in colder north climates. Flavor is less tart than Honeoye. Plants are vigorous; leaflets tend to be cupped but are more dense than Cavendish. For trial. Patented.
Mira K84-5 (Scott x Honeoye) produces high yield in matted rows with bright orange-red color and has a tendency for tart fruit but is similar to Kent. Post-harvest quality is good. Good winter hardiness and produces well in northern climates. Can be more productive than Jewel and Kent but ripens five days later than Kent. Cavendish is larger and more flavorful than Mira. For trial.

Table 2-1 (continued). Listing of Red Stele-Resistant, June-Bearing Strawberry Cultivars Currently Grown or for Trial in the Midwest, USA, 2005.

L'Amour NY1829 (NYUS 256 x Cavendish) is productive; plant is vigorous; has large red fruit with good eating quality and flavor. Can be larger than Cabot. Later and more firm than Honeoye. Berry size can average over 20 gm in plasticulture. Under wet conditions, culls can be over 15%. Cold hardy. For trial. Not tested for red stele, but parents are red stele-resistant. Patent pending.
Eros (Allstar x Elsanta) has darker fruit color than Allstar. Large, firm fruit with good flavor. Very productive. For trial. May do well in plasticulture. Patented.
Allstar [MDUS 4419 (Redstar x Surecrop) x MDUS 3184 (NC-1768 x Surecrop)] is a high-yielding berry with large fruit (15 gm) with good flavor. Resistant to fungal leaf diseases. Firm. A standard cultivar in Ohio. Fruit color improves with cultural practices and maturity. Good for annual or multiyear plasticulture systems in warmer areas.
Cabot K92-17 [(Elsanta x K79-5) x (Arking x K79-4)] ripens at the same time as Mira with very large fruit averaging 20 to 25 gm over the season and 50 gm berries with primary flowers. Fruit are red and glossy with medium-firm flesh. Plants are vigorous but may produce few runners. Patented.
Mesabi (Glooscop x MNUS 99) has large red fruit with good flavor under cool conditions. In Pennsylvania, it has lost flavor and turned dark in color under hot conditions. High yielding. Winter hardy; does not store well. Patented.
Winona MNUS 210 [Earliglow x (Lateglow x MDUSS 4616)] has produced large, firm berries with bright red-orange color. Yields may be low and of marginal quality in warm climates. Similar to Annapolis and Cavendish for winter injury. Plants are vigorous, winter hardy, and late blooming. Patented.
Clancy NYUS 304B (MDUS 4774 x MDUS 5199) fruit has a deep dark red color, is firm, and has very good flavor, good texture, and eating quality. Berry size can average over 25 gm over the season in plasticulture. Can be larger than Cabot. May have fewer culls than L'Amour. Fruit held off ground. Larger and two days later than Jewel. Cold hardy. Not tested for red stele but parents are red-stele resistant. Has been reported to be highly susceptible to leaf scorch. For trial. Patented.
Ovation B440N (Lateglow x Etna) has large (15 gm), firm berries with good flavor and high antioxidants, and ripens in late June in Ohio. Plants are tall, vigorous, and should be spaced at 18 inches if soil is fertile and high in organic matter. Yields are comparable to Allstar and greater or equal to Chandler. Good for eastern plasticulture production. For trial.
Other red-stele-resistant cultivars not mentioned are Guardian, Redchief, Lester, Delmarvel, Lateglow, and Primetime. These cultivars have performed well in Ohio or other areas but may no longer be of value to most growers in the Midwest.

Table 2-2. Listing of Non-Red-Stele-Resistant, June-Bearing Strawberry Cultivars Grown or for Trial in the Midwest, USA, 2005.

Evangeline K93-1 [(Honeoye x Veestar) x NY 119] is a cultivar ripening before Annapolis with medium yields of medium to large, firm conic berries. Flowers earlier than Annapolis and subject to frost. Fruit is darker in color than Annapolis. Partial resistance to red stele, but may be insufficient for the Midwest. Patented.

Honeoye NY 1409 (Vibrant x Holiday) is a large-sized berry. Has performed well in cool harvest seasons and has good winter hardiness. Excellent frozen.

Darselect (Parker x Elsanta) is a large-sized, attractive berry with good flavor but tends to be soft. Plant is vigorous. Yields can be low. Patented.

Jewel NY 132Y [(Senga Sengana x NYE-58) x Holiday] is productive, but fruit can be soft in hot weather. Does not runner well. Some growers only harvest for two seasons but continues to be a favorite in its season. Patented.

Seneca NY 1529 [NY 1261 (Redcoat x NY 844) x Holiday] fruit is round, large, and among the most firm of any cultivar. The plant is vigorous with high yield and is winter hardy. Flavor is mediocre. Potential for plasticulture. Does not runner heavily. Patented.

Canoga NY 1362 [NY 1123 (Senga Sengana x Midland x Holiday)] has large, firm, and tough-skinned fruit with good keeping quality. Flesh is dark red throughout, and seeds are yellow. Low fruit disease incidence. Good frozen. Suggested for plasticulture and organic systems.

Table 2-3. Suggested Strawberry Cultivars for Different Systems of Culture. In this list, only Everest and Seascape are day-neutrals.

Plasticulture System (See Chapter 10, Plasticulture in the Midwest.)
Sweet Charlie FL 85-4925 (FL 80-456 x Pajaro) is an early-ripening strawberry adapted to the mid-Atlantic and southern United States; has large orange-red fruit color and is moderately firm. Easy to harvest. Good flavor. Flowers early. Tolerant to anthracnose. Patented.
Chandler Cal 77.32-103 and C24 (Douglas x Cal 72.361.105). Standard for the system. Plant is vigorous. Berries are firm and large with good flavor. Do not over fertilize with N. Glossy attractive fruit. Susceptible to anthracnose.
Camarosa Cal 88.24-603 (Douglas x Cal 85.218-605). Fruit is larger and more firm than Chandler; color similar to Chandler; earlier, higher yielding, more vigorous than Chandler in warm climates. Cool fall can affect flower bud initiation. Susceptible to leaf spot. Patented.
***Allstar** — see Table 2-1.
***Ovation** — see Table 2-1.
Everest (Evita x Irvine). Harvest from June to October. Day-neutral; not a good plant maker; set plants at 6 to 8 inches. May overwinter. Fruit is large, bright, with good flavor. Fruit can be soft. For trial.
Seascape CN 49 (Cal 83.49-1). Day-neutral. Superior to Selva in flavor but less productive; erect habit; susceptible to leaf spot and two-spotted spider mite. Patented. Does not overwinter. For trial.
Canoga — see Table 2-2.
Seneca — See Table 2-2.
* Red-stele resistant. Other day-neutral cultivars not mentioned that are red-stele resistant are Tristar and Tribute.

Table 2-4. Strawberry Cultivars for the Midwest with General Characteristics for Production and Marketing.

Plasticulture	Large Berry Size	High Yield	Shipping	Shelf Life**
Eros	Clancy	Eros	Eros	L'Amour
Cabot	L'Amour	Allstar	L'Amour	Allstar
Honeoye*	Allstar	Cabot	Allstar	Lester
Jewel*	Cabot	Honeoye*	Lester	Kent*
Kent*	Jewel*	Kent*	Kent*	Earliglow
Seneca*	Honeoye*	Lester	Seneca*	
Allstar	Seneca*		Latestar	
Ovation				

* Not red-stele resistant; some new cultivars should be grown as a trial before adoption in your area.

** Tends to maintain good quality under refrigeration and if chilled within one hour after being picked.

Chapter 3
Cultural Systems

Matted Row

For many years, the standard matted-row system using June-bearing plants has been the major planting system. With this system, no effort is made to limit the number of runner plants, but these runner plants are kept within a 12- to 18-inch wide row. Vigorous cultivars that produce abundant stolons are planted in a single row, with 24 to 30 inches between plants and 48 inches between rows, while less vigorous plants are set 18 to 24 inches apart within the row. Double-row systems with staggered spacing of plants are set at 36 to 48 inches apart with 9 to 12 inches between rows (40 to 48 inches major rows), and plants are allowed to run freely.

The success of these systems depends on early planting and setting of runners. If the soil remains wet during April and May, success is limited. The most preferred spacing for matted rows in the Midwest is 12 to 18 inches between plants and 36 to 40 inches between rows, depending on equipment size and slope of the terrain. On level terrain and with small equipment, the closer row spacings can be used. Wider between-row spacings should be considered on soils with 3 to 5 percent slope. A slope greater than 5 percent is difficult to work; obtaining high yields also is difficult.

Ribbon Row

The ribbon row system usually consists of a single row of plants spaced 6 to 9 inches apart with 36 to 38 inches between rows on a raised bed. Runner removal is suggested to maintain row width, but without special equipment, hand labor costs are very expensive. Many growers purchase a bed shaper and special tillers to reduce row width, place 1 inch of soil on top of the plants, and reshape the beds in one operation.

The advantages of a ribbon-row raised-bed system are the ability to control moisture on compacted or moderately drained soils, deeper plant roots, a higher number of crowns per foot of row, earlier fruit ripening, and easier height for picking. In many reports, raised beds tend to have higher yields, depending on cultivar, but yields may not be high enough to justify the larger investment costs and returns of various systems, which will be discussed later in this manual.

The disadvantages of ribbon rows on raised beds are that they are more susceptible to cold winter winds; they need to be reshaped with special equipment; they require close irrigation scheduling and runner control; and the financial risks are greater.

Ribbon rows are not limited to raised beds. Ribbon rows or high plant-density plantings can be grown on flat or matted-row systems. Production may not increase rapidly once an ideal spacing of a specific cultivar is reached. A 3-inch x 36-inch plant spacing results in twice as many plants per acre as a 6-inch x 36-inch spacing (Table 3-1), but yields resulting from these two spacings may not differ significantly.

Some growers have allowed high plant-density systems to fruit the first year. Generally, yields average 1,400 to 2,800 pounds per acre in the first year, and berry size is one-third to one-half the normal size for the cultivar. In Michigan, five out of seven cultivars on which flowers remained had fewer berries in the following season. Three out of seven cultivars had more than 3,300 pounds per acre net loss over two seasons, with flowers remaining rather than flowers removed.

Some pick-your-own marketing may be lost when customers become dissatisfied with berry size, find few berries to harvest, and walk long distances to obtain the amount they want.

For information on the plasticulture production system, see Chapter 10.

Site Preparation

Table 3-1. Number of Strawberry Plants per Acre for Different In-Row and Between-Row Spacings.

	Between Row Spacing			
In-Row Spacing	36 inches	38 inches	40 inches	42 inches
	Plants/Acre			
3 inches	58,080	55,070	52,293	49,783
6 inches	29,040	27,570	26,241	24,891
12 inches	14,520	13,759	13,120	12,446
18 inches	9,680	9,170	8,712	8,297
24 inches	7,260	6,914	6,540	6,223

Select the site at least one to two years before planting. This management strategy utilizes such practices as weed and nematode control and drainage. If sod is present in the planned area, it should be turned over and a cultivated crop such as field corn should be grown to control grubs and weeds. Soil insecticides and herbicides can be used for corn.

After the corn crop, the site can be prepared for a grain crop, such as wheat, or for strawberries as long as no persistent herbicide such as Atrazine has been used. If persistent weeds exist, the use of Roundup herbicide over the entire field in the fall can be beneficial. Weeds need to be actively growing and green for Roundup to be effective.

For some areas, the growing of sweet corn may be more ideal than field corn so that weeds can be treated in August prior to fumigation. Stalks should be shredded before they are worked into the soil.

When choosing a site, determine row intervals for equipment travel used for spraying and mulching. Generally, every 10 to 15 rows of strawberries at 40” to 48” spacing are easily covered. In addition, 30 to 40 feet at the end of the row are required for turning large equipment. Also, select sodded areas for parking for pick-your-own customers.

Note: Where trade names are used, no discrimination toward similar chemicals is intended or implied.

Soil Testing for Lime and Fertilizer Needs

Test the soil to determine the mineral content, lime requirement, and fertilizer needs of the soil. Do this in July the year prior to planting so that lime or fertilizer can be plowed down or disked into the soil prior to fumigation. Strawberries are sensitive to low soil phosphorus and boron levels. In general, the pH should be 6.0 to 6.5 to aid in phosphorus uptake. Refer to Chapter 9 for information on fertility.

Work needed ground limestone and phosphorus into the top 8 to 12 inches of soil. Once satisfactory levels are achieved prior to planting, the crop may not require additional amounts for three or four years. Nitrogen, potassium, and possibly boron may be required each year as determined by leaf analysis and soil testing. Applications of nitrogen are generally needed after planting and annually at renovation and in late summer.

Ordering Plants

Buy plants from a reputable nursery that adheres to strict standards of soil preparation for control of diseases and nematodes and that produces plants that are true-to-name and essentially virus free and disease free. Certified plants indicate only that plants are free of diseases and insects. The only way to be certain the plants are virus free is to purchase registered plants. Non-registered plants can be grown and sold at lower prices. However, low satisfaction and possible low return come from non-registered plants.

Order plants prior to January of the season of planting. Cultivars in high demand are sold rapidly and may not be available if ordering is delayed. Request shipment in April or early May. Many nurseries can ship close to planting time to avoid grower storage or heeling in of plants. Request shipment from the nursery on a Monday so plants are not held in a warm building over the weekend.

When plants arrive, check the bundles and moisten the roots if necessary. Plants can be held at 30 to 32°F in the plastic bags in which they are shipped. If storage facilities to keep them at this temperature are not available, the plants should be refrigerated at the coldest temperature possible. The storage unit should be free of apples or other ethylene-producing produce. Ethylene in the storage unit can have a negative effect on strawberry plants.

If plants were stored at 28°F and have ice crystals, continue to hold them at that temperature if possible. When plants are stored at 28°F, they need to be brought to air temperature over a 24- to 48-hour period before planting. If plants have started to regrow or start to develop moldy roots, remove them from the box and heel them in. Dig a shallow trench, place bundles in a single layer, keep the crown partly above the soil line, and cover with soil, peat moss, or sawdust and firm carefully. Generally, plants can be heeled in for 10 to 14 days as long as roots remain moist.

Planting

Keep plants in a shaded area. Plants may be placed in a container filled with water one-half hour before planting. Do not allow the roots to dry out during the planting operation. Place plants in the soil so that root systems are spread out. Barely cover the roots with soil at the point where they originate from the crown. If the crown is covered with soil or the roots are exposed, the plants will do poorly or die. (See Figure 3-1.) The correct and incorrect planting depths are illustrated in Figure 3-2.

Figure 3-1. Plants set incorrectly (J-rooted) grow poorly.

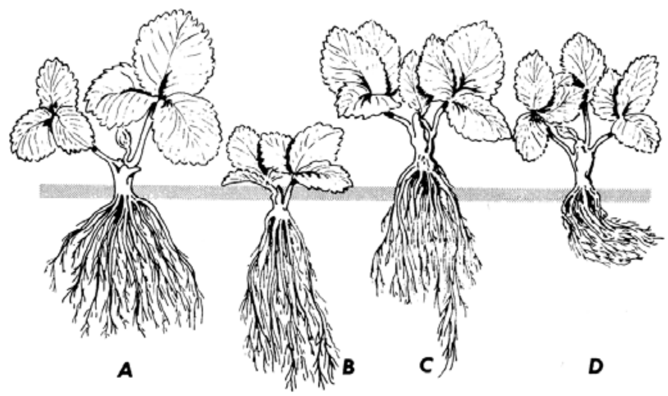

Figure 3-2. Proper planting method (A) and improper methods (B, C, D) for strawberry planting. At B the crown is too deep; at C the crown is too high; and at D the roots are bent and remain near the surface.

Transplanting machines, such as those used for vegetables or tobacco, are suitable for setting strawberries on plantings of an acre or more (Figure 3-3-A). A skilled crew on a two-row planter can set three to four acres per day on a matted-row spacing of 18 to 24 inches (Figure 3-3-B). The same crew, using a two-row planter, can set only one acre per day of plants 6 inches apart. It is important to have one person follow the planter to ensure that plants are set correctly and to plant those that are missed. Some growers have attached a wide rubber tire filled with water on the transplanter to act as a packing wheel and ensure good soil-to-root contact. A low number of growing plants results in reduced yields.

Figure 3-3-A. Two-row planter used for planting strawberries.

Figure 3-3-B. Two row strawberry planter in operation.

Figure 3-4-A. A Buddingham weeding machine being used to place soil around the crowns of newly planted strawberry plants.

Figure 3-4-B. Close up of the Buddingham weeding machine showing plastic "fingers" on the rotating wheel.

Innovative growers have adapted various types of machinery to pass over the newly planted row in order to place soil around plants to ensure that all roots are covered and good soil-to-root contact is established. Figure 3-4-A shows a Buddingham weeding machine mounted on an International Cub tractor being used to ensure proper planting. The weeder has plastic "fingers" on a rotating wheel (Figure 3-4-B) that moves soil around the base of the newly planted plants. Figures 3-5-A and 3-5-B show new plants before (Figure 3-5-A) and after (Figure 3-5-B) the machine has passed over the row.

Plan the planting operation for the matted-row system for April 15 to May 15 because the rate of leaf production is temperature sensitive and tends to be more rapid in early spring than during the main part of the growing season. A new set of leaves can be produced every 10 to 12 days. A plant that will produce an optimal leaf surface for optimal number and size of fruit requires nearly eight mature leaves. This requires that plants be planted 80 to 96 days before September 1.

Figure 3-5-A. A newly planted strawberry plant before the Buddingham weeding machine passes over it. Note that the roots are exposed, and the crown is above the soil level.

Figure 3-5-B. After the weeding machine passes over, the plant's roots are covered with soil, and the crown is properly placed.

Thus, planting after June 1 involves greater risk of a smaller yield the following year, particularly from daughter plants. Irrigation, to reduce water stress and lower the plant temperature from evaporation, allows rapid growth under warmer soil and air temperatures in June. A management strategy for planting after June 1 is to plant at a closer spacing (10 to 12 inches between plants) as in a high-density system.

Irrigation

Overhead sprinkler irrigation is used by a majority of Midwest strawberry growers for supplemental moisture, to reduce plant temperature by evaporative cooling, for pesticide application by injection, and for frost control.

Overhead Irrigation

Overhead irrigation can be installed as a portable unit that may be moved to other crops or as a solid set, which is a permanent unit put underground. Thus, site selection is an important long-term

Figure 3-6-A. Portable pump at irrigation pond.

Figure 3-6-B. Riser and nozzle used in solid set system.

management decision if irrigation is used for crops after strawberries.

A staggered-triangular spacing pattern gives better water coverage than a square spacing. In general, sprinkler and line spacings should be 40 to 50 feet for uniform coverage under winds up to 10 mph. Spacings greater than 50 to 60 feet usually do not give desired results. Generally, low application rates using 1/2-inch nozzles (about 0.12 inches per hour) and a sprinkler pressure of at least 50 pounds per square inch are used. Larger nozzles may be necessary. A flow rate of 54 gallons per minute for each acre is required for 0.12 inch per hour rate.

Supplemental Watering

Supplemental soil moisture is needed as daily temperatures reach 60 to 80°F in June, July, and August when rainfall is less than the evaporative loss of water from the soil. Days of low humidity, high temperatures, and a 10- to 20-mph wind give the greatest loss of soil moisture. The soil loses an average of 0.2 to 0.35 inches of water per day (1.4 to 2.5 inches per week) under these conditions. Different soils vary in their capacity to hold and release moisture (tension). See Table 3-2.

Table 3-2. Common Amounts of Available Moisture-Holding Capacities for Soils of Different Textures.

Soils	Texture	Inches of Water per 12" Soil
Sands	Very coarse	0.4 to 0.8
Sands	Coarse	0.8 to 1.7
Fine sandy loams	Moderately coarse	1.2 to 1.8
Loams, silt loams	Medium	1.7 to 2.3
Sandy clay loams	Moderately fine	2.0 to 2.5
Clay, silty clay	Fine	2.0 to 3.0
Peats and mucks		2.0 to 3.0

Growers often wait too long before watering their strawberries. Irrigation should start when 50 to 60 percent of the available moisture in the root zone (6 to 12 inches) has evaporated. This can be monitored by placing tensiometers in the soil near the strawberry plant's root system.

One should apply 25 to 30 percent more water than is required by the soil to compensate for loss of water during application. Irrigate strawberry plants immediately after planting to aid root-soil contact. It is critical to maintain good soil moisture the first two weeks after planting for excellent growth. Tensiometers at a 12-inch depth should read 20 to 30 centibars.

Drip Irrigation

Drip irrigation can be used in strawberries, but it does not provide frost protection. The main advantage is a lower usage of water and a lower energy requirement to pump the water. Where the water supply is limited, drip irrigation can be integrated into the overhead system.

The best time to install drip irrigation is at planting by placing the tubing on the transplanter and putting it 3 to 4 inches below ground underneath the plant. Drip irrigation is engineered to be a daily watering system to replace the soil moisture loss and reduce plant water stress. It can be automated to turn on and off as needed by the plant. In rocky soils, drip irrigation tapes or tubes need to be 13 mil or higher to resist abrasion and leaks (Figure 3-7).

Figure 3-7. A two-chambered trickle irrigation tube can be automatically placed underground at the root zone in transplanting.

Nitrogen after Planting

The most efficient use of nitrogen fertilizer is to apply 25 to 40 pounds of actual nitrogen (N) per acre (75 to 120 pounds per acre of ammonium nitrate) 10 to 14 days after planting as the roots begin to grow. If the fertilizer is banded 6 to 8 inches away from the plants, use only half of this amount. The low rate is for heavy soil and the high rate for sandy soil. Do not apply fertilizer on wet leaves. Select a dry day or use irrigation to remove fertilizer from the leaf.

As indicated under site preparation, nitrogen is the only element to be routinely applied, with other nutrients applied prior to planting as indicated by a soil test. Monitor the soil and leaf nutrient levels each year to ensure that they remain at optimal levels for maximum yields. (See Chapter 9, *Plant Tissue Analysis for Strawberry and Fertilizer Recommendations*).

A second application of 25 to 40 pounds of nitrogen is suggested for mid-August. Nitrogen applied at this time plays an important role in flower bud formation. For very productive soils and vigorous cultivars, the recommendation can be reduced to 20 pounds actual N per acre. The second application is to replace N that was removed by the growing crop.

Removing Flowers

Remove all flowers the first year to allow plants to produce runner plants and leaf canopy for next year's crop. The best method is to pinch the flower stem by hand. Most of the blossoms can be removed in two operations approximately two weeks apart.

Cultivation

In recent years, growers having heavy soils have reduced equipment travel and soil compaction by doing as little cultivation as possible. The use of overhead sprinklers permits reduced tractor and sprayer movement. New, longer-lasting herbicides also reduce travel. However, not all pesticides will give adequate results through overhead applications under all field conditions. Some tractor-sprayer operations are necessary.

Some cultivation and/or subsoiling between rows is recommended in August for runner removal or in July for renovation. Runner plants produced after August 15 are unproductive and should be removed if a full bed of plants has been established. Excess daughter plants in some cultivars such as Allstar may need to be removed in late August. Do not allow rows to get wider than 18 to 24 inches. Some growers narrow the rows and cross rows in July at renovation, removing 6 to 9 inches of plants every two feet in the third or fourth year of production.

Mulching Before Winter

The strawberry plant should be mulched over the winter for protection from severe cold (below 20°F), fluctuating temperatures, plant heaving, and dessication from wind when there is little snow cover. Plant respiration is more rapid after fluctuating temperatures, and this uses up the carbohydrate reserves. Also, under 10 to 12°F (sometimes 18°F) with no snow cover, unmulched plants are injured, and blossoming is reduced or does not occur. Black root rot, in part, occurs from failure to mulch or mulch properly. Unmulched or improperly mulched plants in heavy soils are especially prone to heaving and poor aeration and under these conditions are susceptible to black root rot.

For mulching, obtain clean wheat, oat, or rye straw during the grain harvest season when prices are lower. Be sure that perennial weed seeds are not present in the harvested grain field or in the straw. Sudan grass can be used but coarser material is not recommended. Store the straw under a shelter because water-soaked or frozen bales are difficult to handle and spread. Apply a herbicide before applying mulch. Do not apply herbicides to frozen ground. Waiting until the ground freezes before mulching is not safe, as plant injury may already have occurred.

Apply mulch after several freezes in the mid or high 20s, generally between November 15 and 30 but not later than December 15 when leaves begin to change from green to gray. A mulch 2 to 3 inches deep requires 2.5 to 3.0 tons per acre. A clay soil requires more mulch than a lighter soil, and a raised bed requires more (up to 4.0 tons) than a flat-surfaced planting.

Cover the entire field, row and aisle (Figure 3-8), either by hand (in a small operation) or by machine (Figures 3-9-A and B). Some growers rent the local highway power mulcher. Any dense piles should be scattered to prevent smothering. In raised-bed production, straw is applied to the aisle and sides of the bed to conserve moisture and reduce weed growth in August. Additional mulch is applied over the plant for winter protection. If the wind removes the mulch, it must be replaced to ensure complete coverage.

Figure 3-8. Strawberry field with good (complete) coverage of straw mulch.

Figure 3-9-A. A "big bale" mulching machine.

Figure 3-9-B. A "small bale" mulching machine.

Removing Mulch

Remove the winter mulch from the plant row in early spring, generally March 15 to April 15, after danger of severe frost is past but before there is much yellowing of the leaves. If the covering is thin, plants grow through it. Place straw between rows to protect berries from dirt, keeping them cleaner and brighter. If the straw is excessive, set a farm hay rake 1 to 2 inches above the plants to remove the excess. When soil temperature in the upper two inches of soil is above 40°F for two days, the straw should be removed. (See Figures 3-10-A and B.)

Figure 3-10-A. Soil temperature probe next to plants just beginning to grow in the spring.

Figure 3-10-B. Remove mulch when soil temperature is above 40°F for two days.

Frost Protection

Strawberry flower buds are susceptible to frost anytime after bud break. Flower buds that develop early (Earliglow) are more susceptible to frost damage even before first bloom. As flower buds develop from tight buds to open flowers, they become more sensitive to freezing temperatures between 14 to 28°F (Table 3-3). The most typical symptom of frost damage is a black dead area in the center of flowers, or black dead tissue on the tips of young fruit (Figures 3-11-A and B).

Figure 3-11-A. Strawberry flowers with symptoms of frost damage. Note the black (dead) centers.

Figure 3-11-B. Strawberry flowers with frost damage next to undamaged flowers.

Economically, the first flowers that open produce the largest berries, and when 5 to 7 percent of the flowers are lost, 10 to 15 percent of the total crop is lost. Thus, it is usually cost effective to protect flowers that open first with overhead irrigation. Overhead irrigation is effective because as water begins to freeze, heat of fusion is released to maintain 32˚F even though the air temperature continues to drop.

However, evaporation can occur, and if one-seventh of the water evaporates, the process results in cooling and ceases to protect. Under little or no wind, 0.10 inches of water per hour is necessary for protection. As the wind increases, the rate of watering must increase (Table 3-4). However, with wind more than 20 mph, coverage becomes difficult.

Without accurate electronic instruments, place a calibrated thermometer at the lowest point of elevation in the field, turn on the overhead system at 34˚F, and continue watering until the ice melts and continues to melt as temperatures rise. A 34˚F temperature is suggested because as irrigation starts, the temperature drops rapidly to 32˚F. To check the accuracy of your thermometer, place it in a water-crushed ice mixture. After 20 minutes the thermometer should read 32˚F. If calibrating a minimum-maximum thermometer, the top portion of the thermometer will need to be immersed in the slurry.

After several eight-hour nights of irrigating, fields become extremely wet, plant growth may be impeded, and the water supply becomes extremely low. With accurate electronic thermistors or thermocouples placed in the blossom, watering can be withheld until 30˚F.

Continue watering if there is a wind and if bud temperatures are 30˚F. Some Midwest growers have faced 12 or more continuous nights of frost protection for eight or more hours. Consider raised beds or tile drainage under these conditions.

Some basic facts about overhead irrigation and frost protection follow:

- Coverage of plants requires proper spacing, nozzles, and pressure. For severe conditions, make sure nozzles rotate at least once per minute.

Table 3-3. Critical Air Temperatures for Strawberry Buds, Flowers, and Fruit.

Stage of Development[1]			
Buds Emerge	Buds Closed	Flower Open	Small Green Fruit
10˚F	22˚- 27˚F	30˚F	28˚F

[1] Duration of temperature for damage can be 20 minutes to 2 hours, depending upon wind, humidity, and cultivar.

Table 3-4. Inches of Water per Hour to Apply with Wind Speed (mph) at Crop Height and Air Temperature Considered.

	Wind Speed — mph (Crop Height)				
Air Temp. Degrees F at Canopy	0-1	2-4	5-8	10-14	18-22
27	0.10	0.10	0.10	0.10	0.2
24	0.10	0.16	0.30	0.40	0.8
20	0.16	0.30	0.60	0.80	—
18	0.20	0.40	0.70	1.00	—

- Temperature alarms, thermometers, and other electronic instruments must be calibrated and checked. Two alarm systems, accurate within one-half-degree F, can be used to test one another. Set these in the lowest part of the field.
- As soon as plants begin to grow, set the alarm for 19 to 20°F; as buds emerge, increase this to 22 to 27°F; and when the first flower is open, increase it to 34°F. Earliglow is one of the most sensitive and early flowering cultivars.
- Adjust the rate for the predicted temperature and wind speed. Irrigation systems can be set to operate intermittently with automatic controls for no more than three minutes off.
- Before frost protection is needed, make sure the system is functioning properly and back-up parts are available.
- Monitor the system under windy conditions (10 mph) because nozzles can freeze and clog. Walk the lines and remove the ice if needed.
- Continue to add water until the ice starts to melt and continues to melt (makes free water) as temperatures rise above 32°F. Continue to water if wind increases and blossom temperature is 30°F.
- Stop watering when melting is assured, and the ice is completely melted.
- Be prepared to water again on another night.

Pollination — Bees

One strong colony of honeybees per acre should be moved into the field just prior to first bloom. If the pistils are not pollinated or are damaged, a misshapen berry or small berry will develop. Avoid the use of insecticides during bloom.

Strawberries are considered to be a self-fertile fruit with achenes, or one-seeded fruitlets, around a receptacle. The fruit of the first blossom to open is called the primary berry and is usually the largest. The second flower to open is the secondary flower, and the fruit it produces is usually second in size. In 1966 Darrow stated that there were 382 to 518 seeds in primary berries but only 92 to 224 in succeeding berries.

Pollination of all the pistils of a flower is necessary for maximum berry size. If few are fertilized, an irregularly shaped berry or "nubbin" of only one-fifth the size of well-fertilized berries will develop. Self-pollination accounts for 53%, wind increases development to 67%, and insect pollination increases to 91%, based on studies of 11 cultivars.

If wild bees are not plentiful, then honeybees can be used, but they are not strongly attracted to strawberries and may be attracted to competing flowers. Honeybee visits are limited to good weather. However, honeybees in sufficient numbers should be effective pollinators. Flowers pollinated at the most receptive time produced 13 to 58 percent heavier fruit than those before or after the best time. The best time is one to four days after the flower is open. Generally, one strong hive per acre is recommended. Bee hives should be placed in the sun on a dry surface (Figure 3-12).

Figure 3-12. Place bee hives in the sun and on a dry surface.

If a grower has a very large acreage of berries and few active beekeepers in the area and little or no natural shelter-belt areas, then it may be very good insurance to have honeybees brought into strawberry fields as the first flower opens. Growers will be in competition with apple growers in some regions, and beekeepers will prefer other crops to strawberries. Prices for bees could exceed $50 to $100 per hive per rental per year. For some cultivars, where primary flowers have been damaged, there may not be an economic advantage for bees. Also, certain insects can cause poor pollination. Therefore, frost control and insect control measures may need to be adequate before bees are considered.

Spring Fertilization — Matted-Row and June-Bearing Plants

Applying nitrogen to vigorous plants in early spring of the fruiting year may cause a lower yield during the first half of the season but more during the second half. High nitrogen applications can cause soft berries, dense foliage, and greater berry rot. Generally, applying granular nitrogen fertilizer in the spring is not recommended for these reasons.

However, foliar applications of nitrogen have shown some benefit when crown-root damage has resulted from winter or heavy wet and cold soil conditions resulting from rainfall or irrigation for frost protection. Generally, 5 pounds of low biuret (a contaminant) urea per acre or 5 pounds of 20-20-20 water soluble fertilizer per acre for foliar applications will aid plant growth.

If these are applied, use 100 gallons of water per acre with temperatures under 85°F. No more than two applications at two-week intervals are suggested. Do not apply if berries are ripening.

Irrigation

For June-bearers, the number of pistils and the number of cells per berry are determined in the fall. Conditions during the fruit development period determine size. If dry conditions occur, fruit size can be improved by supplemental irrigation. Irrigation should start when the soil moisture is at 50 percent of field capacity. Tensiometer readings should be at 20 to 30 centibars for optimal growth. Soils are too wet when readings are 0 to 10 centibars in the top 12 inches of soil.

Harvesting

Generally, berries ripen within 28 to 30 days (as few as 20 days under optimum conditions) after first bloom. The time between first bloom and full bloom can be 11 to 12 days. A great increase in the number of ripe fruit occurs over the first four to six days of harvest. Berries are harvested every other day under normal temperatures for about six to seven pickings.

Avoid picking the fruit when plants are wet. Keep harvested berries out of the sun and place them under refrigeration as soon as possible. Pick berries when they are fully colored for optimal size and flavor. Berries do not improve in quality after picking.

Berries can be harvested by hiring pickers or inviting the public to pick-your-own. Generally, most Midwest growers use the pick-your-own marketing system. However, with an increasing demand for fresh fruit by retail and wholesale outlets, growers may require more hired pickers to move excess berries.

For hand harvest, it is wise to employ enough pickers to harvest the berries by noon during the cool p art of the day when pickers are most efficient. Harvested berries should be delivered and sold within 24 hours of harvest to reduce spoilage. About six pickers can harvest an acre of berries or about 10,000 pounds over the season. Pickers may be paid by piecework or by the hour. If paid by piecework, they are generally paid 20 to

25 percent of the selling price of the unit they pick. The average picker can harvest 10 quarts (12 to 15 pounds) per hour over the entire season. Under excellent conditions, up to 175 quarts in a 10-hour day may be harvested by the average picker.

Storage

The life of a strawberry fruit after harvest is short due to a high rate of respiration. Firm berries, if precooled at 40°F, will do well at roadside markets. Berries stored for up to seven days at 30°F will be attractive after remaining at room temperature for six hours, though storage for this long should be avoided. The ideal temperature for strawberries that need to be held for two to four days is 33 to 34°F.

Renovation — Renewing the Planting

Strawberries may be fruited more than one year but generally no more than three harvest seasons, depending on vigor and number of plants. Plantings that have greater than a 70 percent plant stand should be renewed or renovated. If the planting is infested with weeds, insects, and diseases, then the field should be plowed after the first fruiting season. Renovation restores life, vigor, and growth to the planting. Some cultivars such as Allstar or Earliglow usually yield large crops for several years.

The renovation process must begin immediately after harvest. The new canopy must be sufficiently developed and finished in growth by early September when flower buds will form for June-bearers. Renovation can proceed in a variety of ways. The major goals of renovation are to:

1. Replace diseased leaves with new leaves.
2. Improve sunlight exposure into the canopy.
3. Fertilize for berry size improvement.
4. Place soil over the crown for improved root development.
5. Control weeds.

These goals are achieved through conducting the following practices:

1. Apply 2,4-D herbicide for broadleaf weed control. Wait seven to eight days for weeds to absorb the material.
2. Mow off the leaves as close to the ground as possible without damaging the crowns (Figures 3-13-A, B, and C). Then incorporate leaves and mulch into the soil, using Step 4 to reduce disease.
3. Some Midwest growers use subsoilers, 14 to 18 inches deep, to break up soil compaction on heavy soil. Subsoiling is most advantageous under dry soil conditions. It improves percolation, drainage, irrigation, and weed control. Subsoilers move parallel to the row and do not harm roots. Subsoiling before rototilling allows the rototiller to break up clods and smooth out the row.
4. Narrow the row to 12 to 18 inches wide with a rototiller or cultivator and allow 1 inch of soil to cover the crown. (Figures 3-14-A, B, and C.)
5. Apply 25 to 40 pounds per acre of actual nitrogen.
6. Apply residual herbicides such as Sinbar. Refer to Chapter 7, *Weed Management in Strawberries,* for information on herbicide use. Also refer to the *Midwest Small Fruit and Grape Spray Guide* for the most current information.
7. Irrigate to incorporate fertilizer and herbicide. Maintain adequate soil moisture to maintain growth during the main growing season.

Figure 3-13-A. Leaves are mowed as close to the ground as possible without damaging plants.

Figure 3-13-B. Matted row three days after mowing off leaves in July.

Figure 3-13-C. New strawberry leaves three days after mowing off leaves in July.

Figure 3-14-A. A rototiller is being used to narrow the strawberry rows at renovation for the flat, matted-row system.

Figure 3-14-B. A rototiller is being used to narrow rows and rebuild a raised bed.

Figure 3-14-C. A special two-row rototiller is narrowing the row, applying nitrogen and other elements, and rebuilding and replacing the raised bed in one operation at renovation.

Delayed Renovation

If renovation is delayed beyond July 15, do not remove leaves because there will be insufficient time for completing a new set of leaves. When leaves are present, certain herbicides cannot be used. See the *Midwest Small Fruit and Grape Spray Guide* for alternatives. Fertilize, subsoil, and water as needed.

Irrigation Mist Cooling

Using overhead irrigation with adequate pressure to create a mist will cool plants and increase growth (roots pull more moisture when cooler), particularly as daytime temperatures reach 90°F and nighttime is 55°F. Intermittent sprinkling is effective with an on-off cycle of three minutes at a rate of 0.10 to 0.13 inch per hour. While irrigation and mist cooling aid plant growth, water stress just before flower bud formation in late August – early September for a two-week period aids in increasing the number of flowers for next spring.

Chapter 4
Soil Fumigation

Need for Soil Fumigation

Consider Previous Cropping History

Select a site that does not have a history of Verticillium wilt in any crop. Also, select a site that does not have a history of red stele or black root rot. To minimize the risk of black root rot, do not replant strawberries immediately after removing an old strawberry planting.

In general, it is also not a good practice (due primarily to Verticillium) to plant strawberries immediately after solanaceous or other Verticillium-susceptible crops. These include tomatoes, potatoes, peppers, eggplant, melons, okra, mint, brambles, chrysanthemums, roses, or related crops. If possible, select sites that have not been planted to any of these crops for at least three to five years. There should be no herbicide residual in the soil from previous crops.

Is This the First Planting of Strawberry on the Site?

If the land has no recent (five years or less) history of strawberry production or Verticillium diseases in other crops, soil-borne diseases such as red stele or Verticillium wilt should not be a problem.

Are You Replanting Strawberries on the Site?

If strawberries are to be replanted in the same field, crop rotation must be used or the field should be fumigated. Chemical fumigation is currently not an option in organic production systems.

With rotation, the site should be plowed, worked down, and planted to a crop that is not susceptible to Verticillium wilt for a minimum of two years. Many soil-borne pathogens form specialized survival structures and are capable of surviving for several years in soil, even when strawberries are not present. The longer the site can be rotated away from strawberries prior to replanting, the better.

The combination of crop rotation plus soil fumigation is a sound approach that is used by many conventional growers. However, for organic growers (who cannot use soil fumigation), crop rotation alone often provides acceptable control for most soil-borne diseases, if the rotation is sufficiently long.

Neither crop rotation nor soil fumigation will reliably provide adequate control of red stele. With red stele, disease-resistant cultivars and improved soil drainage must be emphasized. Cultivars with resistance to red stele and Verticillium wilt should always be used.

Points to Consider When Using Soil Fumigation

Soil fumigation kills most weed seeds, plant pathogens, nematodes, and insects in the soil. Fumigants are generally applied as liquid formulations (Figures 4-1-A and B). After application, true fumigants volatilize to form gases; other pesticides used in a similar manner may remain mixed with soil water.

When using soil fumigation, consider the following points:

- **Target pests.**

  Rates vary for different target pests. In general, nematodes and soil insects are killed at lower rates than weed seeds and fungal or bacterial pathogens. Weed seeds are the most difficult to kill with fumigation. At present, methyl bromide is the only fumigant that provides excellent weed control consistently.

- **Soil texture.**

  As the microscopic spaces between soil particles get smaller and less abundant (as in heavy or compacted soils), fumigant rates must be increased to overcome reduced or slower diffusion and penetration. On heavy soils, rototilling (when dry) can increase the pore

Figure 4-1-A. A gravity flow rig on a tractor for injecting liquid fumigants into the soil.

Figure 4-1-B. Shanks for injecting fumigants into the soil.

space of the soil, improving the effectiveness of subsequent fumigation.

- **Soil temperature.**

  For effective fumigation, soil temperature at a depth of 6 inches must be at least 50°F. Higher soil temperatures favor greater volatilization of fumigants and greater movement through soil spaces.

- **Soil organic matter.**

  Decomposed organic matter improves soil structure and generally helps fumigant dispersion in the soil. However, very high amounts of organic matter may adsorb or tie up a fumigant, reducing its effectiveness. Fresh (undecomposed) crop debris may hinder fumigant dispersion in the soil and may also harbor insects and pathogens that escape the fumigant. Organic matter is most beneficial when it is thoroughly decomposed.

- **Soil moisture.**

  Fumigants move through air spaces in soil and dissolve in soil water. They must enter the soil solution to contact and kill pests. Moderate levels of soil moisture therefore aid in obtaining effective fumigation.

During or immediately after application of soil fumigants, the soil surface should be sealed to prevent the fumigant chemical from escaping into the air too rapidly. This can be done by rolling (Figure 4-2), irrigating, or covering with a tarp or plastic (Figure 4-3), depending on the type of fumigant. At least two to three days of fumigant activity and at least four to 14 days of venting (for fumigant dissipation) should elapse between application of fumigants and planting (depending on the type of fumigant). A three- to four-week interval is better. For this reason, fall is usually the best time to fumigate.

Figure 4-2. Rolling the field to seal in the fumigant.

Figure 4-3. Solid tarping with plastic to seal in the fumigant.

Spring fumigation can be very effective, however, if soils are warm enough and the proper preplant interval is observed. Avoid plowing too deeply after fumigation so that untreated soil is not mixed with treated soil near the surface. Shallow plowing or tilling with clean equipment is recommended. See Table 4-1 for a summary of the characteristics of common soil fumigants.

For good fumigation results:

- Ideally, the site should be worked, fitted, and fumigated in September.
- Plow the soil 8 to 10 inches deep and then disk or rototill so there are no clods, large soil particles, or stones. This should be completed in late August or early September.
- Have a soil temperature between 60 and 70°F at a 6-inch depth.
- Soil moisture should be 50 to 75 percent of field capacity. Check soil moisture with a tensiometer.
- Organic matter (cornstalks, grass, straw, etc.) should be well decomposed.
- Depending on soil type, temperature, and the fumigant used, a two-week to two-month period must intervene between fumigation and planting to avoid crop damage. Some fumigants require only a seven-day waiting period.

Soil testing for nematodes, grubs, or other soil problems aids in the decision of whether or not to fumigate. Do this soil testing in July.

We wish to thank Diana Roll, The Ohio Department of Agriculture for assistance with this chapter.

Table 4-1. Fumigant Rates and Spectrum of Activity.

Common Name	Trade Name	Rates/ Acre	Level of Control[a]			Comments
			Nema-todes	Fungi	Weeds	
1,3-dichloro-propene	Telone II	16-20 gal	4	1	0	Slight suppression of some soil-borne organisms.
1,3-dichloro-propene + chloro-picrin	Telon C-17	35 gal	4	5	1	Effective against most soil-borne diseases; some weed seed suppression.
	Telon C-35	35 gal	4	5	1	
methyl iso-thiocyanate com-pounds	Vapam	50-100 gal	4	4	3	Most effective when applied through over-head irrigation; incorporate thoroughly in soil.
methyl bromide	Brom-O-Gas	275-350 lb	5	4	4-5	Requires a plastic seal; highly toxic to humans; weak against some *Pythium* species.
methyl bromide + chloro-picrin	Terr-O-Gas 67	275-350 lb	5	5	4-5	Most effective for control of weeds, soil-borne diseases, nematodes, and insects; requires plastic seal; highly toxic.

[a] 0 = no control; 5 = excellent control.

Note on methyl bromide: Methyl bromide has been the standard for soil fumigation for many years. This is largely due to its efficacy for killing weed seeds as well as other soil-borne pests and diseases. Due to problems with bromine in the atmosphere, the use of methyl bromide as a soil fumigant in the United States is being phased out. Methyl bromide will be used until current stockpiles are used up. A great deal of research has been conducted to develop new fumigants with the same or better activity than methyl bromide. There are some good materials being developed and at the time this bulletin was printed, methyl iodide was reported to be close to registration in the United States for use as a soil fumigant. Methyl iodide is very similar to methyl bromide and has been reported to have very good activity as a soil fumigant. Consult your local cooperative extension service as to the availability and use of any new soil fumigants.

Chapter 5
Integrated Management of Strawberry Diseases

The objective of an integrated disease-management program is to provide a commercially acceptable level of disease control on a consistent (year-to-year) basis. This is accomplished by developing a program that integrates all available control methods into one program. An effective disease-management program for strawberries should emphasize the integrated use of specific cultural practices, knowledge of the pathogen and disease biology, disease-resistant cultivars, and timely applications of approved fungicides or biological control agents, when needed.

In order to reduce the use of fungicides to an absolute minimum, the use of disease-resistant cultivars and various cultural practices must be strongly emphasized. Many strawberry cultivars adapted to the Midwest have good resistance to a number of important diseases. (See Table 5-1 on page 52.) This is generally not the case with other small fruit crops.

Identifying and Understanding the Major Strawberry Diseases

It is important for growers to be able to recognize the major strawberry diseases. Proper disease identification is critical to making the correct disease management decisions. In addition, growers should develop a basic understanding of pathogen biology and disease cycles for the major strawberry diseases. The more you know about the disease, the better equipped you will be to make sound and effective management decisions. Color photographs of disease symptoms on strawberries, as well as information on pathogen biology and disease development, can be found in the following literature:

Strawberry Production Guide — This is a very comprehensive book covering most phases of strawberry production. It can be purchased from the Northeast Regional Agricultural Engineering Service, 152 Riley-Robb Hall, Cooperative Extension, Ithaca, NY 14853. Phone: 607-255-7654.

Compendium of Strawberry Diseases — Published by the American Phytopathological Society, 3340 Pilot Knob Road, St. Paul, MN 55121. Phone: 612-454-7250, 1-800-328-7560. This is the most comprehensive book on strawberry diseases available. All commercial growers should have a copy.

Midwest Small Fruit Pest Management Handbook — Bulletin 861 from Ohio State University Extension. This is a very comprehensive book covering all phases of Integrated Pest Management on strawberry, raspberry, blueberry, and grape. Copies can be obtained from Ohio State University Extension, Media Distribution, 216 Kottman Hall, 2021 Coffey Road, Columbus, OH 43210-1044. Phone: 614-292-1607.

A description of symptoms, causal organisms, and control methods for the most common strawberry diseases in the Midwest is presented here.

Foliar Diseases

There are three major leaf diseases of strawberries in the Midwest. They are leaf spot, leaf scorch, and leaf blight (Figure 5-1). All three diseases can occur singly or together on the same plant or even on the same leaf. All three are caused by fungi.

Under favorable environmental conditions, these three diseases can cause serious reductions in strawberry yields. They damage the strawberry plant by causing premature leaf death, reduction in fruit quality, a general weakening of the plant, and (in some situations) plant death. In order to maximize strawberry production, these leaf diseases must be recognized and controlled. Fortunately, several cultivars have good resistance to leaf spot and leaf scorch.

Leaf spot and leaf scorch usually appear first in early to mid-spring. Leaf blight is more common during the summer and early fall.

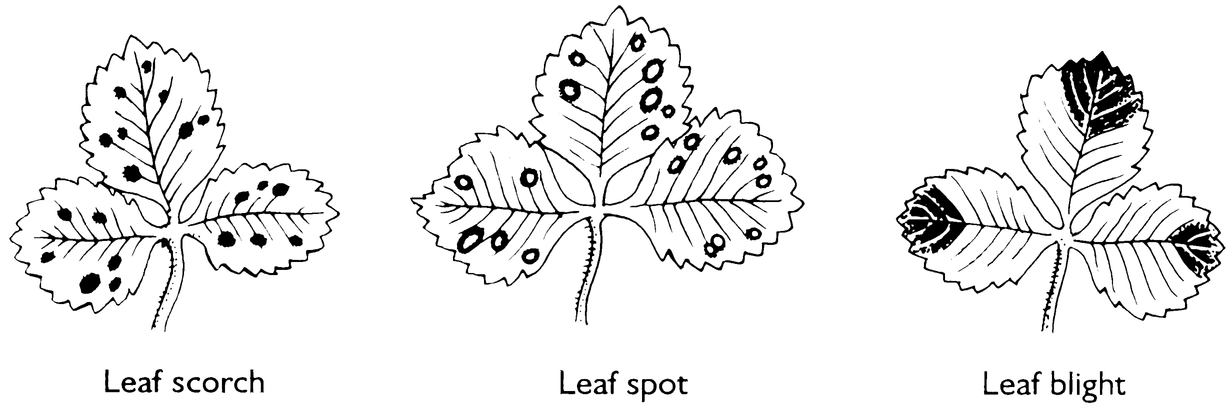

Figure 5-1. Typical symptoms of leaf scorch, leaf spot, and leaf blight on strawberry leaves.

Leaf Spot

Symptoms

Leaf spot is caused by the fungus *Mycosphaerella fragariae*. The leaf spot fungus can infect leaves, fruit, petioles, runners, fruit stalks, and berry caps or calyxes. The most obvious symptoms of the disease are small round spots. These spots develop on the upper surface of the leaf and at first are dark purple to reddish-purple (Figure 5-2). They range in size from 1/8 to 1/4 inch in diameter.

With time, the centers of the spots become tan or gray and eventually almost white, while their margins remain dark purple. Later in the season, tan or bluish areas form on the underleaf surface. Symptoms on other plant parts, except fruit, are almost identical to those on the upper leaf surface.

On fruits, superficial black spots may form during moist weather (Figure 5-3). The spots form on ripe berries and around groups of seeds. They are about 1/4 inch in diameter, and usually there are only one or two spots per fruit. However, some fruits may be more severely infected.

Figure 5-2. Strawberry leaf spot symptoms on a leaflet.

Figure 5-3. Black seed disease on strawberry fruit. This disease is caused by the same fungus that causes strawberry leaf spot.

Disease Development

This fungus can produce two types of spores that infect newly-emerging leaves in spring. First, older infected leaves that remain alive during winter may give rise to conidia (spores) that are spread to new foliage by splashing water or by handling infected plants. Another type of spore (ascospore) is produced in speck-sized black perithecia, which form at the edges of the leaf spots during autumn. In the spring, these ascospores are forcibly ejected from perithecia and are carried by wind or water to new leaf tissue.

Infection by both types of spores occurs through the underleaf surface. Temperatures between 65 and 75°F are optimum for infection and disease development. Infections may occur throughout the growing season, except during hot, dry weather. Young expanding leaves are the most susceptible to infection.

Leaf Scorch

Symptoms

Leaf scorch is caused by the fungus *Diplocarpon earliana.* The leaf scorch fungus can infect leaves, petioles, runners, fruit stalks, and caps of strawberry plants.

Leaf scorch symptoms are very similar to the early stages of leaf spot. Round to angular or irregular dark-purple spots up to 1/4 inch in diameter are scattered over the upper leaf surface (Figure 5-4). As spots enlarge, they resemble small drops of tar. This tar-like appearance is caused by the formation of large numbers of minute, black, fungal fruiting bodies (acervuli). The centers of the spots remain dark purple. This distinguishes the disease from leaf spot where the center turns white.

If many infections occur on the same leaf, the entire leaf becomes reddish or light purple. Severely infected leaves dry up and appear scorched. Similar, but elongated, spots may appear on other affected plant parts. Lesions may girdle fruit stalks, causing flowers and young fruit to die.

Infections on green berries are rare, appearing as red-to-brown discolorations or a flecking on the fruit surface. The leaf scorch fungus can infect strawberry leaves at all stages of development.

Figure 5-4. Leaf scorch on a strawberry. First symptoms are individual red spots.

Disease Development

The fungus overwinters on infected leaves that survive the winter. In the spring, conidia are produced on both leaf surfaces in speck-sized black acervuli. The fungus also produces ascospores in the early spring, within disk-shaped apothecia (fungal fruiting structures) that appear as black dots in old lesions on the lower surface of diseased leaves that died during winter. In the presence of moisture, ascospores germinate within 24 hours and infect the plant through the lower leaf surface. After symptom development, conidia are produced on the leaf spots in large numbers throughout the growing season. Therefore, repeated infections occur whenever weather conditions are favorable. Conidia are spread mainly by splashing water.

Leaf Blight (Phomopsis Leaf Blight)

Symptoms

Leaf blight is caused by the fungus *Phomopsis obscurans.* Leaf blight is found most commonly on plants after harvest. The disease is distinctively different from both leaf spot and leaf scorch. The enlarging leaf spots of this disease are round to elliptical or angular and a quarter of an inch to an inch in diameter (Figure 5-5-A). Spots are initially reddish-purple. Later, they develop a darker brown or reddish-brown center surrounded by a light-brown area with a purple border. Similar spots may sometimes develop on the fruit caps. Usually, only one to six lesions develop on a leaflet. Often the infected area becomes V-shaped, with the widest part of the V at the leaf margin. Fruit infection is rare, but can be severe. Infected fruits eventually appear dark or black as they become covered with tiny black fruiting bodies (pycnidia) of the fungus (Figure 5-5-B).

New lesions appear throughout the summer and fall if weather conditions are favorable. Older leaves become blighted and may die in large numbers. This disease is usually more destructive on slow-growing or weak plants.

Information on resistance to leaf blight in currently used cultivars is limited. If growers encounter a high level of disease on certain cultivars, these cultivars should be avoided.

Figure 5-5-A. Phomopsis leaf blight on strawberry.

Figure 5-5-B. Symptoms of Phomopsis fruit rot. Fruit rot is caused by the same fungus that causes leaf blight.

Disease Development

This fungus produces spores (conidia) in speck-sized black pycnidia (fungal fruiting bodies) embedded in the centers of older leaf lesions. Conidia ooze out of pycnidia during damp weather when temperatures are high. Conidia are splashed to new leaf tissue where they germinate in the presence of free water to initiate new infections on leaves and fruit. The fungus overwinters on either infected leaves that survive the winter or in dead tissue on old infected leaves.

Powdery Mildew

Powdery mildew is caused by the fungus *Sphaerotheca macularis.* Generally, the disease is not a serious problem in the Midwest; however, under the proper environmental conditions and on highly susceptible cultivars, the disease can become serious. Disease resistance is available in several cultivars (See Table 5-1 on page 52). Growers who wish to reduce fungicide use are encouraged to avoid highly susceptible cultivars.

Symptoms

Foliage symptoms usually are the most obvious. An upward curling of leaf edges usually is the first symptom seen. Dry, purplish or brownish patches develop on the lower surface of infected leaves, and reddish discoloration may develop on the upper surface (Figure 5-6). Patches of white, powdery fungus mycelium may appear on leaves as the disease progresses (Figure 5-7).

Figure 5-6. Reddish-purple discoloration of leaves is often associated with powdery mildew infection.

Figure 5-7. Patches of white fungus growth on strawberry infected with powdery mildew.

Disease Development

The fungus that causes strawberry powdery mildew infects only wild and cultivated strawberries. This pathogen cannot survive in the absence of living host tissue. It apparently overwinters in infected leaves. Spores are carried by wind to infect new growth in the spring.

Development and spread of powdery mildew is favored by moderate to high relative humidity and temperatures of about 60 to 80°F (15 to 27°C). Unlike most other fungi that cause plant disease, powdery mildew does not require free water for spores to germinate and infect. In dry years, when most other diseases are not a problem, powdery mildew can be very serious.

Angular Leaf Spot (Bacterial Blight)

Angular leaf spot or bacterial blight of strawberries is caused by the bacterium *Xanthomonas fragariae.* In the Midwest, it is the only reported strawberry disease that is caused by a bacterium. The disease was first reported in Minnesota in 1960 and has since been found in other regions of the United States. Angular leaf spot appears to be spreading rapidly to many strawberry-growing areas of the world with the importation of planting material. The disease has become a serious problem in several strawberry plantings throughout the Midwest.

Symptoms

Typical symptoms of angular leaf spot appear initially as minute water-soaked lesions on the lower leaf surface (Figure 5-8). These lesions enlarge to become angular spots, usually delineated by small veins. An important distinguishing characteristic of this disease is that lesions are translucent when viewed with transmitted light, but dark green when viewed with reflected light (Figure 5-9).

Under moist conditions, lesions often have a viscous bacterial exudate on the lower leaf surface. When it dries, the exudate forms a whitish, scaly film. This exudate or film is an additional characteristic that is useful in the identification of angular leaf spot.

Lesions may coalesce to cover large portions of the leaf. Eventually, lesions become visible on the upper leaf surface as irregular, reddish-brown spots, which are necrotic and opaque to transmitted light. A chlorotic halo may surround the lesion. At this stage, symptoms may be difficult to distinguish from those of common leaf spot and leaf scorch.

Heavily infected leaves may die, especially if major veins are infected. Occasionally, under natural conditions, infection follows the major veins, resulting in veinal water-soaking that may or may not spread to the interveinal regions.

Infection by *X. fragariae* may become systemic. The pathogen can infect all plant parts except fruits and roots and, in some cases, even the fruits have been infected, apparently only in the tissue adjacent to an infected calyx (fruit cap). Calyx infection can be serious. Infected calyx tissues turn brown to black, resulting in unattractive fruit (Figure 5-10).

Figure 5-8. Angular leaf spot (bacterial blight) symptoms on lower leaf surface. Note the water-soaked spots.

Figure 5-9. Angular leaf spot (bacterial blight) symptoms on upper leaf surface. Note the translucent yellow spots.

Figure 5-10. Angular leaf spot (bacterial blight) symptoms on strawberry calyx. Note the brown discoloration and drying.

Disease Development

Inoculum for the primary infection of new growth in the spring comes from infected dead leaves where the pathogen overwintered. *X. fragariae* may survive for extended periods in dry leaves or in infected leaves buried in the soil. The bacterium can also survive within tissues of systemically infected plants. Spread in early spring is primarily from infected leaf debris or infected crowns of systemically infected plants.

Bacteria that exude from leaf lesions under high-moisture conditions may provide secondary inoculum for further spread of the disease. Bacteria may be disseminated to uninfected plants or leaves by splashing water, such as rain or overhead irrigation. *X. fragariae* gains entrance into host tissue either passively through wounds or actively as motile cells swim into natural plant openings by means of drops of dew, gutation fluid, rain, or irrigation water.

Development of the disease is favored by moderate to cool daytime temperatures around 68°F (20°C), low nighttime temperature (near or just below freezing), and high relative humidity. Long periods of precipitation, sprinkler irrigation to protect plants from freezing, or heavy dews in the spring also favor the disease. Young leaf tissue or leaves on healthy, vigorous plants are more likely to become infected than those on diseased or environmentally stressed plants.

Copper fungicides have been recommended for control of bacterial blight with varying degrees of success when applied in a protectant program. Once the disease is established in the planting, there is little that can be done to control it. Hot, dry weather is the best cure for the disease.

Cultivars differ in their susceptibility to the disease. None are completely resistant, but Cavendish, Annapolis, Allstar, Honeoye, and Kent are all highly susceptible.

Strawberry Root Diseases

Red Stele

Red stele is caused by the soil-borne pathogen *Phytophthora fragariae*. The red stele pathogen is a fungus-like organism called an oomycete and is not a true fungus. Many commercial strawberry cultivars are susceptible to the red stele pathogen; however, many cultivars have good resistance to several races of the pathogen (Table 5-1 on page 52). The use of disease-resistant cultivars and selection of sites with good soil drainage are the key methods of control.

This root-rot disease has become a serious problem facing strawberry production in the northern two-thirds of the United States. The disease is most destructive in heavy clay soils that are saturated with water during cool weather. Once it becomes established in the field, the red stele pathogen can survive in soil up to 13 years and probably much longer.

Normally, the disease is prevalent only in the lower or poorly drained areas of the planting; however, it may become fairly well distributed over the entire field, especially during a cool wet spring. The red stele pathogen may become active at a soil temperature of 40˚F. However, the optimum soil temperature for growth and disease development is between 55 and 60˚F. Under favorable conditions of high soil moisture and cool temperatures, plants will show typical disease symptoms within 10 days after infection.

Symptoms

When plants start wilting and dying in the more poorly drained portions of the strawberry field, the cause is very likely red stele disease (Figure 5-11). Infected plants are stunted, lose their shiny green luster, and produce few runners. Younger leaves often have a metallic bluish-green cast. Older leaves turn prematurely yellow or red.

With the first hot, dry weather of early summer, diseased plants wilt rapidly and die. Diseased plants have very few new roots compared to healthy plants that have thick, bushy white roots with many secondary feeder roots (Figure 5-12). Infected strawberry roots usually appear gray, while the new roots of a healthy plant are yellowish-white.

Figure 5-11. Plants dying from red stele root rot.

Figure 5-12. Root system from a red-stele-infected strawberry plant.

The best way to identify the disease is to carefully dig up a wilted plant and peel off the outside portion of several roots. The inside or central portion of the root is known as the stele. If the stele is pink to brick red or brownish red, the plant probably has the red stele disease (Figure 5-13). The stele of normal plants is yellowish-white. The red color may show only near the dead tip of the root, or it may extend the length of the root. The red stele is best seen in the spring up to the time of fruiting. No other disease of strawberry produces this symptom.

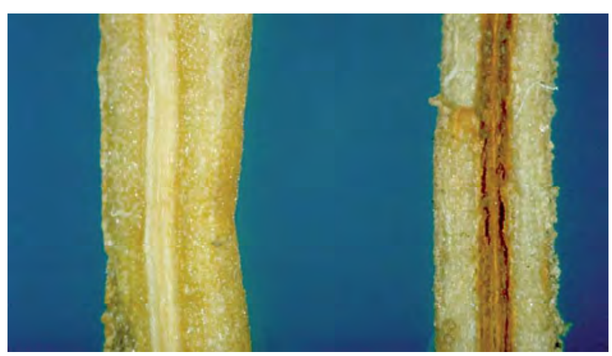

Figure 5-13. Longitudinal section of a healthy (left) and red-stele-infected (right) strawberry root.

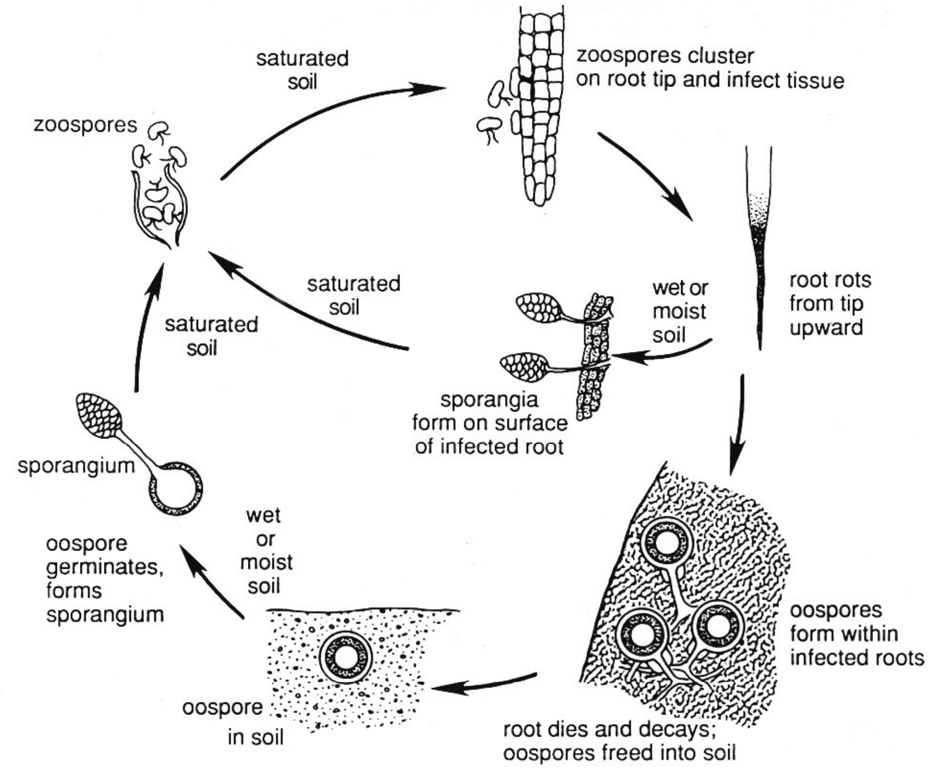

Figure 5-14. Red steel disease cycle. From the Small Fruit IPM Disease Identification Sheet No. 2, New York State Agricultural Experiment Station. Used with permission.

Disease Development (Figure 5-14)

The red stele pathogen is introduced into new planting sites mainly through the distribution of infected plants. The pathogen can be spread within a field or area by anything that carries or moves infested soil (implements, shoes, water, etc.). Once in the field, spores (oospores) germinate and produce large numbers of another type of spore (sporangium) in the presence of free water. Also in the presence of free water, sporangium produce another type of spore called zoospores. Zoospores are motile and swim about when soils are saturated with water.

Zoospores invade the tips of young fleshy roots. Once in the roots, the pathogen grows and destroys the water- and food-conducting tissues, resulting in wilting and plant death. As soil temperatures rise, the pathogen forms large numbers of oospores in the stele of infected plants. These oospores survive periods of hot, dry, and freezing weather for several years in the soil.

Verticillium Wilt

Verticillium wilt, caused by the soil-borne fungus *Verticillium dahliae,* can be a major factor limiting production. When a plant is severely infected, the probability of it surviving to produce a crop is greatly reduced. The Verticillium fungus can infect nearly 300 different host plants, including many fruits, vegetables, trees, shrubs, and flowers as well as numerous weeds and some field crops.

Once the fungus becomes established in the field or garden, it may remain alive for 25 years or longer. Several cultivars have resistance to Verticillium wilt. The use of resistant cultivars, proper site selection, and crop rotation to avoid infested soil are the key methods of control.

Cool, overcast weather interspersed with warm, bright days is most favorable for development of Verticillium wilt. Optimal conditions for infection and disease development occur when soil temperatures are 70 to 75°F.

Many soils in the Midwest contain the Verticillium wilt fungus. The fungus can be introduced into uninfested soil on seeds, tools, farm machinery, and from the soil and roots of transplants.

Symptoms

The first symptoms of Verticillium wilt in new strawberry plantings often appear about the time runners begin to form. In older plantings, symptoms usually appear just before picking time. Symptoms on above-ground plant parts may differ with the susceptibility of the cultivar affected. In addition, above-ground symptoms are difficult to differentiate from those caused by other root-infecting fungi. Isolation from diseased tissue and culturing the fungus in the laboratory are necessary for positive disease identification.

On infected strawberry plants, the outer and older leaves drop, wilt, turn dry, and become reddish-yellow or dark brown at the margins and between veins (Figure 5-15). Few new leaves develop, and those that do tend to be stunted and may wilt and curl up along the midvein. Severely infected plants may appear stunted and flattened with small yellowish leaves. Brownish-to-bluish black streaks or blotches may appear on the runners or petioles. New roots that grow from the crown are often dwarfed with blackened tips. Brownish streaks may occur within the decaying crown and roots.

If the disease is serious, large numbers of plants may wilt and die rapidly (Figure 5-16). When the disease is not so serious, an occasional plant or several plants scattered over the entire planting may wilt and die.

Figure 5-15. Strawberry plant dying from Verticillium wilt. Note the outer leaves die first.

Figure 5-16. Strawberry field showing severe symptoms of Verticillium wilt.

Disease Development

The fungus overwinters in soil or plant debris as dormant mycelium or black speck-sized bodies (microsclerotia). These microsclerotia can remain viable in the soil for many years. Under favorable environmental conditions, they germinate and produce thread-like fungal structures (hyphae). Hyphae can penetrate root hairs directly or through breaks or wounds in the rootlets.

Once inside the root, the fungus invades and destroys the water-conducting tissue. Destruction of water-conducting tissue results in reduced water uptake by the plant; thus, plants wilt and eventually die. As fungal colonies get older, they produce microsclerotia in infected host tissue, and the disease cycle is completed.

Black Root Rot

Black root rot is the general name for several root disorders that produce similar symptoms. The disorders are not clearly understood and are generally referred to as a root-rot complex. Although the exact cause of the black root rot is not known, one or more of the following is thought to be responsible — soil fungi (such as *Rhizoctonia* and *Fusarium),* nematodes, winter injury, fertilizer burn, soil compaction, herbicide damage, drought, excess salt, excess water (saturated soils), or improper soil pH.

Black root rot has been found in every strawberry-growing area of the United States. Injured plants may be scattered throughout the planting or localized in one or more areas (Figure 5-17). A considerable incidence of black root rot has been observed in recent years throughout the Midwest. Once the disease is established (shows up) in the planting, little or nothing can be done to control it.

To recognize black root rot symptoms, it is necessary to know what a normal root looks like. Newly developed main roots of a normal strawberry plant are pliable and almost white. After several months of growth, they generally become woody and are dark brown to black on the surface. When this dark surface is scraped away, a yellowish-white living core can be seen. Small feeder roots that branch out from the main roots should be white as long as they are active.

Roots affected by black root rot have one or more of the following symptoms:

- The root system is much smaller than normal.
- The main roots are spotted with dark patches (lesions) or zones (Figure 5-18).
- The feeder roots are lacking or are spotted with dark patches or zones.
- All or part of the main root is dead (Figure 5-19).

Figure 5-17. Strawberry field showing black root rot symptoms.

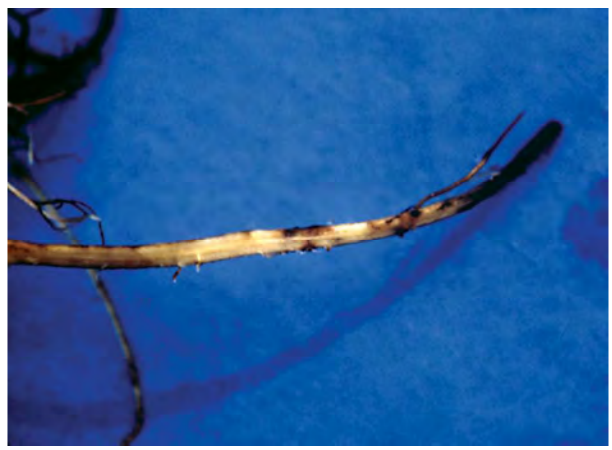

Figure 5-18. Strawberry root with black root rot symptoms. Note the black discoloration (lesions) on the root.

Figure 5-19. Strawberry root system with advanced stages of black root rot. Note the dead, black "rat-tail" roots.

Strawberry Fruit Rots

Botrytis Fruit Rot (Gray Mold)

One of the most serious and common fruit rot diseases of strawberry is gray mold. Gray mold is caused by the fungus *Botrytis cinerea*. Under favorable environmental conditions for disease development, serious losses can occur. The gray mold fungus can infect petals, flower stalks (pedicels), fruit caps, and fruit.

The disease is most severe during prolonged rainy and cloudy periods during bloom and harvest. Abundant gray-brown, fluffy, fungal growth on infected tissue is responsible for the disease's name of gray mold. Resistance is not available in most cultivars; therefore, fungicide application during bloom and the use of various cultural practices are key control methods.

Symptoms

Young blossoms are very susceptible to infection. One to several blossoms in a cluster may show blasting (browning and drying) that may spread down the pedicel. Fruit infections usually appear as soft, light brown, rapidly enlarging areas on the fruit (Figure 5-20). If the infection remains on the plant, the berry usually dries up, mummifies, and becomes covered with a gray, dusty powder (Figure 5-21).

Fruit infection is most severe in well-protected, shaded areas of the plant where the humidity is higher and air movement is reduced. Berries resting on soil or touching another decayed berry or a dead leaf in dense foliage are commonly affected. The disease may develop on young (green) fruits, but symptoms are more common as the fruits mature.

Figure 5-20. Immature strawberry fruit with symptoms of Botrytis fruit rot (gray mold). Note the symptoms usually develop first on the calyx end of the fruit.

Figure 5-21. Botrytis fruit rot (gray mold) on a mature strawberry fruit. Note the dense coating of fungal mycelia and spores (the gray mold).

Often, the disease is not detected until berry picking time. During harvest, the handling of infected fruit will spread the fungus to healthy berries. After picking, mature fruits are extremely susceptible to gray mold, especially if bruised or wounded. Under favorable conditions for disease development, healthy berries may become a rotted mass within 48 hours after picking.

Disease Development (Figure 5-22)

The fungus is capable of infecting a great number of different plants. It overwinters as minute, black, fungal bodies (sclerotia) and/or mycelium in plant debris, such as dead strawberry leaves within the row. Research has shown that most spores that cause primary infections in the spring are produced on dead leaves within the row that were produced during the previous growing season. In early spring, these fungal bodies produce large

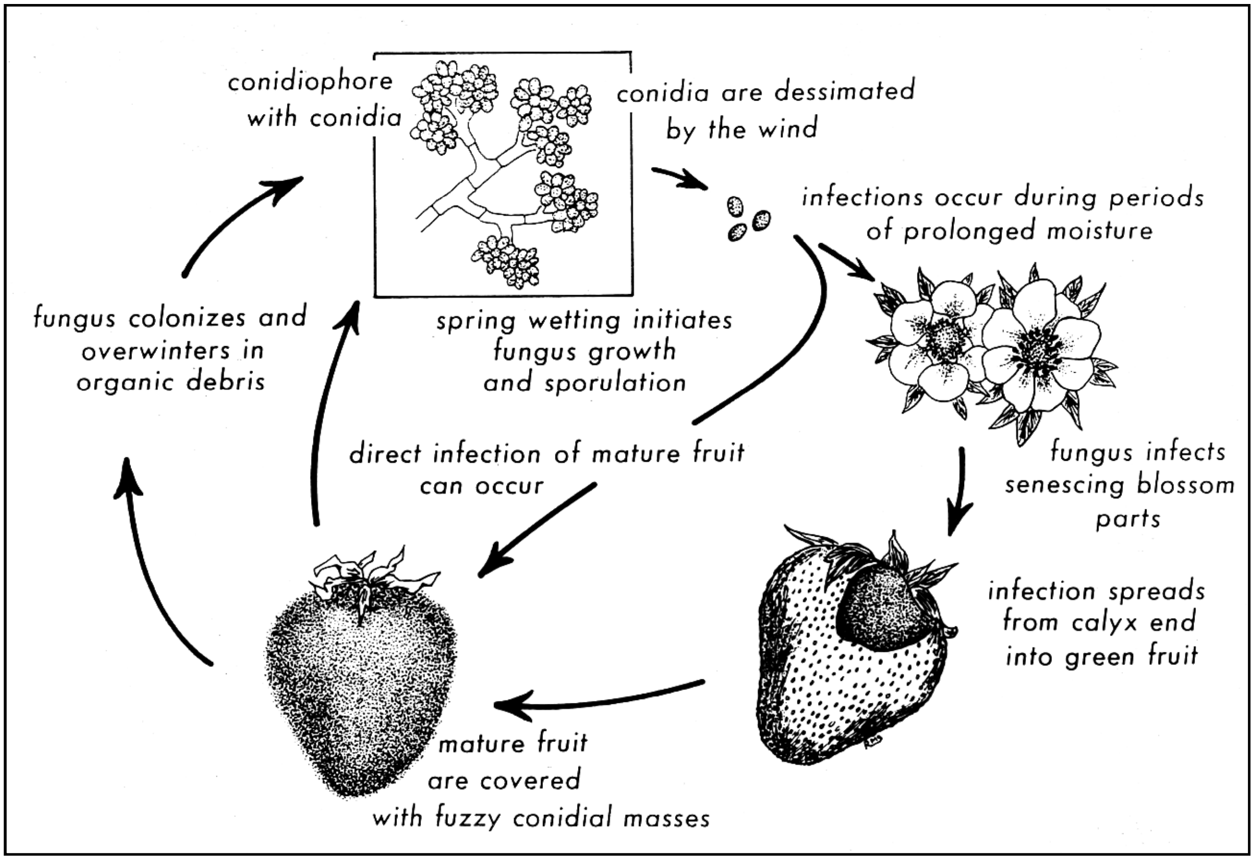

Figure 5-22. Disease cycle of gray mold on strawberry. From the Small Fruit IPM Disease Identification Sheet No. 1, New York State Agricultural Experiment Station. Used with permission.

numbers of microscopic spores (conidia), which are spread by wind throughout the planting. They are deposited on blossoms and other plant parts where they germinate in a film of moisture. Infection occurs within a few hours.

Disease development is favored by wet conditions accompanied by temperatures between 41 and 86°F. Conditions that keep flowers and fruit wet, such as rain, dew, or sprinkler irrigation, encourage Botrytis rot.

Strawberries are susceptible to Botrytis during bloom and again as fruits ripen. During bloom, the fungus colonizes senescing flower parts, turning the blossoms brown. The fungus usually enters the fruit through flower parts, where it remains inactive (latent) within the tissues of infected green fruits. As the fruit matures, the fungus becomes active and rots the fruit close to or during harvest. Thus, while infection actually occurs during bloom, symptoms are usually not observed until harvest. It is very important for growers to realize that the majority of fruit infection actually occurs through flowers during bloom, in order to time fungicide applications for gray mold control during bloom.

Leather Rot

Leather rot is caused by the soil-borne pathogen *Phytophthora cactorum.* The leather-rot pathogen is a fungus-like organism called an oomycete and is not a true fungus. Leather rot has been reported in many regions throughout the United States. In many areas, it is considered a minor disease of little economic importance. However, excessive rainfall during May, June, and July can lead to severe fruit losses and quality reduction. In 1981, many commercial growers in Ohio lost up to 50% of their crop to leather rot.

The leather rot pathogen primarily attacks the fruit but may also infect blossoms. The key control methods are maintaining a good layer of straw mulch between fruit and the soil, selecting well-drained planting sites, improving water drainage through tiling before planting, or using other methods to improve soil drainage. Avoiding soils that become saturated with water is critical for leather rot control.

Symptoms

The leather rot pathogen can infect berries at any stage of development. When the disease is serious, infection of green fruit is common. On green berries, diseased areas may be dark brown or natural green outlined by a brown margin (Figure 5-23). As the rot spreads, the entire berry becomes brown, maintains a rough texture, and is leathery in appearance.

Figure 5-23. Leather rot symptoms on an immature strawberry fruit.

The disease is more difficult to detect on ripe fruit. On fully mature berries, symptoms may range from little color change to discoloration that is brown to dark purple (Figure 5-24). Generally, infected mature fruit are dull in color and are not shiny or glossy. Infected ripe fruit are usually softer to the touch than healthy fruit.

Figure 5-24. Leather rot symptoms on a mature strawberry fruit. Note the purplish to pink discoloration.

When diseased berries are cut across, a marked darkening of the water-conducting system to each seed can be observed. In later stages of decay, mature fruits also become tough and leathery. Occasionally, a white moldy growth can be observed on the surface of infected fruit. In time, infected fruit dry up to form stiff, shriveled mummies.

Berries that are affected by leather rot have a distinctive and very unpleasant odor and taste. Even healthy tissue on a slightly rotted berry is bitter. This presents a special problem to growers in pick-your-own operations. An infected mature berry with little color change may appear normal and be picked and processed with healthy berries. Consumers have complained of bitter tasting jam or jelly made with berries from fields where leather rot was a problem. Leather rot is most commonly observed in poorly drained areas where there is or has been free-standing water or on berries in direct contact with the soil.

Disease Development (Figure 5-25)

The pathogen survives the winter as thick-walled resting spores, called oospores, that form within infected fruit as they mummify. These oospores can remain viable in soil for long periods of time. In the spring, oospores germinate in the presence of free water and produce a second type of spore called a sporangium. A third type of spore called a zoospore is produced inside the sporangium. Up to 50 zoospores may be produced inside one sporangium. The zoospores have tails (flagella) and can swim in a film of water. In the presence of free water on the fruit surface, the zoospores

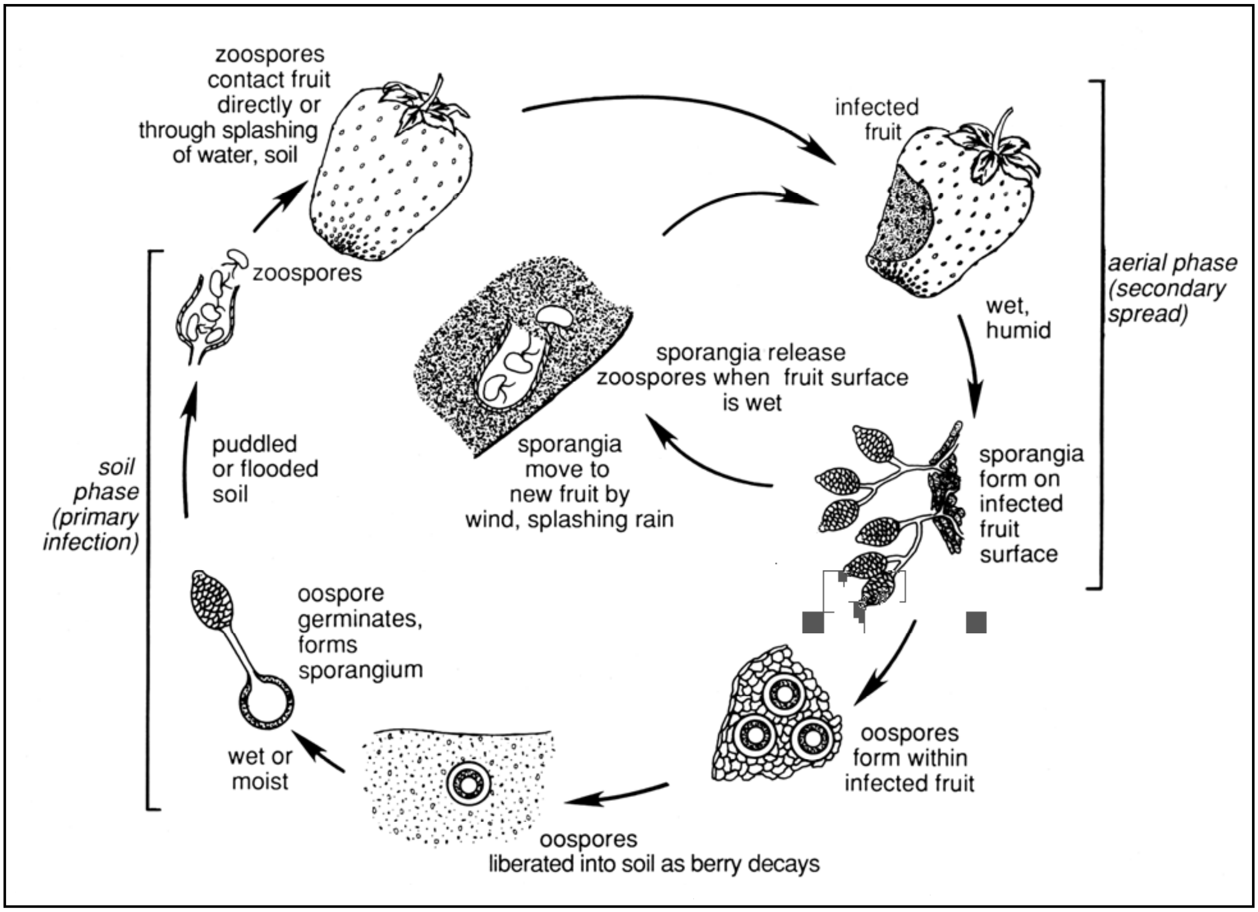

Figure 5-25. Disease cycle of leather rot on strawberry. Taken from the Small Fruit IPM Disease Identification Fact Sheet No. 4, New York State Agricultural Experiment Station. Used with permission.

germinate and infect the fruit. In later stages of disease development, sporangia are produced on the surface of infected fruit under moist conditions.

The disease is spread by splashing or wind-blown water from rain or overhead irrigation. Sporangia and/or zoospores are carried in water from the surface of the infected fruit to healthy fruit where new infections occur. Under the proper environmental conditions, the disease can spread very quickly. A wet period (free water on fruit surface) of two hours is sufficient for infection. The optimum temperatures for infection are between 62 and 77°F.

As the length of the wet period increases, the temperature range at which infection can occur becomes much broader. As infected fruit dry up and mummify, they fall to the ground and lie at or slightly below the soil surface. Oospores formed within the mummified fruit enable the fungus to survive the winter and cause new infections the following year, thus completing the disease cycle.

Strawberry Anthracnose

Anthracnose is a disease that can affect foliage, runners, crowns, and fruit. Various forms of anthracnose can be caused by several fungi. In the Midwest, the most common form of the disease is fruit rot, caused by the fungus *Colletotrichum acutatum.* If the disease becomes established in the planting, serious losses can occur.

Very few Midwest cultivars with resistance are available. Several new fungicides are effective for controlling anthracnose; however, once the disease develops on fruit in the planting, it is difficult to control with fungicides. Managing the movement of pickers into and out of infested areas and adjusting irrigation practices can be beneficial in preventing disease spread.

Symptoms

Affected stems are sometimes girdled by lesions, causing individual leaves or entire daughter plants to wilt. Under warm, humid conditions, salmon-colored masses of spores may form on anthracnose lesions.

When crown tissue is infected and becomes decayed, the entire plant may wilt and die. When infected crowns are sliced open, internal tissue is firm and reddish brown. Crown tissue may be uniformly discolored or streaked with brown.

On fruit, symptoms first appear as whitish, water-soaked lesions up to 1/8 inch in diameter, which turn brown and enlarge within two to three days to involve most of the fruit (Figure 5-26-A and B). Lesions are covered with salmon-colored spore masses. Infected fruit eventually dry down to form hard, black, shriveled mummies. Fruit can be infected at any stage of development.

Disease Development

The disease is probably introduced into new plantings on infected plants. Spore production, spore germination, and infection of strawberry fruits are favored by warm, humid weather and by rain. Spores require free water on the plant surface in order to germinate and infect.

Anthracnose fruit rot is considered to be a warm-weather disease with an optimum temperature for disease development near 80°F. Thus, the disease is generally a problem in the Midwest when abnormally high temperatures and rainfall occur during fruit set and harvest. Spores are dispersed primarily by water splash. Once the disease is established in the field, the fungus can overwinter on infected plant debris, primarily old, infected, mummified fruit.

Figure 5-26-A. Anthracnose lesion on strawberry fruit.

Figure 5-26-B. Strawberry fruit with multiple anthracnose lesions.

Plant Parasitic Nematodes

Plant parasitic nematodes are microscopic round worms and are common in soils throughout the Midwest. Lesion and root-knot nematodes are probably the most destructive kinds in Midwestern plantings. These organisms restrict root growth by feeding directly on roots. This makes plants less efficient at taking up water and minerals from the soil.

Nematodes can also cause strawberry roots to be more susceptible to root-rotting fungi. Strawberry plantings in nematode infested soils are not long-lived. Production will decline rapidly after one or two seasons. Nematode damage is most common and most severe in replant situations, because preceding crops increase nematode numbers, and high populations of these parasites may be present when the young plants are set. Under these conditions, strawberries never develop strong root systems.

Symptoms

Strawberry plants infested with nematodes may be stunted and show symptoms of mineral deficiencies and water stress, particularly as the berries form. Because nematodes are unevenly distributed in the field, damaged plants tend to occur in patches. Heavily infested plantings decline rapidly.

Root-knot nematodes cause the formation of knots or galls on fine roots. Heavy galling may cause abundant adventitious root formation and lead to a whiskery-root condition. Other types do not form such distinct root symptoms. Infested roots are not well developed. Lateral roots may be few. Roots attacked by lesion nematodes are dark in color.

Causal Organisms

The lesion nematode *(Pratylenchus penetrans)* and the northern root-knot nematode *(Meloidogyne hapla)* are common in the Midwest. The dagger nematode *(Xiphinema americanum)* is also frequently found. The dagger nematode is the vector of tomato ring-spot virus, which it can acquire from common weed hosts, such as dandelion. Ring nematodes *(Criconemella* spp.) and lance nematodes *(Hoplolaimus* spp.) are also found in soils in the Midwest. Their effect on strawberries is not known.

Use of Disease-Resistant Cultivars

In the integrated disease management program, the use of cultivars with disease resistance must be emphasized. Many commercial cultivars have resistance and/or tolerance to leaf spot, leaf scorch, red stele, verticillium wilt, and powdery mildew. The more disease resistance within the program, the better. Table 5-1 lists ratings for disease resistance in several of the more commonly grown cultivars. This type of information is available from a number of sources. Most nurseries should be able to provide information on disease resistance for the cultivars they sell.

Table 5-1: Disease Resistance of Several Strawberry Cultivars Commonly Grown in the Midwest.

		Disease Resistance[a]					
Cultivar	Season	Verti-cillium Wilt	Red Stele	Leaf Spot	Leaf Scorch	Pow-dery Mil-dew	Comments
June Bearing							
Earliglow	Early	R	R	I	I	I	Standard for early cultivars; berry size medium. Excellent flavor, but only moderately productive.
Veestar	Early	T	S	T	T	I	Early; productive. Has performed well in southeastern Pa., with medium bright berries. Fruit shows some Botrytis resistance.
Annapolis	Early	I	R	S	S	S	Fruit medium-large, firm, and glossy with good flavor. Plants runner freely. Fairly susceptible to Botrytis.
Noreaster	Early	R	R	I	I	S	Very large; early; firm fruit with aromatic flavor and aroma. King berries slightly rough. Well adapted to heavy soils.
Mohawk	Early	R	R	I	I	T	Medium-sized fruit, comparable to Earliglow. Good flavor. Tolerant of Botrytis. Has been very variable, as two lines of plant material exist. Plant only small quantities.
Avalon	Early	R	R	T	T	R	Large berry with good color and flavor, average productivity, and vigor. Has performed well in southeastern Pa. For trial only.
Sable	Early	U	R	R	R	S	Veestar x Cavendish cross. Productive, well suited to U-pick operations. Available in small quantities. For trial only. Produces dense beds. Botrytis control may require more effort than usual.

Table 5-1 (continued): Disease Resistance of Several Strawberry Cultivars Commonly Grown in the Midwest.

		Disease Resistance[a]					
Cultivar	Season	Verti-cillium Wilt	Red Stele	Leaf Spot	Leaf Scorch	Pow-dery Mil-dew	Comments
Evange-line	Early	U	S	R	R	R	Medium yields of conical, firm berries. Flavor good if fully ripe. Berries produced on stiff, upright stalks. May not runner well. For trial only. Limited quantities available.
Honeoye	Early-mid	S	S	R	R	T	Large fruit; productive; has performed well in Pa., but lack of red stele resistance is a concern. Tends to become soft in hot weather. Flavor distinctive, "perfumy."
Caven-dish	Early-mid	I	R	R	R	S	Very large firm fruit with good flavor. Very productive (yields 85% of Kent) and moderately vigorous. Tends to ripen unevenly in certain years.
Brunswick	Early-mid	U	R	R	I	I	Good size and flavor. May perform better in cooler locations. Susceptible to Phytophthora crown rot. For trial.
Raritan	Mid	S	S	S	S	S	Widely planted cultivar in spite of disease susceptibility; first fruits are large, but size decreases more rapidly than most cultivars. Very flavorful.
Guardian	Mid	R	R	R	R	S	Very productive; firm, large fruit, sometimes rough (uneven) looking. Botrytis is generally more prevalent in Guardian. Tends to get a long neck, which breaks down and allows easy entry for slugs and sap beetles. Susceptible to Sinbar injury.
Redchief	Mid	PR	R	R	R	R	Productive, with good color and size. Flavor average. Excellent disease resistance.
Lester	Mid	S	R	R	R	U	Productive, good-sized berry. Flavor is good, though size tends to run down quickly. Fruit is fairly susceptible to Botrytis.

Table 5-1 (continued): Disease Resistance of Several Strawberry Cultivars Commonly Grown in the Midwest.

		Disease Resistance[a]					
Cultivar	Season	Verticillium Wilt	Red Stele	Leaf Spot	Leaf Scorch	Powdery Mildew	Comments
Kent	Mid	S	S	U	I	T	Extremely productive berry with large firm fruit. Tends to yield fruit in middle of rows, resulting in high rot, so keep rows narrow. Flavor average. Susceptible to Sinbar injury.
Settler	Mid	T	U	T	T	S	Large attractive moderately firm fruit. Very susceptible to Sinbar injury. In Pa., for trial only.
Del-Marvel	Mid	R	R	R	R	U	Very vigorous plants, with high production; large, firm, aromatic fruit. In Pa., for trial only.
Primetime	Mid	R	R	R	R	U	Medium-firm berry with mild, lightly aromatic flavor. Good Botrytis resistance. In Pa., for trial only.
Mira	Mid	U	R	I	I	R	Glossy, medium-red, tart berries. High yielding in areas north of Pa. Good winter hardiness. Vigorous plants. In Pa., for trial only.
Eros	Mid	S	R	I	I	U	'Allstar' hybrid from England, with darker fruit color than 'Allstar.' Large fruit, well-balanced flavor. Available in small quantities. For trial only.
Darselect	Mid	U	U	I	I	U	Attractive fruit with good color and quality. Vigorous. Available in small quantities for trial.
Jewel	Mid-late	S	S	R	R	R	Large soft fruit; can be very dark. Tends to soften in hot weather. Very productive, though dense foliage can encourage Botrytis.

Table 5-1 (continued): Disease Resistance of Several Strawberry Cultivars Commonly Grown in the Midwest.

		Disease Resistance[a]					
Cultivar	Season	Verticillium Wilt	Red Stele	Leaf Spot	Leaf Scorch	Powdery Mildew	Comments
Allstar	Mid-late	R-T	R	R	I	T	Productive, elongated, flavorful berries. Lighter color than most berries. Good fruit size. Has become the standard mid-season berry in Pa., in spite of light color. Has potential for the annual system on plastic mulch. Susceptible to angular leaf spot.
Seneca	Mid-late	S	S	U	U	U	Round, large, medium-red, exceptionally firm fruit with firm skin. Plant is vigorous. Flavor mediocre, but firmness of fruit may be useful for shipping market. Has potential for the annual system on plastic mulch.
Lateglow	Mid-late	R	R	R	R	T	Productive; good size and flavor. First berries extremely large, though size runs down over season. Extremely vigorous plant and needs to be controlled.
Latestar	Mid-late	R	R	R	R	U	Mild flavor, but variable yields and small fruit size. Vigorous plants. Flowers and ripens a few days later than 'Allstar.' In Pa., for trial only. Susceptible to gray mold.
Winona	Mid-late	T	R	R	R	U	Large, firm conical fruit with bright red-orange color and good flavor. Released from Minnesota. May be marginal quality when warm. In Pa., for trial only.
Mesabi	Mid-late	R	R	I	I	R	Large, dark-red fruit with good flavor. Winter hardy. Skin tends to become weak in warm weather.

Table 5-1 (continued): Disease Resistance of Several Strawberry Cultivars Commonly Grown in the Midwest.

		Disease Resistance[a]					
Cultivar	Season	Verticillium Wilt	Red Stele	Leaf Spot	Leaf Scorch	Powdery Mildew	Comments
Tribute		PR	R	T	T	R	Slightly later than 'Tristar,' with larger fruit. Flavor not as strong, and plants are more vigorous.
Tristar		R	R	T	T	R	Bears an early crop; smaller than 'Tribute;' flavor is excellent. Flesh and skin firm. Moderate vigor. Size reduced when weather too hot.
Everest		S	R	U	U	R	An alternative for growers who wish to try a day-neutral other than Tribute or Tristar. Recommended for small quantity trials only.
Plasticulture System (See Chapter 10 for additional information about cultivars for plasticulture production.)							
Sweet Charlie	Early	U	U	I	U	R	Good flavor and size. Yields lower than for Chandler but produces crop for early market. Tends to break dormancy and flower during warm spells in late winter and early spring. Resistant to Anthracnose fruit rot.
Chandler	Mid	U	S	S	T	R	Standard berry for this production system. Large, firm berries. Flavor is sweet if allowed to ripen fully and not over-fertilized with nitrogen.
Camarosa	Mid	U	U	I	T	S	Large, firm berries. Productive and vigorous in warmer climates. Flavor fair. Cool fall temperatures may negatively affect flower bud initiation.

[a] I = Intermediate; PR = Partially Resistant; R = Resistant, S = Susceptible; T = Tolerant, U = Unknown.
[b] Includes leafscorch and leaf spot.

From the *Commercial Berry Production and Pest Management Guide, 2002-2004,* The Pennsylvania State University. Used with permission.

Cultural Practices for Disease Control in Strawberry

The use of any practice that provides an environment within the planting that is less conducive to disease development and spread should be used. The practices described here should be carefully considered and implemented in the disease-management program whenever possible.

Use Disease-Free Planting Stock

Always start the planting with healthy, virus-indexed plants obtained from a reputable nursery. Remember that disease-free plants are not necessarily disease resistant — cultivar selection determines disease resistance.

Select the Site Carefully

Soil Drainage (Extremely Important)

Select a planting site with good water drainage. Avoid low, poorly drained wet areas. Good water drainage (both surface and internal drainage) is especially important for control of leather rot and red stele. Both of these diseases require free water (saturated soil) in order to develop. If there are low areas in the field that have a tendency to remain wet, this is the first place that red stele will develop.

Under Midwestern growing conditions, any time there is standing water in the field, plants are subject to leather rot infection. Any site in which water tends to remain standing is, at best, only marginally suited for strawberry production and should be avoided.

Any practice, such as tiling, ditching, or planting on ridges or raised beds, that aids in removing excessive water from the root zone will be beneficial to the disease-management program.

Previous Cropping History

Select a site that does not have a history of Verticillium wilt in any crop. Select a site that does not have a history of red stele or black root rot. To minimize the risk of black root rot, do not replant strawberries immediately after removing an old strawberry planting.

In general, it is also not a good practice (due primarily to Verticillium) to plant strawberries immediately after solanaceous or other Verticillium-susceptible crops. These include tomatoes, potatoes, peppers, eggplant, melons, okra, mint, brambles, chrysanthemums, roses, or related crops. If possible, select sites that have not been planted to any of these crops for at least three to five years. There should be no herbicide residue in the soil from previous crops.

Site Exposure

A site with good air circulation that is fully exposed to direct sunlight should be selected. Avoid shaded areas. Good air movement and sunlight exposure are important to aid in drying fruit and foliage after a rain or irrigation. Any practice that promotes faster drying of fruit or foliage will aid in the control of many different diseases.

Crop Rotation

First Planting of Strawberry — If the land has no recent (five years or less) history of strawberry production or Verticillium diseases in other crops, soil-borne diseases such as red stele or Verticillium wilt should not be a problem.

Replanting Strawberries, Crop Rotation, and Soil Fumigation — If strawberries are to be replanted in the same field, crop rotation must be used or the field should be fumigated. Fumigation is currently not an option in organic production systems.

With rotation, the site should be plowed, worked down, and planted to a crop that is not susceptible to Verticillium wilt for a minimum of two years. Many soil-borne pathogens form specialized survival structures and are capable of surviving for several years in soil, even when strawberries are not present. The longer the site can be rotated away from strawberries prior to replanting, the better.

The combination of crop rotation plus soil fumigation is a sound approach that is used by many conventional growers. However, for organic growers (who cannot use soil fumigation), crop rotation alone often provides acceptable control for most soil-borne diseases, if the rotation is sufficiently long.

Neither crop rotation nor soil fumigation will reliably provide adequate control of red stele. With red stele, disease-resistant cultivars and improved soil drainage must be emphasized. Cultivars with resistance to red stele and Verticillium wilt should always be used.

Fertility

Fertility should be based on soil and foliar analysis. Soil should be analyzed and nutrient levels adjusted before planting. The use of excess fertilizer, especially nitrogen, should be avoided. Sufficient fertility is essential to produce a crop, but excess nitrogen results in dense foliage that increases drying time in the planting (stays wet longer) and also results in softer berries that are more susceptible to fruit rots.

Avoid the application of nitrogen in the spring prior to harvest on medium to heavy soils. Excessive use of nitrogen has been shown to increase the level of Botrytis fruit rot (gray mold).

Weed Control

Good weed control is essential to successful strawberry production. From the disease control standpoint, weeds in the planting prevent air circulation and result in fruit and foliage staying wet for longer periods. Gray mold, in particular, is a much more serious problem in plantings with poor weed control compared to plantings with good weed control.

In addition, weeds will reduce production through direct competition with strawberry plants for light, nutrients, and moisture and will make the planting less attractive to pick-your-own customers, especially if you have thistles!

Mulch

Research and grower experience has shown that a good layer of straw mulch is very beneficial for controlling fruit rots, especially leather rot. Bare soil between the rows should be avoided, and a good layer of straw mulch is highly recommended. The mulch keeps berries from contacting the soil where the leather rot fungus overwinters. In addition, it also aids in preventing infested soil from splashing onto the berries.

Recent research has shown that plastic mulch (a layer of plastic) under the plants and/or between the rows increases splash dispersal of the pathogens that cause anthracnose and leather rot.

Sanitation

Any practice that removes old leaves and other plant debris from the planting is beneficial in reducing the amount of Botrytis inoculum. Leaf removal at renovation is highly recommended.

Irrigation Practices

The application of supplemental water should be timed so that the foliage and fruit will dry as rapidly as possible. For example, irrigating early in the day is better than in the evening. If diseases, such as gray mold, leather rot, anthracnose, or bacterial blight, become established in the planting, overhead irrigation should be minimized or avoided.

Control Movement of People and Machinery

Movement of people (pickers) and machinery from a field or area that is infested to a clean or uninfested field should be avoided. Diseases of primary concern are anthracnose, leather rot, and angular leaf spot (bacterial blight). Diseases such as these are usually spread over relatively short distances by splash dispersal (rain or irrigation). Movement from one field to another field through the air (wind-blown spores) is generally not a problem with these diseases.

However, pickers moving from a field where the disease is present to a non-infested field can transport fungal spores or bacteria very efficiently on shoes, hands, and clothing. If people or machinery are used in fields where these diseases are a problem, they should complete work in non-infested fields before moving to infested fields.

In addition, any machinery that moves soil from one field to another can introduce soil-borne diseases, such as red stele, Verticillium wilt, leather rot, and nematodes, from infested into non-infested fields.

Harvesting Procedures

- Pick fruit frequently and early in the day before the heat of the afternoon (preferably as soon as plants are dry). Picking berries as soon as they are ripe is critical. Overripe berries will cause nothing but problems during and after harvest.

- Handle berries with care during harvest to avoid bruising. Bruised and damaged berries are extremely susceptible to rot.
- Train pickers to recognize and avoid berries that have disease symptoms of gray mold and leather rot. If at all possible, have pickers put these berries in a separate container and remove them from the field.

Post-Harvest Handling

- Always handle fruit with care during movement from the field to market to avoid any form of damage.
- Get the berries out of the sun as soon as possible.
- Refrigerate berries immediately to 35 to 40°F in order to slow the development of gray mold (Botrytis) and other fruit rots.
- Market the berries as fast as possible. Encourage your customers to handle, refrigerate, and consume or process the fruit immediately. Remember that even under the best conditions, strawberries are very perishable.

Fungicides for Strawberry Disease Control

Most fungicides used on strawberries are directed at the control of fruit rots and foliar diseases (Table 5-2 on page 62). By using resistant cultivars to control foliar diseases, the use of fungicides can be directed primarily toward controlling fruit rots. The fruit rots that are most prevalent in the Midwest are leather rot, Botrytis fruit rot (gray mold), and anthracnose fruit rot.

Leather Rot

Most fungicides currently available for use on strawberries are generally ineffective for controlling leather rot. Although Captan and Thiram are beneficial in suppressing leather rot, they will not provide adequate control if an epidemic develops. Furthermore, the use of these fungicides is restricted or prohibited during harvest due to re-entry restrictions or preharvest intervals.

Ridomil Gold EC is registered for use on strawberries for control of red stele and leather rot. Ridomil is very effective for control of leather rot and may be applied in the spring after the ground thaws and before first growth. This early application is recommended primarily for control of red stele but may be beneficial in providing some control of leather rot. A second application is recommended specifically for leather rot and can be made during the growing season at fruit set.

Aliette 80% WDG is also registered for use on strawberries and should provide good control of both red stele and leather rot. It can be applied from the initiation of bloom through harvest on a seven- to 14-day schedule and has no preharvest restriction.

Several products containing phosphorous acid (PA, also called phosphite or phosphonate) are sold as nutritional supplements and plant conditioners. Agri-Fos, ProPhyt, and Phostrol are currently registered as fungicides for control of plant diseases. These products are registered on strawberry for control of leather rot. They are essentially the same active ingredient that occurs in the fungicide Aliette (fosetyl-AL).

Abound (azoxystrobin), Cabrio (pyraclostrabin), and Pristine (pyraclostrabin plus boscalid) are strobilurin fungicides registered for use on strawberry for control of powdery mildew and anthracnose fruit rot. Although leather rot is not listed on the label, Abound, Carbrio, and Pristine are very effective for controlling leather rot if applied on a protectant schedule.

Although the previously mentioned fungicides are effective against leather rot, the emphasis for controlling leather rot should be placed on the use of cultural practices, such as using a good layer of mulch and preventing standing water in the planting (good drainage). In well-drained plantings throughout the Midwest and in drier growing seasons, leather rot is generally not a problem.

Botrytis Fruit Rot (Gray Mold)

Several fungicides have excellent activity against Botrytis. Topsin-M has been registered for many years and is highly effective in areas where Botrytis has not developed resistance to it.

Rovral is registered for control of Botrytis on strawberry and was highly effective for gray mold control prior to some changes in the label use recommendations in 1999. At present, the label states that not more than one application can be made per year, and it cannot be applied after first fruiting flower. These label restrictions make Rovral of little value for gray mold control on strawberry.

Elevate, Switch, Scala, and Pristine are fungicides that have excellent activity against Botrytis. A major problem involved with using these fungicides — Topsin-M, Elevate, Switch, Scala, or Pristine — for control of Botrytis fruit rot is that all of them are at risk with respect to the development of resistant strains of Botrytis. Because of differences in fungicide chemistry and previous frequency of use, the threat of resistance developing may be somewhat greater for Topsin-M than it is for Elevate, Switch, Scala, or Pristine.

In order to aid in fungicide-resistance management, the use of minimal numbers of fungicide applications, alternation of fungicides, and fungicide combinations should be encouraged in the disease-management program. The benefits of these fungicide-use strategies (at least in theory) are to provide a wider spectrum of disease control and to reduce or delay the development of fungicide-resistant strains of the fungus. The strobilurin fungicides Abound and Cabrio will provide some suppression of Botrytis fruit rot.

Captan and Thiram are protectant fungicides that will provide moderate to good control of Botrytis. They are not as effective against Botrytis as the previously mentioned fungicides and are often used in combination with them.

Fungicide application timing is important for gray mold management. Sprays applied during bloom are much more effective than sprays applied after fruit set and during harvest. Bloom sprays are critical for control of Botrytis. Sprays at harvest may leave visible residue on harvested berries. Care should be taken to select fungicides for sprays during harvest that leave little or no visible residues.

Anthracnose Fruit Rot

Anthracnose fruit rot is not a common problem in many areas, but its occurrence is increasing across the Midwest. The disease is very important in plasticulture systems. Once anthracnose fruit rot is established in a planting, it is difficult to control and can be very severe, resulting in complete loss of the crop.

Captan and Thiram are protectant fungicides that have some activity against anthracnose. If used in a protectant program, they will provide some level of control. Abound, Cabrio, and Pristine are strobilurin fungicides and are labeled for control of anthracnose on strawberry. They have the best activity against anthracnose on strawberry of all currently registered fungicides.

For purposes of fungicide-resistance management and increased efficacy, Abound, Cabrio, and Pristine should be used in alternation with or in combination with Captan or Thiram. Abound, Cabrio, and Pristine are the same class of chemistry so they should not be alternated with each other as a fungicide-resistance strategy. The label states that no more than two applications of one of these fungicides can be made without switching to a fungicide with a different mode of action.

Switch has also been reported to have moderate to good activity against anthracnose fruit rot. Therefore, Switch may be used in alternation with Abound, Cabrio, or Pristine for anthracnose control and fungicide resistance management.

Leaf Diseases

Leaf Spot, Leaf Scorch, Leaf Blight

The emphasis for controlling leaf diseases should be placed on the use of resistant cultivars whenever possible (Table 5-1 on page 52). If resistance is not available, highly susceptible cultivars should be avoided. Several fungicides are registered for control of strawberry leaf diseases (Table 5-2 on page 62). Topsin-M, Captan, Thiram, Nova, and Syllit (previously marketed as Cyprex) are all registered for use on strawberries.

The label states that Topsin-M cannot be applied before early bloom; thus, applications made very early in the season (as new growth starts) should use Syllit, Captan, Nova, or Thiram. The strobilurin fungicides (Cabrio, Abound, and Pristine) also have excellent activity against leaf diseases. If leaf diseases are a serious problem, post-harvest or post-renovation applications of these fungicides may be required.

Nova and the strobilurin fungicides have the highest level of activity against leaf diseases. An alternating program of Nova and a strobilurin fungicide should provide excellent control of leaf diseases as well as fungicide resistance management.

Powdery Mildew

Topsin-M is labeled for use on strawberries and was very effective against mildew when it was first introduced; however, due to the development of fungicide resistance, Topsin-M generally does not provide adequate control in many production areas across the country. In areas where Topsin-M has not been used to control powdery mildew, it still might provide effective control.

Nova, Procure, Abound, Cabrio, and Pristine are all registered for control of powdery mildew on strawberry and should provide excellent control. As with other leaf diseases, an alternating program of Nova with a strobilurin fungicide should provide excellent control of powdery mildew as well as fungicide resistance management.

Sulfur is also effective for powdery mildew control if used in a seven- to 10-day-interval protectant program. Sulfur has little or no activity against the other strawberry diseases.

The use of cultivars with resistance to powdery mildew should be emphasized, and the use of highly susceptible cultivars must be avoided.

Red Stele in Established Plantings

The emphasis for control of red stele should be placed on the use of resistant cultivars and good soil drainage. However, if red stele develops in an established planting, the use of Ridomil Gold may help reduce losses. Ridomil Gold should be applied in sufficient water to move the fungicide into the root zone of the plants. The label states: "Make one application at time of transplanting or in the spring after the ground thaws before first growth. Make another application in the fall after harvest."

Aliette WDG is also registered for red stele control. It is registered as a pre-plant dip and a foliar spray. The pre-plant dip label reads as follows: Use 2.5 lbs per 100 gallon and "Apply as a pre-plant dip to strawberry roots and crowns for 15 to 30 minutes. Plant within 24 hours after dipping." The foliar application label reads as follows: "In the spring, begin foliar applications when the plants start active growth. If disease conditions persist or re-occur, make additional applications on a 30- to 60-day interval." The use rate is 2.5 to 5 lbs per acre.

Several products containing phosphorous acid (PA, also called phosphite or phosphonate) are sold as nutritional supplements and plant conditioners. Agri-Fos, ProPhyt, and Phostrol are currently registered as fungicides for control of plant diseases. These products are registered on strawberry for control of Phytophthora root rot (red stele). They are essentially the same active ingredient that occurs in the fungicide Aliette (fosetyl-AL).

Table 5-2. Efficacy of Fungicides for Strawberry Disease Management.

Fungicide[a]	Gray Mold	Leather Rot	Leaf Spot	Powdery Mildew	Anthrac-nose	Preharvest Interval Days
Alone						
Abound[b]	++	+++	+++	+++	+++	0
Aliette	0	+++	0	0	0	0
Cabrio[b]	++	+++	+++	+++	+++	0
Captan[c]	++	+	++	0	++	0
Elevate[e]	+++	0	0	0	0	0
Nova	0	0	+++	+++	0	1
Ridomil	0	+++	0	0	0	0[a]
Sulfur	0	0	0	+++	0	0
Switch[e]	+++	0	0	0	++	0
Thiram[d]	++	+	++	0	+	0[c]
Topsin[e]	+++	0	+++	+++	0	1
Phosphorous Acid	0	+++	0	0	0	0
Pristine[b]	+++	+++	+++	+++	+++	0
Scala [e]	+++	0	0	0	0	0
In Combination						
Abound + Captan	++	+++	+++	+++	+++	0[c]
Cabrio + Captan	++	+++	+++	+++	+++	0[c]
Elevate + Captan	+++	+	++	0	++	--
*Elevate + Thiram	+++	+	++	0	+	--
Switch + Captan	+++	+	++	0	++	--
Switch + Thiram	+++	+	++	0	++	--
Topsin + Captan	+++	+	+++	+++	++	--
Topsin + Thiram	+++	+	+++	+++	++	--

* Scala will perform similar to Elevate in combination with Captan or Thiram.

Efficacy rating system: +++ = highly effective; ++ = moderately effective; + = slightly effective; 0 = not effective.

[a] See label for harvest restrictions.
[b] Abound, Cabrio, and Pristine have good activity against leather rot.
[c] Although the preharvest interval for Captan is 0 days, protective clothing must be worn for 24 hours after application when entering the planting or harvesting fruit.
[d] Thiram cannot be applied within three days of harvest.
[e] Always apply Topsin, Elevate, Scala, or Switch in combination with an unrelated fungicide such as Captan or Thiram, or in an alternating program with a fungicide of different chemistry.

Strawberry Disease Disease Control Strategies

An effective program to manage and control strawberry diseases needs to integrate all available control methods into one program to achieve an acceptable level of disease control on a consistent (year-to-year) basis. Various strategies to use in controlling strawberry diseases are shown in Table 5-3.

Table 5-3. Strawberry Disease Control Strategies.

Disease Control Considerations	Verticillium Wilt	Red Stele	Black Root Rot	Nematodes	Viruses	Fruit Rot	Leaf Spots	Powdery Mildew
1. Good drainage	-	++	++	-	-	++	+	-
2. No shade	-	+	-	-	-	++	++	-
3. No infested runoff	+	++	+	+	-	U	-	U
4. Rotation	++[a]	++[a]	++[a]	++[a]	-	-	+	-
5. Resistant cultivars	++[b]	++[c]	-	-	-	-	++[d]	++
6. Disease-free plants	++	++	+	+	++	-	+	+
7. Adequate plant and row spacing	-	-	-	-	-	++	++	+
8. Mulch for winter injury/fruit rot	-	-	++	-	U	++	-	-
9. Fruit storage conditions	-	-	-	U	-	++	-	-
10. Renovation	+	-	-	+	-	-	++	+
11. Weed control	+	-	-	+	U	++	+	+

All possible control strategies must be employed if strawberry diseases are to be controlled.

Key: ++ = most important controls; + = helpful controls; - = no controls; and U = unknown.

[a] Rotations for Verticillium wilt, black root rot, and nematodes are at least three to five years; red stele is much longer, perhaps more than 20 years.

[b] Resistant to Verticillium wilt: Earliglow, Sunrise, Catskill, Guardian, Midway, Redchief, Surecrop, Delite, Sparkle.

[c] Resistant to some strains of red stele: Earliglow, Redglow, Sunrise, Guardian, Midway, Redchief, Surecrop, Delite, Sparkle.

[d] Resistant to leaf spot: Guardian, Midland, Redchief, Surecrop. Resistant to leaf scorch: Catskill, Guardian, Midland, Redchief, Sunrise, Surecrop.

Chapter 6
Strawberry Pests and Their Management

Fruit- or Flower-Feeding Pests

Tarnished Plant Bug
; order Hemiptera, family Miridae)

Damage: Slightly to severely uneven berry growth and deformed berries with hollow seeds can result from tarnished plant bug feeding on flower buds and seeds in developing fruit. Ripening berries that remain small, with a concentration of seeds at the tip, are called button berries, cat-faced berries, or nubbins. Injured berries can be woody and unmarketable. Later-maturing cultivars are more seriously affected by this pest than early cultivars.

Appearance: Adult tarnished plant bugs are about 1/4-inch long, coppery brown with yellow and dark brown markings, and somewhat shiny in appearance (Figure 6-1). A yellow-tipped triangular plate is present in the middle of their backs. The immature stages, or nymphs, are smaller and green (Figure 6-2). Nymphs are plain green when young but marked with black spots when older. Both nymphs and adults have needle-like mouth parts used for sucking plant juices.

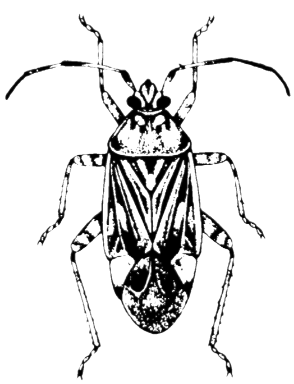

Figure 6-1. Tarnished plant bug adult.

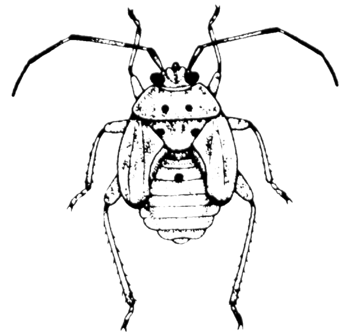

Figure 6-2. Tarnished plant bug nymph.

Life Cycle and Habits: Adults overwinter in vegetation or stubble that provides protection from extreme cold. In the spring, they are attracted to flower buds (Figure 6-3) and shoot tips of many plants, including strawberry, peach, and apple. They lay eggs in the plant tissues of many agricultural crops and weeds. Eggs hatch in about one week, and the nymph stages last about three weeks. Tarnished plant bugs suck sap from developing seeds during and after bloom, or from the receptacle of developing fruit. Their feeding kills surrounding cells and leads to distorted seedy berries. Several generations of this insect develop each year, and adults and nymphs are present on many different plants from April or May until a heavy frost in the fall.

Figure 6-3. Tarnished plant bug on flower.

Cultural Control: Strawberry cultivars that are least susceptible to plant bug injury are Honeoye, Sparkle, Canoga, Catskill, and Veestar, according to studies in New England. Plants that produce more flowers and fruit, on a per area basis, tend to suffer less fruit damage than less productive plants. Cultivars that flower earlier tend to have less severe damage than later-flowering cultivars.

Controlling weeds in and around strawberry fields reduces overwintering sites and removes sources of early-season flowers that attract adult tarnished plant bugs to fields. However, weeds in and near strawberry fields should not be mowed or pulled when strawberry buds are swelling and flowers are beginning to open, because tarnished plant bugs will move from weed hosts to strawberries at a time when the crop is especially vulnerable to damage. If mowing must be done during this period, it is better to mow after applying insecticide than to mow before applying insecticide. Weeds preferred by the tarnished plant bug include dandelion, chickweed, goldenrod, curly dock, pigweed, lambsquarters, ragweed, and shepherds purse.

Mechanical Control: Row covers put on in the fall to exclude plant bugs in the spring have been shown in New England to reduce, but not eliminate, plant bug injury.

Biological Control: Several natural enemies of tarnished plant bug have been studied but details on how best to use them in strawberries are not yet available. A braconid wasp, *Peristenus digoneutis,* attacks the nymphs. A mymarid wasp, *Anaphes iole,* attacks the eggs.

Monitoring and Thresholds: Guidelines for monitoring tarnished plant bug infestations and determining whether to use an insecticide vary depending on whether adults or nymphs commonly cause damage in a particular region.

Where migratory adults appear to cause more damage than subsequent nymphs, as happens during most seasons in Illinois, producers are advised to monitor the bug population by sweep net sampling as buds begin to form. Control is suggested if the population is found to be above the threshold of two tarnished plant bug adults per 10 sweeps.

Where damage tends to be caused by nymphs that are present when buds are forming, particularly for later cultivars or day-neutral cultivars, shake sampling is more useful than sweep net sampling. Sampling should be done at least once, preferably twice, per week. At each of five sites per field, shake six flower clusters over a white pan or paper to dislodge the nymphs and then count them. Calculate the average number per flower cluster. If counts exceed 0.25 nymph per flower cluster before 10% bloom, or if counts exceed 0.5 nymph per flower cluster during mid- to late-bloom, or more than 10% of the flower clusters are infested (regardless of count), then application of an insecticide is warranted.

White sticky traps are commercially available for monitoring tarnished plant bug adults, but recent evaluations of these traps in Iowa has shown them to be unreliable for detecting plant bug infestations in strawberries.

Control by Insecticides: Control of tarnished plant bugs may be justified if the field has suffered substantial damage from tarnished plant bugs in previous years or where the threshold (as described earlier) is exceeded. Insecticide should be applied soon after blossom buds first become visible and again if reinfestation occurs just before bloom. To protect bees and other insect pollinators, do not spray insecticide during bloom. Chemical control can be difficult because the adult bugs are very mobile and can recolonize the field quickly.

Flower Thrips or Eastern Flower Thrips

(Frankliniella tritici; order Thysanoptera, family Thripidae)

Damage: Strawberry fruits can be dull or bronzed, small, and seedy as a result of the flower thrips feeding during bloom and fruit set (Figure 6-4). Thrips may also cause blemished seeds on achenes and uneven maturity of fruit. Berries can be marketable if thrips damage is light but unmarketable when damage is severe. In California, a related species called the western flower thrips causes golden brown discoloration of fruit that renders berries unmarketable when populations of thrips are large.

Figure 6-4. Thrips damage on strawberries.

Thrips damage to strawberries was rare until 1994, when problems were reported throughout the Midwestern and eastern United States. The strawberry crop failed to develop normally in 1994; berries failed to enlarge or ripen and remained golden brown and leathery. Some plantings had yield reductions of up to 90%. Scattered infestations have been observed in most years since 1994.

In Illinois, this problem was greatest in the central portion of the state and less severe in the far south and the north. Whether or not the flower thrips caused these dramatic strawberry losses cannot be proved, but many observations now suggest that thrips were to blame. The thrips injury in 1994 probably resulted from an earlier-than-normal immigration of thrips that coincided with strawberry bloom and fruit set in a large portion of the Midwest.

Growers who did not traditionally apply an insecticide for control of tarnished plant bug or meadow spittlebug experienced greater losses due to thrips during outbreaks.

Appearance: The flower thrips, which is sometimes called the eastern flower thrips, is a tiny, slender, cigar-shaped insect (Figure 6-5). Nymphs and adults have the same general shape. Nymphs are wingless, whitish yellow when small, and yellow when fully grown. Adults are yellowish brown, 1/16-inch long, and have narrow wings that are fringed with hairs. While resting, the wings are folded lengthwise over the back.

Figure 6-5. Flower thrips.

Life Cycle and Habits: The flower thrips is not known to overwinter outdoors in the upper Midwest, but overwintering in greenhouses probably occurs. Populations of flower thrips develop each year as a result of long-distance migrations from southern states on high-level winds associated with weather fronts. Migration of thrips probably occurs simultaneously with migration of the potato leafhopper.

Adult flower thrips are attracted to flowers of many different plants. Adults and nymphs feed using rasping-sucking mouthparts to obtain sap. On strawberry fruit, they begin feeding on seeds soon after the buds open. They feed on the tissue between the seeds as the fruit expands. Bronzing results from surface cells being killed.

Thrips are often overlooked because they are tiny and prefer to feed in protected sites, such as under the calyx (cap) and in grooves around seeds, rather than exposed sites. When the population is large, they run out of space in protected sites and thus may be found anywhere on the fruit. They actively run when disturbed.

The adults lay eggs in plant tissue. There are two active nymph stages and two inactive pupal-like nymph stages. The life cycle can be completed in several weeks; there can be many generations per year.

Monitoring and Thresholds: To determine whether or not thrips control is warranted, strawberry growers should begin sampling for thrips by examining early flower clusters on early cultivars and continue sampling all cultivars as they begin to bloom. Tap flowers onto a white or very dark plate or saucer and look for the slender yellow thrips. As an alternative, flower blossoms can be placed into a zipper-type reclosable plastic bag and shaken to dislodge thrips and allow counting.

Although the relationship between eastern flower thrips density and strawberry damage is not well understood, control is probably warranted if populations exceed two to 10 thrips per blossom. Once berries are 1/4 inch in diameter, 50 randomly selected fruits should be picked and examined; control is suggested if an average of 0.5 or more thrips per fruit are detected.

Control by Insecticides: If insecticides are to be used for thrips control, applications must be timed to avoid killing pollinators. Insecticide should be applied prebloom or before 10% of the plants have open blossoms. This timing may coincide with control measures for tarnished plant bug.

Strawberry Bud Weevil or Strawberry Clipper

(Anthonomus signatus; order Coleoptera, family Curculionidae)

Damage: Nearly mature blossom buds are injured by adult clippers that puncture buds with their snouts, girdle the flower buds, then clip the stem below the buds (Figure 6-6). Clipped buds hang down or fall to the ground. Injured buds that survive to flowering may have small holes in the petals.

Many cultivars can compensate for this injury, especially if it occurs early and if only secondary or tertiary flower buds are affected. Examples of cultivars with high compensation are Seneca and Jewel. Examples of cultivars with low compensation are Honeoye and Earliglow.

Appearance: The strawberry clipper adult is a dark, reddish-brown weevil about 1/10-inch long; its head is prolonged to form a slender, curved snout about one-third as long as the body (Figure 6-7). The larva is white and 1/16-inch long.

Life Cycle and Habits: Adult clippers overwinter in fence rows and woodlots near strawberry plantings. Once temperatures reach 60°F, the adults move to strawberry fields where flower buds are emerging from the crown. A small portion of a population may remain in the strawberry field over the winter. Strawberry flowering coincides with the time that clippers move out of their overwintering sites, so strawberries are ideal host plants for this insect. Redbud trees are another early host.

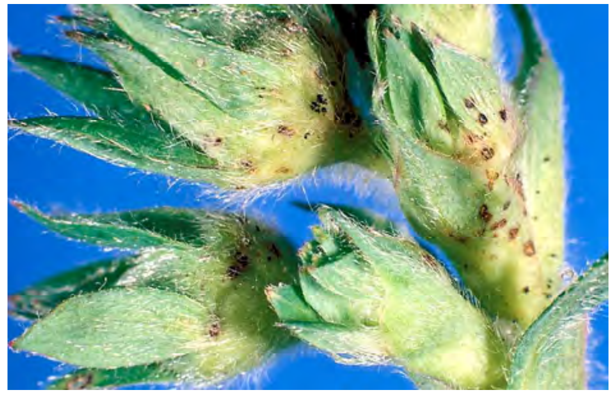

Figure 6-6. Strawberry clipper damage.

Figure 6-7. Strawberry clipper adult.

Adult clippers first feed on immature pollen by puncturing nearly mature blossom buds with their snouts. Each female then deposits a single egg inside the bud and girdles the bud, which prevents it from opening and exposing the developing larva. The female then clips the stem. Eggs hatch in about one week. Larvae feed within the damaged bud for three to four weeks; a new generation of adults emerges in late June and July. These weevils feed on the pollen of various flowers for a short time, but seek shelter in midsummer in preparation for overwintering. There is one generation per year.

Cultural Control: Because the strawberry clipper does not disperse over long distances, locating strawberry plantings away from woodlots and hedgerows that harbor this insect through the winter can reduce the number of adults that move into strawberries in the spring. Because early cultivars are usually damaged more than later ones, planting two or three rows of an early cultivar as a trap crop around the perimeter of each field has been suggested as a way to reduce overall damage or to concentrate the adults for control by use of an insecticide only in the trap crop.

Monitoring: Early detection of clipper activity is important. Watch for clipper adults and damage when flower buds start coming out of the crown and when temperatures approach 65°F. Check one meter (3 feet) of row at each of five sites per field. Sampling should be most intensive along field edges near woods or hedgerows or where weeds are heavy. Get down on hands and knees and look closely for clipped buds of unopened flowers and look for adult weevils in unexpanded flower clusters. Keep separate counts for primary buds vs. secondary or tertiary buds; one strawberry truss produces 15 buds: one primary bud that opens first, then two secondary buds, then four tertiary buds, then eight quaternary buds.

Thresholds: Treat with insecticide if there are three or more clipped primary buds per meter of row, or 30 or more clipped secondary or tertiary buds per meter of row. The reason that this much injury is allowed is that many cultuvars can compensate for injury.

Control by Insecticides: If control is necessary, insecticide should be applied as soon as the threshold is exceeded; this can occur before most flowers have begun to open. When damage is observed only in rows along a field border, then insecticide application can be limited to border rows.

Strawberry Sap Beetle

(Stelidota geminata; order Coleoptera, family Nitidulidae)

Damage: Deep cavities or tunnels in ripe berries are chewed by strawberry sap beetle adults (Figure 6-8). This injury also can lead to infection of berries by rot organisms. Because over-ripe fruit is especially attractive to sap beetles, damage is often greatest in pick-your-own operations where pickers leave large numbers of ripe and over-ripe berries in the field.

Appearance: Adult strawberry sap beetles are about 1/8-inch long, oval shaped, flat, and mottled brown in color (Figure 6-9). Larvae are white with a brown head and up to 1/10-inch long.

Figure 6-8. Strawberry sap beetle damage.

Figure 6-9. Strawberry sap beetle adult.

Life Cycle and Habits: Strawberry sap beetle adults fly into strawberry plantings from wooded areas at about the time berries begin to ripen. They chew on berries, often in groups of several beetles per berry. They may be hard to see because they drop to the ground when disturbed.

Females deposit eggs on the injured fruit. Eggs hatch in two to three days. Although larvae feed in berries for about one week, they usually are unnoticed because the fruit has already begun to decompose as a result of damage caused by adults.

A parasitic wasp contributes to suppression of this pest by laying eggs in the adult beetles; parasitized beetles lay fewer eggs than healthy beetles.

Cultural Control: Strawberry sap beetles are best controlled by timely and complete picking of harvestable berries and the removal of over-ripe and damaged berries.

Mechanical Control: Trap buckets of over-ripe fruit can be placed outside field borders as the crop begins to ripen, to intercept immigrating beetles and reduce pest numbers in the crop.

Control by Insecticides: Because sap beetle populations usually do not build up until the picking cycle is underway, the use of insecticides is limited by frequent harvests. The required preharvest interval specified on the insecticide label must be obeyed.

Slugs

[*Deroceras (Agriolimax)* species (family Limacidae) and *Arion* species (family Arionidae); Phylum Mollusca, Class Gastropoda]

Damage: Slugs damage fruit by chewing deep ragged holes into the surface of berries, especially under the cap (Figure 6-10). Slugs leave slime trails on the fruit or leaf surfaces as they move around.

Appearance: Soft-bodied and slimy, slugs are worm-like molluscs that range in size from 1.5 to 7 inches long. They may be dark gray, black, yellow-gray, or brown and may be covered with spots.

Life Cycle and Habits: Slugs that damage strawberries in the spring and early summer hatched from eggs deposited in the soil in strawberry plantings the previous fall. Conditions that favor egg-laying in the fall include the continuous presence of straw mulches. Slugs survive best and damage fruit the most in fields with rows close together and thick mulch, and when overcast and rainy weather creates continuously moist conditions in strawberry beds. Slugs feed mainly at night.

Figure 6-10. Slug and its damage on strawberry.

Cultural Control: Planting at lower densities, removal of straw mulch after harvest, summer renovation, and delaying fall mulching as long as is practical are effective steps in reducing slug populations. Removal of trash and debris around the field helps to eliminate slug breeding grounds.

Mechanical Control: Traps made of wet boards or burlap bags may be set out in the evening. Remove and destroy trapped slugs the following morning. Shallow dishes of beer can be used as a bait under the traps. Although trapping can remove many slugs, it usually does not remove enough to result in significantly less injury to fruit.

Control by Insecticides: Slug baits that contain metaldehyde or iron phosphate may be used in strawberries only if the baits are applied to the soil or mulch surface and do not contact plants. Baits are most likely to work when used at the full labeled rate and when they are applied before ripe berries are present. If metaldehyde baits are used, care must be taken to keep dogs out of the treated area.

Root- or Crown-Feeding Pests

Strawberry Root Weevil and Black Vine Weevil

(*Otiorhynchus ovatus* and *Otiorhynchus sulcatus;* order Coleoptera, family Curculionidae)

Damage: Infested plants have leaves that turn red and berries that are undersized. Plants are weakened, stunted, or killed by the larvae of root weevils, which are grubs that feed on strawberry roots and crowns. Root systems weakened by weevils are then more susceptible to winter injury and diseases. Infestations are generally in patches in the field. A pocket of damage in one corner of a field can expand and cause heavy losses the following year. Damage is worse when plants are under stress such as during drought periods (Figure 6-11). Although the adult weevils chew notches from the edges of leaves, their feeding usually causes no economic losses.

Appearance: Adult strawberry root weevils are black or dark brown beetles that are about 1/5-inch long (Figure 6-12). They have a prominent blunt snout and elbowed antennae on the snout. Their backs are marked by many rows of small pits. Larvae are thick-bodied, white, legless grubs with brown heads; they are usually found in a curved position (Figure 6-12). Grubs reach about 1/4 inch in length.

Another species of weevil similar to the strawberry root weevil is the black vine weevil *(Otiorhynchus sulcatus)*. A third species is the rough strawberry weevil *(Otiorhynchus rugo-sostriatus)*. These species are similar in appearance to the strawberry root weevil except that they are larger — 1/4 inch for rough strawberry weevil and 1/3 inch for black vine weevil. They are also similar to the strawberry root weevil in damage and life cycle.

Figure 6-11. Root weevil damage.

Figure 6-12. Root weevil life stages: egg, larva, pupa, adult.

Life Cycle and Habits: Root weevils overwinter as full-grown grubs, pupae, or adults in soil, or as adults in plant debris or other protective habitat. Most damage is caused in the spring by grubs after they resume feeding. Overwintered adults become active in strawberries in May.

Grubs complete development in the spring and emerge as new adults in May or June. The adults feed on leaves at night and hide in crowns or under mulch during the day. After feeding for as short as 10 to 14 days (strawberry root weevil) to as long as 30 to 60 days (black vine weevil), the adult weevils begin laying eggs in soil near strawberry plants. Each female deposits 150 to 200 eggs, and eggs hatch in about 10 days. After eggs hatch in late summer or early fall, larvae burrow through the soil to feed on roots until they mature or until cold temperatures suspend their activity.

The adult root weevils cannot fly, but they can walk from one field to another. Where food is available, they walk only short distances, but if they are searching for a new food source, they can travel longer distances such as several hundred feet. Mass migration of weevils can occur from an infested field as it is being disked.

Mechanical and Cultural Controls: Infested old plantings should be disked under soon after harvest, to destroy grubs before new beds are planted. To reduce mass migration of weevils during disking, one or two rows of plants should be left at the edge of the old field to serve as a trap crop. The trap crop should be turned under at the end of the season. New plantings should be isolated from existing fields and wooded overwintering sites by a distance of several hundred feet.

Monitoring: Plants should be examined in the spring if patches of poor vigor are noticed. Lift up a section of row with a spade and examine the roots within a 6-inch layer of soil. If grubs are found, control measures should be taken after harvest, when the adults emerge. In mid- and late summer, look every one to two weeks for notch-like feeding damage on leaves.

Biological Control by Beneficial Nematodes: This new pest management option is untested in the Midwest but has been under development in New Jersey and Oregon. Nematodes can be purchased from commercial suppliers and applied to soil in mid-May, by means of a sprayer or irrigation. The two species of nematodes that are best for root weevil control are *Heterorhabditis bacteriophora* and *Heterorhabditis marelatus.*

Control by Insecticides: Sprays that target the adult weevils are not usually very effective but can be helpful if applied at night at the time of peak feeding, which is usually in July. In some states, a systemic insecticide (carbofuran) is permitted after harvest for control of root weevil larvae under a Special Local Needs (SLN) label, also called a 24(c) label. Check in the annual *Small Fruit Spray Guide* or check with your state's Department of Agriculture to find out if your state has such a SLN label. Soil fumigation can be used to kill overwintering larvae.

White Grubs

(*Phyllophaga* species; order Coleoptera, family Scarabaeidae)

Damage: White grub larvae feed on crop roots. Root injury weakens the plant and also provides an entry site for root diseases like black root rot. Risk of white grub infestation is highest in new plantings established on newly plowed sod or other grasses. As adults, the beetles feed on leaves in late summer, which results in skeletonized leaves.

Appearance: Adults are called May beetles or June beetles (Figure 6-13). They range in length from 1/2 to 1 inch and vary in color from tan to dark brown and are shiny. C-shaped larvae are whitish gray with brown heads and three pairs of legs; they are 1/2- to 1-1/2-inches long (Figure 6-14). White grub species in the genus *Phyllophaga* are known as perennial white grubs or true white grubs. Other beetle species that have similar grubs are Japanese beetle *(Popilla japonica)*, rose chafer *(Macrodactylus subspinous)*, and green June beetle *(Cotinis nitida)*.

Life Cycle and Habits: Females deposit eggs in soil during late spring or early summer; they especially prefer grass sod near wooded areas for egg-laying. Eggs hatch in two to three weeks. Newly hatched larvae feed on crop roots throughout the summer, then burrow deep in the soil to overwinter. The following year they again migrate to the root zone to feed. These larger larvae cause much greater damage than they did the year before. After overwintering again well below the soil surface, white grubs pupate early in the following summer, and adults emerge from pupal cells the next spring, three years after the cycle began. Adult beetles hide in soil during the day and fly to trees to feed at night.

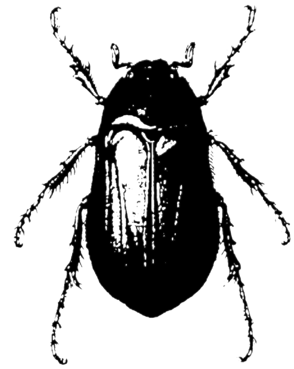

Figure 6-13. White grub adult.

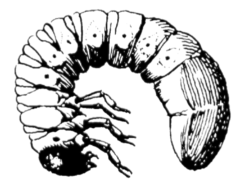

Figure 6-14. White grub larva.

Cultural Control: Do not put new strawberry plantings on newly turned ground that was used for sod, pasture, or grass set-aside the previous year. On such sites, plow the field and let it lie fallow or in a rotational cover crop such as sudan grass or buckwheat, or a salable crop such as pumpkins or squash, for at least one season prior to planting with strawberries. Avoid setting a strawberry field next to large grassy fields that could be a source of these beetles and their larvae.

Control by Microbial Insecticides: This method currently is not effective in northern soils and thus is not recommended for Midwestern fruit growers but is included here because growers sometimes ask about it. Milky spore is a bacterial disease that kills white grubs; it is commercially available as a product that is incorporated into the ground. Several formulations are on the market. Once this kind of bacteria is established in the soil, grub control is perennial and effective. There has been difficulty in getting the bacteria established in northern soils; milky spore cannot be considered a reliable control measure in the Midwest until this problem is overcome.

Control by Conventional Insecticides: An insecticide labeled for grub control can be banded over the row to reduce the amount and cost of insecticide treatment.

Strawberry Crown Borer

(Tyloderma fragariae; order Coleoptera, family Curculionidae)

Damage: Strawberry plants are weakened, stunted, or killed as one or more larvae bore downward in the crown. Field borders or the portions of fields nearest older, infested plantings are often most heavily damaged. Infestations spread slowly. Leaves of infested plants might turn red. The adult beetles chew many small round holes in leaves in the fall, but this defoliation rarely is economically damaging.

Appearance: Adult crown borers are reddish-brown weevils about 1/6-inch long. They have a short thick snout. Their backs are marked with punctures and three pairs of dark irregular spots. The larva is a yellowish white, legless grub, about 1/5-inch long when fully grown (Figure 6-15).

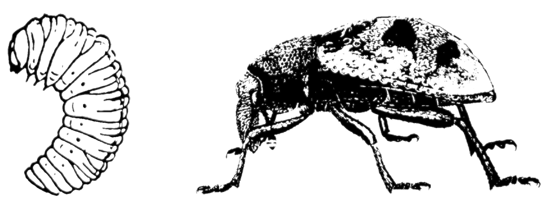

Figure 6-15. Strawberry crown borer larva (left) and adult (right).

Life Cycle and Habits: Adults overwinter in plant debris in strawberry fields or in surrounding areas.

They become active in the spring at about the same time that strawberries begin to bloom. They feed in crowns, opening holes into which they lay eggs that hatch in about one week. Egg laying continues through mid-June.

Eggs hatch into grubs that feed for several weeks in strawberry crowns before pupating in late summer and emerging as adults in the fall. Adults are unable to fly; they feed on strawberry foliage and then seek shelter in plant debris to pass the winter.

Cultural Control: Isolating new fields from existing infestations greatly reduces the likelihood that this insect will cause significant losses, because adult strawberry crown borers cannot fly. Commercial growers should purchase plants that are free of crown borer and establish new fields at least 300 yards from existing fields. To prevent crown borer survival and migration, infested fields should be destroyed and tilled soon after the final picking.

Control by Insecticides: Although chemical control is rarely advised, some insecticides applied to control other insects may kill crown borers as well. Prebloom sprays intended to limit damage by tarnished plant bug can kill some crown borer adults, but peak adult activity occurs slightly later. Egg-laying adults are especially active during bloom, a time period when insecticides should not be applied.

Insecticide applied between bloom and harvest for the control of leafroller or sap beetle may also kill crown borer adults if they are still active on foliage, but killing adults at this time is unlikely to significantly reduce crown damage. Post-harvest sprays may be used to reduce the population of newly emerged adults in late summer before they overwinter, but this practice is seldom warranted.

Foliage- or Stem-Feeding Pests

Meadow Spittlebug

(Philaenus spumarius; order Hemiptera, family Cercopidae)

Damage: Spittlebugs pierce the plant and suck on sap, which can result in reduced plant vigor, stunting, and decreased yield. Early-season feeding can result in stunted, off-color plants; this damage can appear much like that caused by cyclamen mite. Spittlebugs are also a nuisance pest because they are not liked by pickers at pick-your-own operations because of the unsightly foam on plants when picking.

Appearance: Hidden beneath masses of frothy spittle on stems or leaves (Figure 6-16) are the immature spittlebugs, which are soft-bodied, elongated bugs. Young nymphs (Figure 6-17) are 1/8-inch long and yellow; older nymphs are 1/4-inch long and green. The adults, which are called froghoppers, are brown or gray and 1/4-inch long.

Life Cycle and Habits: The meadow spittlebug overwinters as egg masses in the stubble of strawberries and other hosts, such as small grains or alfalfa. Eggs hatch at about the time that the

Figure 6-16. Meadow spittlebug.

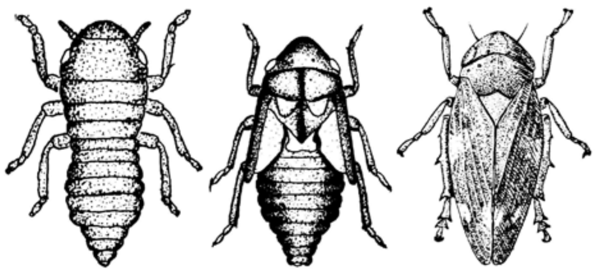

Figure 6-17. Meadow spittlebug – young nymph, older nymph, and adult (left to right).

earliest strawberry flowers appear. Once nymphs begin feeding, they begin to produce spittle.

Spittlebugs feed first at the base of plants, then move up on stems and blossom clusters before and during bloom. They pierce the plant and suck on plant sap. The nymph stages last for five to eight weeks. Once they reach adulthood, they leave the spittle mass. Female adults lay eggs in September. There is only one generation per year.

Cultural Control: Spittlebugs are most abundant in weedy fields, so weed control can contribute to spittlebug management. Often heavy rains or irrigation can wash froth from plants.

Monitoring: Plants should be scouted weekly starting at 10% bloom. Randomly inspect five one-foot-square areas per field. Look for white frothy spittle masses while spreading apart leaves to inspect crowns, leaf bases, leaf stems, flower stems.

Threshold: Complaints most often occur when there is one or more spittle mass per square foot of canopy. Treatment is suggested when there are two or more spittle masses per square foot of canopy.

Control by Insecticides: Insecticide applications early in the season, such as those targeting the tarnished plant bug, are usually adequate for keeping spittlebugs in check.

Potato Leafhopper

(*Empoasca fabae;* order Hemiptera, family Cicadellidae)

Damage: Leaves turn yellow at the edges and between the veins, and become curled and distorted (Figure 6-18) due to leafhopper adults and nymphs feeding on the underside of leaves. Damage is most noticeable in new strawberry plantings. Feeding activity is most serious during the late spring and early summer.

Appearance: Potato leafhoppers (Figure 6-19) are 1/8-inch long, green, bullet-shaped insects that take flight quickly if disturbed. The nymphs are light green, 1/16 inch long, and do not fly. Nymphs are easily identified by their habit of moving sideways when disturbed.

Life Cycle and Habits: The potato leafhopper does not overwinter in Ohio but must fly in from the southern states each spring. Migratory adults can infest alfalfa, potato, and snap beans in addition to strawberry.

Monitoring: Scouting is especially important in new strawberry plantings. Scout by brushing the leaves with the hand and looking for small adult leafhoppers flying off. Examine the underside of injured leaves to see if nymphs are present.

Control by Insecticides: Insecticides should be applied only when large populations of nymphs

Figure 6-18. Potato leafhopper damage.

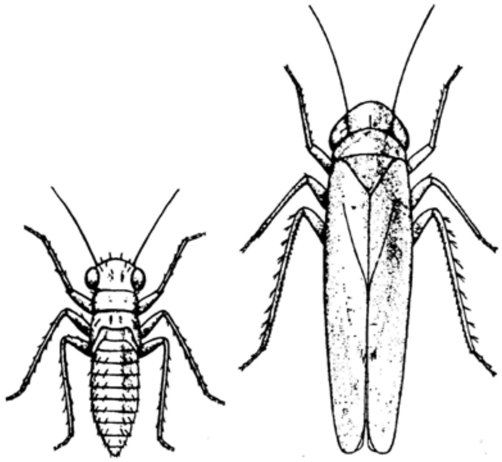

Figure 6-19. Potato leafhopper nymph (left) and adult (right).

are noted on the leaves or symptoms become apparent. No threshold has been determined.

Strawberry Rootworm

(Paria fragariae; order Coleoptera, family Chrysomelidae)

Damage: Strawberry leaves attacked by strawberry rootworm beetles are riddled with small holes (Figure 6-20). Some leaf damage occurs in May, but most occurs in August. Heavy infestations can reduce plant growth or kill plants. Although larvae of the strawberry rootworm feed on the roots of strawberry, leaf-feeding by adult beetles is more damaging to strawberry production.

Appearance: Adult strawberry rootworms are brown to black, shiny, oval-shaped beetles with four blotches on the shell-like wing covers (Figure 6-21). They are 1/8-inch long. The immatures (Figure 6-22) are grubs that are 1/8-inch long, creamy white, with three pairs of legs.

Life Cycle and Habits: Adult strawberry rootworms overwinter in mulch and soil crevices and become active in May and June. Adults feed primarily at night and hide in soil or mulch during the day. They chew small holes in leaves, and females lay eggs on older leaves near the soil surface. Larvae burrow into the ground to feed on strawberry roots from late spring to early summer. New adults begin emerging in mid-summer, and these beetles feed on strawberry foliage through early fall.

Figure 6-20. Strawberry rootworm damage.

Figure 6-21. Strawberry rootworm adult.

Figure 6-22. Strawberry rootworm larva.

Monitoring: Scouting for the presence of adult beetles is best done after dark using a flashlight to examine plants. No threshold has been established for this insect, but a population of 10 to 20 beetles per square foot is considered high.

Control by Insecticides: As with all the root-feeding insects, control of the root-feeding stage is very difficult. Therefore, control measures for strawberry rootworm should be directed toward the adult stage. If feeding injury is observed in

May or June, an insecticide spray at this time will reduce the number of egg-laying females and, therefore, the number of grubs feeding during the summer. When the next generation of adults emerges in July or August, control measures may be needed again. Post-harvest foliar sprays of registered insecticides applied according to label directions provide control of adult strawberry rootworms.

Two-Spotted Spider Mite

(Tetranychus urticae; order Acari, family Tetranychidae)

Damage: Mottling, speckling, or bronzing of foliage is caused by spider mites feeding on plant sap by rasping and sucking on leaf surfaces, which destroys leaf chlorophyll (Figure 6-23). Severely damaged leaves die and drop, which can lead to reduced plant vigor and yield reduction. The undersides of infested leaves can be covered with a fine webbing. Two-spotted spider mites are common pests in Midwestern crops, but infestations in most strawberry fields do not reach densities high enough to require control by pesticides.

Figure 6-23. Spotted spider mite damage.

Figure 6-24. Spider mite adults and eggs.

Appearance: Adult two-spotted spider mites are 1/50-inch long and barely visible to the naked eye. They are yellowish-white with two large dark spots (Figure 6-24). They have eight legs. Immature forms are usually dark in color.

Life Cycle and Habits: Mated adult females overwinter in the cover of vegetation in fields and along roadsides and hedgerows. They begin feeding and laying eggs when temperatures rise in the spring, and many generations develop each season. Adults and immatures feed on the underside of leaves.

Although wingless, the adults are highly mobile, as they disperse by ballooning in the wind on fine silken threads that they secrete while feeding. Warm, dry weather favors spider mite outbreaks, and problems occur most often in new fields where spider mites are carried in by winds before predatory mites have reached the field or in older plantings where insecticides have eliminated predators.

Cultural Control: Annual renovation of strawberry beds reduces the potential for mite outbreaks in the following season, because the destruction of leaf tissue by renovation removes the mites' food and habitat.

Biological Control: There is a natural predator called *Neoseiulus (Amblyseius) fallacis* that feeds on the two-spotted spider mite. This predator is also a mite that is equally as small as two-spotted mites but is flatter and lacks the two spots on its back; it is teardrop shaped, shiny, and yellowish white.

The predatory mites move around on the leaf much more rapidly than the two-spotted mite. It is important to encourage natural enemies of spider mites by reducing the use of pesticides that harm them.

Several companies commercially produce predatory mites, including *N. fallacis.* These predators can be released in strawberry plantings and may provide some control of spider mites, but more research is needed to determine appropriate release rates and timing.

Monitoring and Thresholds: Early detection of mites is critical for successful management. Mite colonies are usually localized in hot-spots in the field rather than being evenly distributed throughout the field. Look over the whole field and choose the first samples in any spots where bronzing is seen on leaves. Collect and examine 60 strawberry leaflets per field. Examine the underside of the leaves for the presence or absence of mites. A magnifier can help. Record the information on a field map so that hot spots can be identified and treated.

The use of a miticide for control of spider mites is justified if 25% of the leaflets (15 out of 60) are infested by one or more mites. This threshold corresponds to an average infestation of five mites per leaflet during random sampling.

When sampling a field, presence of predatory mites, as well as two-spotted spider mites, should be noted. Where predatory mites such as *N. fallacis* are present, miticide applications usually are unnecessary. A ratio of one predatory mite per 10 two-spotted mites is an approximate target for adequate biological control.

Control by Insecticides: Several miticides and combination miticide/insecticides are currently registered for use on strawberries. Most miticides do not kill eggs, so if eggs and motile mites are both present at the time of application, then a second application may be needed five to seven days later to kill motile mites that emerge from eggs. Thorough coverage of the canopy is needed for the miticide to be effective.

Cyclamen Mite

(Phytonemus pallidus; order Acari, family Tarsonemidae)

Distorted, crinkled leaves can result from the cyclamen mite feeding on young, unfolding leaves in the crowns of plants. Infested leaves can look purplish or yellow. Distorted blossoms and small seedy fruits can result from the cyclamen mite feeding on blossoms. This mite is most common as a pest of greenhouse plants, but it can cause serious losses where infested strawberry plants are transplanted in new fields. It is important to buy nursery stock from a reputable source to avoid bringing in mite-infested plants. Infestations are generally localized within a field. The cyclamen mite is tiny (Figure 6-25); it is only 1/100-inch long and is not visible without the aid of a magnifying glass. The cyclamen mite varies in color from orange-pink to white or green.

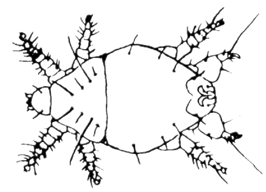

Figure 6-25. Cyclamen mite adult.

Control of cyclamen mites is best accomplished by planting only transplants that are mite-free, as determined by careful examination as soon as plants arrive from the nursery. This pest is difficult to control by pesticides once it becomes established. If a field infestation is discovered, use a registered pesticide in a high volume of water, one to two days before bloom and again 10 to 14 days later. Pesticides are not effective at controlling cyclamen mite if application is delayed until mid-summer.

Strawberry Leafroller

(Ancylis comptana fragariae; order Lepidoptera, family Tortricidae)

Damage: Strawberry leaflets infested by leafroller are folded and tied together with silken threads. Only the epidermis of each leaf is fed upon, but entire leaflets usually turn brown. Damage by first-generation larvae occurs in late May and June. Damage by second-generation larvae occurs in late July and August.

Other leafroller species that can cause similar damage in strawberries are the variegated leafroller *(Platynota flavedana)*, the oblique-banded leafroller *(Choristoneura rosaceana)*, and the blueberry leafroller *(Sparganothis sulfureana)*.

Appearance: Strawberry leafroller larvae change from pale green when young to grayish brown when fully grown (Figure 6-26). Larvae are approximately 1/2-inch long when fully grown. The adult stage of strawberry leafroller is a reddish brown moth, with distinctive yellow markings on the forewings (Figure 6-27). The wingspan is approximately 1/2-inch.

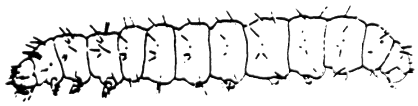

Figure 6-26. Strawberry leafroller larva.

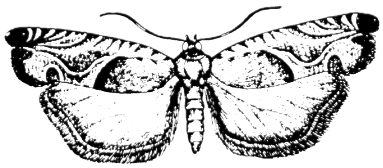

Figure 6-27. Strawberry leafroller moth.

Life Cycle and Habits: Strawberry leafrollers overwinter as fully grown larvae or pupae in folded leaves or leaf litter. Adult moths emerge in April and May and deposit translucent eggs, usually on the lower surface of strawberry leaves. Eggs hatch in one to two weeks. As larvae feed on leaves, they secrete silken threads to fold and tie leaves around them. They pupate for about one week inside the folded leaves.

The strawberry leaf-roller undergoes two or three generations each year. Moths of the summer generations are often present from July through September. Infestations may develop in spring and early summer, but they may also build up after harvest. Natural enemies of strawberry leafroller include two parasitoid wasp species that often kill a high percentage of larvae, especially during summer generations.

Threshold: Low levels of leafroller infestation do not warrant control because they do not cause reductions in plant vigor or yield during the current or subsequent season. The definition of low-level infestation has not been determined, but 10 to 20% of strawberry leaflets, especially after harvest, is a reasonable estimate.

Mechanical Control: If an infestation is detected at an early stage, rolled leaves can be removed and destroyed.

Control with Insecticides: Where control is necessary, several registered insecticides are effective. Products that contain *Bacillus thuringiensis (Bt)* can provide effective control if spray coverage is good and applications are made when many larvae are young and have not yet webbed leaves together fully. For *Bt* products to work, sprays must reach the leaf surfaces where larvae are feeding.

Strawberry Aphid

(*Chaetosiphon fragaefolii;* order Hemiptera, family Aphididae)

Aphids cause damage primarily by transmitting viruses from infected to non-infected plants. When present in great numbers, aphid feeding can result in stunted, malformed plants. Aphids occur on new shoots, undersides of leaves, and on buds while they are still in crowns. There are several species of aphids that infest strawberries; all are small (1/16-inch long), soft-bodied insects. Both wingless and winged forms of aphids can be found. Viruses are best managed by using virus-tolerant cultivars, planting certified virus-free plants, and eliminating wild strawberries from the area.

Strawberry Whitefly

(*Trialeurodes packardi;* order Hemiptera, family Aleyrodidae)

Strawberry plants infested with whiteflies may show a large number of tiny white adults (Figure 6-28) that move actively when plants are shaken, or they may show a large number of immobile scale-like immatures on the underside of leaves. Both immatures and adults suck on plant sap. They produce honeydew, a sticky substance that drips onto plants and serves as a substrate for growth of black sooty mold. They overwinter as eggs on the underside of leaves.

Figure 6-28. Whiteflies.

Summary of Strawberry Insect Pest Management Procedures

I. Cultural controls when establishing a new planting.

   A. Site selection:

      1. Do not plant after sod or grasses to avoid problems with white grubs.
      2. Avoid planting near woods or fence rows to avoid problems with clipper weevils.
      3. Do not plant near old plantings if root weevils or crown borers were present.

   B. Cultivar selection: Avoid cultivars highly susceptible to tarnished plant bug injury.

   C. Source of nursery stock: Get plants that are free of cyclamen mite.

   D. Plant density and row spacing: Wide plant spacing will contribute to slug management.

II. Cultural controls while maintaining a planting.

   A. Weed control: Contributes to tarnished plant bug and spittlebug management.

   B. Harvest: Prompt removal of all ripe and cull berries helps sap beetle management.

   C. Mulch: Remove mulch after harvest and delay mulching in fall to discourage slugs.

   D. Renovation: Helps with slug and mite management.

   E. Sanitation: Remove debris that may shelter pests, in and around fields.

III. Mechanical control options.

   A. Bait buckets prior to and during harvest for sap beetles.

   B. Traps for slugs.

   C. Row covers to exclude tarnished plant bug.

IV. Scouting for pests.

   A. Pre-bloom (once per week)

      1. Strawberry clipper: Examine plants for clipped buds.
      2. Two-spotted spider mite and predatory mites: Examine leaflets.
      3. Tarnished plant bug, adults: Sweep-net sampling.

   B. During bloom (once per week)

      1. Flower thrips: Shake flowers in plastic bag.
      2. Tarnished plant bug, nymphs: Shake flowers over dish.
      3. Spittlebug: Examine plant stems.

   C. Post-harvest (once every two weeks)

      1. Two-spotted spider mite and predatory mites: Examine leaflets.
      2. Strawberry rootworm beetles: Examine leaflets.
      3. Miscellaneous pests: Leafrollers, leafhoppers, whiteflies, aphids, root weevils.

Chapter 7
Weed Management in Strawberries

The strawberry plant is shallow rooted and is a poor competitor against weeds for sunlight (for growth and flower buds), nutrients, and moisture. Weeds can reduce yields up to 40% or more. Harvesting fruit by hand presents a challenge when weeds are present. Where customers pick their own berries, weed-free fields are important for repeated sales and customer satisfaction. A weed control program integrates knowledge of how weeds enter the field (prevention of infestation), cultural control practices, and chemical control.

General Information and Guidelines

The primary goal of weed management is to optimize yield by minimizing weed competition. Weeds reduce yields by competing with the crop for water, light, and nutrients. Weeds intercept crop protectant sprays, preventing penetration to crop foliage. Weeds may promote development of disease by maintaining high humidity in the crop canopy, and some species are alternate hosts for pathogens and insect pests. Timely cultivations, wise use of herbicides and mulches, and prevention (never letting weeds go to seed) are integral parts of a good weed management system.

Among the factors that can influence weed control are the species present, their stage of growth when controls are applied, crop competition, soil characteristics, and rainfall or irrigation. Understanding how each of these aspects may affect weed control will enable the grower to develop an effective weed-management program. In addition, the weed-management program must be thought of as a continuous management effort and not as a seasonal duty. Make it a practice to record any changes in predominant weed species and to modify the control program in response.

Often, repeated use of one successful control technique can lead to shifts in composition of the weed community. This happens when weeds that are not controlled by the technique in use (these species are referred to as escapes) become the most prevalent species in time. When weed shifts occur, or preferably before they become serious, change the control tactic to one that will control escapes.

Obviously, the ability to correctly identify weeds is essential to selection and proper use of controls. Images of many of the most common weed problems in strawberry crops can be found in Ohio State University Extension Bulletin 861, *Midwest Small Fruit Pest Management Handbook.*

Weed Identification and Scouting

Identifying weeds is essential so that the right control tactic can be used. Several excellent guides to weed identification are available. One we have found particularly useful is *Weeds of the Northeast,* published by Comstock Press. On-line weed identification guides can be found on most university Internet sites.

Patches of perennial weeds must be located and identified so that rhizomes, stolons, and rootstocks can be destroyed by herbicide spraying and cultivation well in advance of planting. Problem annuals may also be identified during the pre-planting year, and controls, such as summer fallow, can be used to reduce weed seed in the soil before planting. Scout for weeds every year.

In the establishment year, scouting should begin in spring, even before planting, so that prevalent annual weeds can be identified and controls planned. After planting and in fruiting years, scout for weeds whenever fields are scouted for insects and diseases or at least weekly during May to early July and again in late August to late October.

Pay careful attention to problem weeds in the field at harvest time as many controls can be implemented during renovation. Scout renovated fields carefully in late summer and early fall when many winter annuals germinate. Scouts should watch for occurrence of new and invasive weeds and perennials such as quackgrass and Canada thistle at all scouting opportunities. Record the distribution of each species as:

- General = found throughout the field
- Local = found in a small portion of the field
- Spotty = found in just a few places.

Also record the density of each species as:

- 1 = Scattered, just a few weeds
- 2 = Slight, 1 weed per 6 feet of row
- 3 = Moderate, 1 weed per 3 feet of row
- Severe = More than 1 weed per 3 feet of row.

Pay special attention to low spots, wet areas, and field margins where new weed problems develop first. Many species will fall into the General category and will be the primary targets of the weed-control program.

Local distribution may indicate that the species has been recently introduced to the field, and eradication by preventing seed production may be possible.

Spotty distribution of common weeds, such as lambsquarters, may indicate that herbicide resistant bio-types have developed, in which case herbicides with alternate modes of action should be adopted.

Take samples of weeds that cannot be identified in the field. Small weeds (less than 1-inch high) can usually be dug up with a small amount of soil attached to, and protecting, the roots. Samples should be placed in an inflated zip-lock bag and placed in a cooler for later identification. In some instances, it may be necessary to plant unknown seedlings in the greenhouse and allow them to size up before identification can be made.

Action thresholds for weeds have not been established for strawberry crops. Strawberry crops do not compete well with most weeds, and maintenance of nearly weed-free conditions is important for optimum production. Therefore, it is best to prevent weed seed production within the berry field, thereby reducing future weed problems.

Combining cultivation, hand weeding, and herbicide use is essential to maintain good weed control. Cultivation, hoeing, and hand weeding are most effective when weeds are small (less than 1/2 inch in height). Herbicides should be selected and applied at the appropriate timing to control the most dominant species.

But, remember that species occurring in small numbers that are not controlled may quickly become the dominant species! Therefore, carefully remove weeds that tolerate herbicides before they go to seed, thereby preventing buildup of resistant species.

Cultural Controls

Cultural controls are those good agricultural practices that minimize the growth of weeds, while optimizing crop growth. Many decisions and practices influence the effectiveness of cultural controls. These include:

- **Site Selection**

  Select well-drained, coarse-textured soils, that are free of perennial weeds. Repeated tillage and cultivation one or two years before planting reduces perennial and annual weeds. If a field has been in sod or pasture for several years, cultivation reduces grubs that feed on strawberry roots and can reduce plant vigor and cause the loss of plants. After cultivation, plant a crop that does not increase verticillium wilt disease, nematodes, or insects. For strawberries, consider a grain crop such as wheat, which can be used for straw mulch for winter protection and disease control in the berry crop.

- **Crop Rotation**

  The seeds of annual weeds in the soil (the weed seed bank) can be reduced by planting a series of annual crops prior to planting berries. Field or sweet corn is an excellent rotational crop because cultivation and chemical weed control can reduce weeds. With sweet corn, the crop is harvested by early August, making the field available for winter cover crops or additional chemical weed control, cultivation, or fumigation in the fall before spring planting. Successive grain crops or rotating from legumes to grain and to strawberries are rotations that have been used successfully.

Be sure to use herbicides in the preceding crop that will not leave a high residual in the soil when strawberries are planted six to 12 months later. Inserting a period of summer fallow the year before planting can be very effective in reducing the number of annual weed seeds in the soil. Summer fallow consists of tillage and cultivation to prepare a good seed bed for germination of weed seed followed by harrowing or light disking whenever a flush of weeds occurs. To be effective, harrow when weed seedlings are in the cotyledon stage.

- **Soil Fertility and Water Use**

  Provide the optimum fertilization for the berry crop, based upon testing the soil before planting. Consider drip irrigation that will place irrigation water and nutrients in the zone of crop roots while minimizing availability to weeds growing between the rows.

- **Cultivar Selection**

  Plant only adapted, vigorous transplants that will compete with weeds. Consider that some crop cultivars vary in sensitivity to certain herbicides.

- **Planting Density**

  Dense plantings compete best with weeds.

- **Mulches**

  Black or opaque plastic can be used to prevent weed growth for one or more years. Straw and various other mulches can prevent or reduce weed growth, depending on the amount used.

- **Sanitation and Prevention**

  The old adage that says *One year's seeding, seven year's weeding!* should be heeded by every berry grower. Preventing new weeds from invading the farm and minimizing or eliminating seed production in the field will prevent future weed problems.

  Prevention of weeds is best practiced by careful attention to cultural practices, such as cleaning equipment before moving it into the field, using clean straw mulch, and preventing annual weeds from producing seeds. Pay careful attention to any weed that is new on the farm; it may soon be your worst weed problem if it goes to seed. Ensure that straw used to mulch strawberries is weed free; for instance, grow your own straw and practice excellent weed control throughout its production.

Mechanical Controls and Hand Weeding

Hand hoeing and mechanical cultivation are important components of weed management in berry crops, particularly during the establishment year. Cultivate and hoe carefully to prevent damage to the root systems and above-ground portions of the strawberry plants. Remove all established weeds between the rows and within rows during establishment in order to obtain maximum sunlight for growth. Maintaining full sunlight throughout the establishment year is essential to obtain maximum flower bud formation.

In strawberries, mechanical cultivation between rows is necessary to train runners during the establishment year and to maintain a row width of 12 to 18 inches at renovation, with no more than 20 to 24 inches in early September.

Weed Control with Herbicides

Herbicides are selective; there will always be some escapes; and these, if not controlled, will in time become the dominant weeds in the field. To prevent this, do not depend exclusively on herbicides. Cultivate, hoe, and pull escapes. Rotate crops and be sure to use herbicides with differing modes of action in rotational crops.

There are several types of herbicides. Regardless of the type of herbicide, improper concentration, improper calibration, or overlapping the spray can cause reduced yields and death of plants.

Terms Used to Describe Herbicides

- **Selective** — A selective herbicide *(e.g.,* 2,4-D) will only control certain species or only one type of weed.

- **Non-selective** — A herbicide that kills all plants, both crops and weeds *(e.g.,* Roundup).

- **Contact** — A herbicide that kills only the parts of the plant on which it is sprayed *(e.g.,* Gramoxone and Liberty).
- **Systemic** — A herbicide that is applied to an actively growing weed; it is absorbed through the leaves or the roots and moves to other areas of the plant.
- **Residual** — A herbicide that is applied to the soil and remains in the soil for one to several months, or more than a year, continuing to control weeds and potentially damage crops.
- **Preplant (PREPLANT)** — A herbicide applied to weed foliage before crops are planted, as in site preparation.
- **Preemergence (PRE)** — A herbicide applied to the soil before weed (and/or crop) emergence.
- **Postemergence (POST)** — A herbicide applied to the foliage of weeds.

Herbicides are usually formulated as wettable powders *(e.g.,* 50 WP), emulsifiable concentrates *(e.g.,* 2 EC), aqueous suspensions *(e.g.,* AS), or granulars *(e.g.,* 10 G). Granular formulations improve the ease of application and minimize contact of herbicides with crop foliage.

Preemergence herbicides are applied before weeds emerge above the soil surface. Postemergence herbicides are applied after weeds have emerged. Residual herbicides are usually applied preemergence to weed-free soil in the spring. Residual herbicides may control weeds for one month, for three to six months, or longer. Some herbicides, including those used on berries, may persist long enough to damage crops planted one or more years after their last use. The best control is achieved when the application is not impeded by trash or actively growing ground cover.

Preemergence herbicides may be selective or non-selective, depending upon the rate applied. A post-emergence recommendation indicates that application typically consists of a systemic herbicide and should be applied to actively growing weeds in order for the herbicide to be absorbed by the weed leaves. However, a non-systemic herbicide, such as Gramoxone, is also applied postemergence to weed foliage. Good coverage is essential because the herbicide does not move. Gramoxone, Liberty, and Roundup Ultra are non-selective and must be directed away from the crop or applied before planting.

Selective herbicides only control certain species of weeds; for instance, Poast, Fusilade, and Select only control grasses and can be safely applied to the foliage of strawberry.

Systemic herbicides generally need to be applied when plants are actively growing. This means that the weeds are young, not bearing seeds, and are growing under good soil moisture and moderate temperature conditions. Plants under these conditions are not under stress, have their stomates open, and are respiring normally. For the best control, applications should be made with day-time temperatures of 55 to 75°F and with six to eight hours drying time (without irrigation or rainfall) for maximum absorption by the weed.

Consult the label or technical bulletin for the range of weeds controlled. Also check the broadcast rate for different types of weeds. Read all precautions for each crop.

What Rate Should Be Used When a Range Is Provided?

Generally, heavier soils require more herbicide than lighter soils, because in heavier soils the chemicals are adsorbed by clay particles and organic matter. The presence of trash on the soil surface can lower the effectiveness of applied herbicides. Therefore, control may be reduced if the herbicide is applied over mulching materials. In the effective use of herbicides, there is no substitute for thorough knowledge of soil and herbicide characteristics.

Selective herbicides will control certain weed species while being ineffective on others. Weeds not controlled are called escapes, and if the herbicide program is not changed, in time the escapes will become the prevalent weeds in the field. For this reason, it is essential to accurately identify the weeds in your field and select herbicides that will control those weeds according to the information on the product label.

Be sure to read and understand the label before using any herbicide. Failure to follow label directions is illegal and may result in crop damage or poor weed control. Preventing injury to the crop plant depends on applying the right herbicide at the correct time and rate of application. Weak, unhealthy, or injured plants can be damaged by herbicides. Environmental conditions that stress the crop may also predispose the crop to herbicide injury.

If you choose to try a new herbicide or alter your existing weed-control program, try the proposed program on a limited area first. This will help you decide whether the new program is compatible with the ongoing production system. In addition, it will allow for changes and refinement before full-scale use.

Herbicide rates listed on the product label and in this bulletin are for broadcast applications. Reduce rates proportionally for banded or strip applications. For best results with herbicides, follow the manufacturer's application directions regarding rates, additives, soil type, soil moisture conditions, stage of weed growth, environmental conditions, and product limitations.

Certain herbicides listed in this publication may be discontinued by the manufacturer and thus may no longer be available. Using remaining stocks on dealers' shelves or stored on the farm is encouraged and legal.

Trade names are used for identification. No product endorsement is implied, nor is discrimination intended against similar materials not mentioned. Extension and the participating universities make no warranty or guidance of any kind, expressed or implied, concerning the use of these products.

Herbicide Injury

Strawberry injury resulting from the use of herbicides is common, particularly on light soils. Most herbicide injury can be traced to using too high a rate on light soils, incorrect timing of sprays, incorrectly calibrated sprayers, sensitive cultivars, and weak plants growing under unfavorable conditions. The grower usually has some control over these factors. Any factor that injures the crop (other pests, winter injury, exposure of crowns and root systems as a result of erosion, improper mineral nutrition, wet spots in the field, etc.) will make the crop more susceptible to injury.

Newly planted strawberries are especially sensitive to herbicides. Crop tolerance increases in late summer and fall. This corresponds to the time when preemergence herbicides can be used to control many winter annual and perennial weeds.

Remember that light, sandy soils require less herbicide than heavier soils for comparable levels of weed control. Strawberries growing on soils low in organic matter are especially prone to herbicide injury. Accordingly, lower rates of herbicide should be used on fields low in organic matter (less than 2%).

To minimize the risk of crop injury, growers must be careful not to exceed maximum recommended annual application rates. They should fully understand and follow the instructions on the product labels. Do not expect herbicides to control all weed problems. Understand that hand weeding and cultivation will be required to obtain complete weed control. Weakened plants are more susceptible to herbicide injury. Conversely, healthy strawberry plants are most capable of tolerating recommended treatment rates.

Be cautious with tank-mixes. Severe Sinbar-type injury has occurred when certain postemergence grass herbicides and Sinbar were tank-mixed or even applied in close sequence.

Uniform application is absolutely necessary if herbicides are to provide the desired results. Variations in the spray pattern, speed of the rig, worn nozzle tips, etc., may change the application rate sufficiently to damage the crop or reduce weed control. Devrinol, Dacthal, and Sinbar are wettable powders that do not dissolve in water. These herbicides form a suspension in water that can only be maintained by constant agitation in the spray tank. Consequently, you must take several precautions to maintain a uniform application.

Precautions

1. Screens in the line should be no more than 50 mesh to avoid clogging.

2. The material will settle to the bottom of the tank if not constantly agitated. Either continuous mechanical agitation by paddles in the tank or hydraulic agitation by return flow jets (pressure regulator by-pass) is necessary.

3. Wettable powders are abrasive; therefore, do not use these herbicides in gear, roller, or impeller pumps. The clearances in these positive displacement pumps are close; they wear quickly when abrasives are pumped.

4. Wettable powders wear nozzles readily. Brass nozzles wear sooner than polymer and stainless steel nozzles. Because of wear, the amount of spray being pushed through the nozzle will gradually increase. The spray rig must be properly designed and calibrated often (approximately every 20 hours of use with brass nozzles) if you are to be sure of the amount of material being applied per acre.

Herbicides recommended in this guide are referred to by their brand name, and application rates are provided in the actual amount of product per acre. The guide provides enough information to assist you in selecting a herbicide for a particular crop and weed situation. For complete information, it will be necessary to consult the label.

Too often growers neglect the label until something goes wrong. Wouldn't it be better to spend 20 minutes reading the label in advance and thereby preventing problems from ever developing? Labels contain explicit directions on using herbicides correctly and indicate all weeds that are controlled.

Full text labels and Material Safety Data Sheets (MSDS) should be available from your pesticide dealer. The MSDS information can also be obtained for most herbicides over the Internet from company web sites or from compilers such as CDMS, Inc. (**http://www.cdms.net/pfa/LUpdateMsg.asp**).

Herbicides used to control weeds in strawberry plantings are applied:

- PREPLANT — Preplant treatments applied before the crop is planted.
- PRE — Preemergence treatments, applied at the time of planting or some time before weed seedlings emerge.
- POST — Postemergence treatments, applied after planting and after weed seedlings have emerged.

Mixing two or more herbicides may improve control and the spectrum of weeds controlled (Table 7-1), while minimizing required rates. However, do not mix herbicides unless the mixture is approved on at least one label of the products intended for use.

Strawberries can be injured by residues of herbicides used in preceding rotational crops that still remain in the soil. Herbicides used to control weeds in corn and soybeans are most likely to carry over and damage strawberries. A few herbicides will damage strawberries two or more years after they were last used. If you purchase or rent new land, be sure to ask the owner or manager about herbicides used in previous years — the farther back, the better! Labels contain information on permissible rotational crops and the required time interval between use and rotational crops.

A bioassay is the simplest and most cost-effective method to check for herbicide carry-over. To do this, collect, at random, soil from all areas of the field in question. Sample the root zone, typically 6 inches deep. Each test requires about 1 gallon of soil. Ends of fields, knolls, and low areas often have higher residues and may need to be tested separately.

From a nearby area, collect a second sample of the same soil that was not treated with herbicide and use this for a control (for comparison) soil. If untreated soil is not available, add 1 teaspoon of activated charcoal per quart of dry soil and mix thoroughly. Activated charcoal can be purchased at most drug stores.

Three or four pots of the test and control soils should be made and seeded out to oats, radish, and lentils. Place the pots in a warm, sunny location and monitor seedling growth for symptoms. If any injury is noted, then contact your pesticide dealer or local Extension specialist for advice on the probable sensitivity of strawberry.

Table 7-1. Herbicide Efficacy Against Common Weeds in Strawberries.

Common Weeds	Herbicides					
	Postemergence			Preemergence		
	Select	2,4-D	Poast	Devrinol	Dacthal	Sinbar
Perennial Grass						
Quackgrass	E	N	G	N	N	P
Bluegrass	G	N	P	N	N	P
Yellow Nutsedge	P	F	N	P	N	F
Perennial Broadleaf Weeds						
Dandelion	P	E	N	N	N	F
Clovers	P	E	N	N	N	F
Thistle	P	G	N	N	N	N
Curley Dock	P	G	N	N	N	N
Annual Grasses						
Crabgrass/Foxtails/	E		E	E	E	F
Barnyard Grass	E	N	E	E	E	F
Oats or Rye (from mulch)	E	N	E	E	E	F
Annual Broadleaf Weeds						
Lambsquarters	P	E	N	F	G	E
Redroot Pigweed	P	E	N	F	G	G
Galinsoga	P	G	N	G	P	G
Yellow Wood Sorrel	P	P	N	P	G	F
Chickweeds	P	F	N	E	G	E
Purslane	P	G	N	G	G	G
Shepherd's Purse	P	G	N	P	P	E
Carpetweed	P	G	N	G	G	G
Horseweed	P	G	N	N	N	G
Common Groundsel	P	F	N	F	P	F
Field Violet	N	P	N	P	G-E	F-G

E = Excellent; G = Good; F = Fair; P = Poor; N = No Control

Herbicide Application

Strawberries can be easily injured if too much herbicide is applied. To prevent this, calibrate the sprayer frequently and adjust nozzle tips to the proper height above soil level. Herbicides should be applied with a boom sprayer. Backpack and airblast sprayers should not be used because they will not give uniform application.

An excellent fact sheet from Ohio State University Extension that provides detailed information on this subject is AEX-520, *Boom Sprayer Calibration.* This fact sheet can be downloaded from the Internet at **http://www.ohioline.osu.edu/aex-fact/0520.html** and Ohio residents can also obtain it from most county offices of OSU Extension.

Controlling Weeds Before Planting

Many of the worst weeds found in berry crops are perennials such as quackgrass, johnsongrass, yellow nutsedge, Canada thistle, and field bindweed. Perennials spread and reproduce mainly by underground rootstocks or rhizomes and are very difficult to control once berry crops are planted. Therefore, eliminate all perennial weeds before establishing a new planting by using a planned program of tillage, rotational crops, and herbicides (Table 7-2).

Time and money spent before planting will eliminate the need for more costly and on-going weed control methods during the establishment and production years. In addition, without the presence of competing perennial weeds, there will be a greater potential for vigorous, healthy establishment of the strawberry crop.

Glyphosate — hereafter referred to as Roundup or Touchdown (many formulations and brands are available though most simply refer to this herbicide as Roundup) — applied directly to the foliage of perennial weeds before plowing is the most effective means of control. Roundup application must be timed correctly and the right rate used for the perennial weeds you are trying to control.

Most perennials are best controlled with fall-applied Roundup. Grasses should be at least 8 inches tall when treated. An extended period of drought just before spraying may adversely affect control. Spring applications are effective on grasses but do not provide as good control of broadleaf perennials as fall applications.

Descriptions of the perennial weeds presented here were extracted from the *Ohio Perennial and Biennial Weed Guide,* which is available on the Internet at **www.oardc.ohio-state.edu/weedguide/.** In the recommendations for controlling these weeds, application rates are provided for two of the most common formulations of glyphosate. The use of these brand names does not imply an endorsement of these over other glyphosate products, or a criticism of those products that are not named.

Canada Thistle

Canada thistle can be treated in the flower bud to flowering stage in early summer or in late summer and fall during the rosette to flower bud stage. In fallow fields, stop tillage in late July and allow thistles to regrow for at least five weeks. Apply Roundup Ultra or Touchdown before a killing frost and when Canada thistle regrowth reaches the flower bud stage or is at least 10 to 12 inches high. Apply Roundup Ultra at 2 to 3 quarts per acre in 5 to 10 gallons of water or Touchdown at 2 quarts per acre. Spot sprays of a 2% solution (0.5 pints in 6 gallons of water) of either herbicide will also be effective.

Field Bindweed

Field bindweed is a twining perennial vine. Characteristics distinguishing it from other vines include arrowhead-shaped leaves, thin stems, pinkish petals fused into funnel-shaped flowers, the presence of small bracts attached to flower stalks about an inch below the base of the flower, a perennial taproot, and invasive rhizomes (horizontal underground stems). The plant reproduces by seeds and regenerates new plants from adventitious buds on roots and rhizomes.

Field bindweed must be treated when it is actively growing and at or beyond bloom. Fall treatment is best, but apply herbicides before a killing frost. Apply Roundup Ultra at 3 to 4 quarts or Touchdown at 5.33 pints per acre. Spot spray with a 2% solution of either product.

Table 7-2. Herbicides for Perennial Weed Control the Year Before Planting and for Spot Treatment.

Prevalent Weeds	Timing of Treatment[a]	Herbicide/Acre[b]
Canada thistle	Bud to early bloom stage; regrowth in autumn following tillage.	• Roundup 2 to 3 qt. or 2% spot spray.
Field bindweed	When plants are at or past full bloom and before killing frost.	• Roundup 3-4 qt. or 2% spot spray; • 2,4-D 1 pt. or Banvel 8 oz. + Roundup 1 qt.[c]
Horsenettle	Late bud to flowering	• 2.5-4 qt. Roundup; • Banvel or 2,4-D ester at 2 qt.
Dogbane	Late bud to flowering stage	• Roundup at 3.25 qt.; • Roundup 1 qt. + 1 pt. 2,4-D; • Roundup 1 qt. + Banvel 1/2 pt.
Poison Ivy	7/1 to 9/15	• Roundup 2.5 to 5 qt.; • Banvel 1 qt. + Roundup 2 qt.; • Crossbow 2 qt.
Quackgrass	Spring — 8" tall to heading or Fall — 8" tall regrowth	• Roundup 1 to 2 qt.
Wild brambles	Bud to bloom stage	• Banvel 1 qt. + Roundup 1 qt. • Crossbow 6 qt. (1 to 1.5% solution)
Swamp smartweed	7/1 to 9/15	• Banvel 8 oz. + Roundup 1 qt.

[a] With the exception of quackgrass, apply before frost.
[b] Adding a surfactant to these herbicides will improve their effectiveness; Roundup already contains a surfactant. Rates are given in amounts of commercial product per acre.
[c] Apply Roundup with Banvel or 2,4-D where several weed species are present. Roundup alone is best applied on tall weeds, applied in 5 to 10 G of water per acre with surfactant and ammonium sulfate.

Follow label recommendations. Do not apply Banvel, 2,4-D, or Crossbow near brambles or grapes.
Avoid drift. Apply spot treatments using low pressure or a wick applicator.

Horsenettle

Horsenettle is a perennial that spreads through creeping rootstocks, in addition to reproduction by seed. A main distinguishing feature of horsenettle is the bristly stem, which is covered with hairs and spines. Leaves are alternate, oblong, and lobed, with yellow prickles on the petioles, midrib, and veins. The plant produces juicy, yellow berries that are about 1/2-inch in diameter and contain the seeds.

Horsenettle is found mainly in no-till fields and is difficult to control. It typically emerges after crop planting, and postemergence herbicides are only marginally effective.

Apply Roundup Ultra at 2.5 to 4 quarts per acre or use a 2% solution for spot treatment, when most of the plants have reached the bud to flowering stage. Banvel at 2 quarts per acre or 2,4-D ester at 2 quarts per acre when horsenettle is in the late bud to flowering stage can also be effective. Control ranges from fair to good with these treatments.

Hemp Dogbane

Hemp dogbane is a tall-growing perennial broadleaf weed often mistaken for common milkweed. It spreads by seed and over-wintering rootstocks. In Ohio, hemp dogbane tends to appear in areas that have not been tilled for a number of years.

Apply Roundup Ultra at 3.25 quarts per acre or a 2% solution for spot treatment when dogbane is in the late bud to flower stage of growth. Roundup and 2,4-D can also be used effectively at 1 quart plus 1 pint per acre, respectively. Treatments following crop harvest or mowing should be delayed until weeds regrow to a mature stage.

Poison Ivy

Poison ivy is a deciduous woody perennial distinguished by its leaves that have three leaflets. The stalk attached to the middle leaflet is considerably longer than that attached to either of the two outer leaflets. Poison ivy grows in a variety of forms, including trailing, shrubby, or a vine.

Reproduction is primarily by seeds that are dispersed by birds and animals. Also, it may spread by rhizomes (horizontal underground stems). Stems are capable of forming roots and sending out new shoots when in contact with soil.

Apply Roundup Ultra at 2.5 to 5 quarts per acre to thoroughly wet the foliage but do not spray to run-off. Banvel at 1 quart per acre plus Roundup at 2 quarts per acre may also be effective.

Quackgrass

Quackgrass is a creeping, sod-forming perennial grass, characterized by its straw-colored, sharp-tipped rhizomes (horizontal underground stems) and the pair of whitish-green to reddish, claw-like structures (auricles) that clasp the stem at the top of the sheath. It reproduces through seed and creeping rhizomes. This species can form large patches.

When killing sod, use Roundup Ultra at 2 quarts per acre or Touchdown at 3.33 pints per acre. Use the 1-quart-per-acre rate of Roundup Ultra in 5 to 10 gallons of water per acre on land that has been in row crops. Spray when the grass is about 8 inches high and wait at least three full days (72 hours) but generally not more than seven days before plowing.

Fall frosts before spraying will not affect control provided at least 60% of the foliage is still green when you spray. If planning a spring application, do not fall plow; simply wait until quackgrass reaches the right growth stage (four to five new leaves) and spray.

Swamp Smartweed

A native of North America, swamp smartweed is a highly variable perennial. It exhibits two forms, terrestrial and aquatic. For this reason, the plant will invade shores, wet prairies, swamps, ponds, ditches, and quiet streams. However, it is quite common for plants to grow in drier soil.

Swamp smartweed reproduces using rhizomes (rootstocks) and seeds. Plants normally grow from two-feet to three-feet tall. The stems are usually unbranched and thicken to form nodes at the leaf joints. Swamp smartweed blooms from July to September. The spreading root system allows for competition with other plants while making it difficult to kill the plants. Apply Roundup plus Banvel at 1 quart and 1/2 pint per acre, respectively.

Yellow Nutsedge

Yellow nutsedge is an erect, grass-like perennial, characterized by its shiny yellowish-green leaves, triangular stem, golden-brown flower head, and shallow rhizomes (horizontal underground stems) that produce many nut-like tubers. Young seedlings are often confused with grasses. This species reproduces primarily by tubers and less often by seeds. Rhizomes help to enlarge patches. Nutsedge persists by producing nutlets that grow at the end of rhizomes.

Nutsedge emergence continues summer-long as more nutlets break dormancy and shoots emerge from expanding rhizomes. New nutlets begin to form on the end of rhizomes soon after shoot emergence in the spring. Nutsedge control with herbicides is rarely or never complete because insufficient herbicide translocates into the nutlets.

Attack nutsedge one or two years before planting berries using an integrated approach. Apply preplant glyphosate on small nutsedge plants (control with Roundup Ultra is best when nutsedge is 6 to 12 inches high; earlier applications will provide some suppression — Monsanto Research) and/or till before planting.

For one or two years before planting berries, plant competitive crops and use close spacings. Plant and harvest early season crops before nutsedge emerges, then plant crops with selective herbicides later, around the anticipated time of nutsedge emergence. Selective herbicides can be used for seasonal control in corn, soybeans, dry and snap beans, potatoes, and green peas. Finally make use of post-harvest tillage and summer fallow. Yellow nutsedge is sensitive to dense shade, thus close spacing of crops such as pumpkins will minimize growth and nutlet formation.

If you do not already have nutsedge in a field, prevent its introduction. Wash all soil from recently purchased equipment before allowing it on your farm. If you have some infested fields and others that are not, or if your equipment is used on fields of other farmers, be sure to wash all soil off the equipment before using it on land that is nutsedge-free.

Nutsedge has also been introduced in transplants, nursery stock, and seed potatoes. Make sure all transplant materials were produced under netsedge-free conditions.

Wild Brambles

Brambles are a diverse group of perennial herbs, shrubs, or trailing vines that are noted for their prickly stems and berry-like, usually edible, fruits. They can reproduce by many different methods including seeds, root sprouts, underground stems (rhizomes), and branches that root at the tips (stolons).

In some species, individual stems live only two years, but new stems are continually produced. In all species, roots are perennial; apply Roundup Ultra plus Banvel at 2 quarts plus 1 quart per acre, respectively. Spray foliage till wet but not to runoff.

Water Volumes and Adjuvants with Glyphosate

Low water volumes of 5 to 10 gallons per acre provide best weed control. If higher water volumes must be used, use the maximum rate of glyphosate for the weed to be controlled. At high water volumes, adding a non-ionic surfactant at 0.5% (one pint in 25 gallons) or ammonium sulfate (2 to 4 pounds per acre) to the spray mix will improve control. Always add ammonium sulfate to the water before adding glyphosate.

Hard water with more than 500 parts per million of calcium or magnesium will usually reduce glyphosate activity. If hard water must be used, keep the volume low (five gallons per acre) or increase the rate of herbicide. Use clean water. Silt, clay, and organic debris in water will also reduce glyphosate activity.

Table 7-2 provides information on use of herbicides to control perennial weeds during the year before planting and for spot treatment.

Herbicides for Strawberries the Year of Planting

The weed control program should aim to promote vigorous crop growth and have the field relatively free of weeds by the time mulch is applied in late fall. This usually requires the use of cultivation in conjunction with herbicides. However, fields that have been fumigated at herbicidal rates should not require a herbicide application during the spring and summer of the establishment year.

Cultivation is especially important to prevent the rapid growth of annual weeds during the first several weeks after planting as the crop establishes. Many growers do not use herbicides on newly planted fields until early fall. Herbicides that can be used during crop establishment will control germinating or very small seedlings but are ineffective on established weeds.

Weed emergence will usually occur within one to two weeks of planting. Dacthal or Sinbar can be applied immediately after transplanting. Dacthal does not control emerged weeds but is especially effective in preventing establishment of field violet and some annual grasses. Sinbar will control small emerged weeds and control germinating broadleaf weeds for several weeks after application. Hand weeding and cultivation will be required to maintain complete control during the establishment period.

Cultivation is most effective when weeds are very small and should occur each time emerging weeds are observed between the rows. Cultivation at weed emergence can be shallow, which will prevent buried weed seed from being brought to the surface where germination is then likely to occur. Shallow cultivation also minimizes dilution of preemergence herbicides by deep mixing in the soil. A wiggle-hoe can be used to cultivate weeds between rows and between strawberry plants within rows.

Poast can be used at any time during the establishment year to control seedling annual grasses and perennials such as quackgrass and Johnson grass. An adjuvant is always required with Poast. Fusilade and Select can also be used for grass control during the establishment (non-bearing) year. Both products offer similar control to Poast. Prism is the only grass herbicide that is highly effective on annual bluegrass.

Cooler weather in late summer and early fall will trigger germination of fall annual weeds and many perennials. Matted rows of strawberry should be filled in by early fall; therefore, it will not be possible to control weeds occurring this time of year with cultivation. An application of Sinbar or Sinbar plus Devrinol at this time will minimize weed establishment. Usually, new plantings should be treated no later than mid-September. Devrinol controls annual grasses and a number of summer and winter annuals, including common groundsel. The herbicide acts primarily through soil uptake and requires irrigation or rain to be effective. Under dry conditions if rainfall does not occur within 7 days of application and irrigation is not available, a shallow cultivation will help activate Devrinol.

Sinbar in fall of the planting year will improve control of seedling winter annuals and perennials over that obtained with Devrinol. Do not tank-mix Sinbar with any grass herbicide or apply a grass herbicide within six weeks after applying Sinbar or severe crop injury may occur. Of all the herbicides used in strawberry production, Sinbar is most likely to cause crop damage. Strawberry plants that are under stress are most likely to be injured. Certain varieties such as Jewel are more sensitive to Sinbar than others. Growers should be sure the variety(ies) they are growing are tolerant of Sinbar prior to using this herbicide.

In late fall, just before mulching, Sinbar and/or Devrinol can be applied to provide residual control of weeds, including volunteer cereals, during the fruiting season. These applications may follow earlier applications of Sinbar or Devrinol provided the cumulative dosage used over the course of two or more sequential treatments does not exceed the total annual dosage permitted by the label.

The spray schedule (Table 7-3) lists the choice of treatments that can be used to control specific weeds or weed groups at various treatment times throughout the season. Apply only one herbicide or herbicide combination (tank-mix) at each application time. Growers must be careful not to exceed the maximum application rate or total number of applications per season for a particular product.

Herbicides for Established Plantings

An early spring herbicide, applied soon after removing mulch in the fruiting year may be necessary to control germinating summer annual weeds when a late fall application of Sinbar or Devrinol was not used (Table 7-4). Dacthal should be applied as soon as the winter mulch is removed and can be applied again at renovation. Devrinol

Table 7-3. Recommended Herbicides for Strawberries: THE YEAR OF PLANTING.

Weeds	Timing of Treatment	Herbicide/Acre
Preemergence		
Annual grasses, some broadleafs	Anytime before or after transplanting.	• Dacthal W-75, 8-12 lb.
Annual grasses, some broadleafs	After adequate number of runners have rooted, or in late fall.	• Devrinol 50WP, 4-8 lb; irrigate within 2-3 days.
Broadleaf weeds, some grasses	After transplanting, but before rooting of runners.	• Sinbar 2-3 oz, followed immediately by rainfall or irrigation equal to 1/2 - 1”.
Winter annual weeds	Late summer/ early fall.	• Sinbar 2-6 oz, followed immediately by rainfall or irrigation equal to 1/2 - 1”.
Postemergence		
Grasses	When grasses are 2-8” tall (before seed head formation).	• Fusilade DX, 16-24 oz + 2 pt crop oil concentrate/25 gal. or 1/2 pt nonionic surfactant/25 gal. • Poast 2 pt + 2 pt crop oil concentrate. • Select, 8 oz + 1 quart crop oil concentrate/A; apply no more than 32 oz/season.
Nonselective (kills all)	Before weed growth is 6”. Directed spray only (do not spray strawberry plants).	• Gramoxone Extra, 1.5 pt. in 20-60 gal water + non-ionic surfactant. Directed spray only.
Nonselective (kills all)	Late summer-fall (August – mid-September).	• Roundup Ultra, 1-3 qt. *Directed spray or wiper only.*

may be applied anytime before bloom but will only be effective on emerging seedling weeds. Poast or Select may be used in the spring.

Renovation and late fall treatments are used to clean-up the field for the next year, to maintain a sufficient concentration of residual herbicide near the soil surface to control germinating weeds in the late summer/early fall, and to provide residual control through the following spring/early summer. Growers should pull or spot spray weeds that have established during the planting year and the picking season.

2,4-D amine (Formula 40) should be applied at renovation, after the final harvest to control broadleaf weeds. It is very effective on most annuals and also controls dandelions and plantain. It will not control red sorrel, yellow toadflax, and field violet. Strawberry beds should be mowed within three days of applying 2,4-D, rows narrowed if necessary, and fertilized. Within two weeks of applying 2,4-D, apply Sinbar at 2 to 6 oz/A. If late summer annual and winter annual weeds are likely to be a problem, use the higher rate. Remember that Sinbar is the most likely herbicide to injure strawberries and must be used with caution and knowledge. Strawberry plants may be stressed at this time of year, following an especially heavy harvest or because of pest problems such as strawberry mite, and more sensitive to herbicide injury.

Shallow cultivate renovated beds if necessary to control seedling weeds between the rows and apply Poast or Select for grass control on an as-needed basis. Do not use these herbicides within six weeks of applying Sinbar.

As in the planting year, cooler weather of early fall will trigger germination of winter annuals and some perennial weeds. To minimize their establishment, apply Devrinol no later than mid-September as soil residues from renovation applications of Sinbar and/or Dacthal are declining in effectiveness. Late fall applications of Sinbar and Devrinol may be used just before mulching provided the cumulative usage during the growing season has not exceeded the total amount that can be used.

Table 7-4. Recommended Herbicides for ESTABLISHED STRAWBERRY PLANTINGS.

Weeds	Timing of Treatment	Herbicide/Acre
Preemergence		
Annual grasses, some broadleafs	Late fall or early spring.	• Dacthal W-75, 8-12 lb.
Annual grasses, some broadleafs	Fall or early spring.	• Devrinol 50WP, 4-8 lb; irrigate within 2 to 3 days.
Broadleaf weeds, some grasses	Renovation, before new growth begins. Late fall, just before mulching.	• Sinbar 4-8 oz. • Sinbar 4-8 oz.
Postemergence		
Dandelions, other broadleafs	Renovation (before mowing).	• 2,4-D (Formula 40) 1-3 pt.
Annual and perennial grasses	When grasses are 2-8" tall, before seed head formation.	• Poast 2 pt + 2 pt crop oil concentrate; • Select, 8 oz + 1 qt crop oil concentrate/A; apply no more than 32 oz/season.
Nonselective (kills all).	When weeds are 6" or less.	• Gramoxone Extra, 1.5 pt in 20 to 60 gal water + non-ionic surfactant.

Chapter 8
Reducing Bird and Other Wildlife Damage in Strawberries

Birds

Birds can cause serious damage to small fruit crops, including strawberries. Growers may experience destruction of up to 30% of a crop within a few days of birds feeding. Large flocks of birds can consume large quantities of fruit over a 10-day period. It has been observed that mid-season ripening strawberries may have several fruit either fully or partially pecked. Robins, starlings, finches, orioles, and cedar waxwings have been observed feeding in ripening fruit crops throughout the Midwest. Bird populations are increasing due to changes in weather and migration patterns and the overall availability of fruit being produced in the Midwest.

Bird damage patterns can vary from year to year and can be localized, depending on the source. Birds can fly 10 to 15 miles from a resting site to feed. It is difficult to stop birds from feeding once they start. They can establish their home territory in late April and May and remain until the crop ripens. Crops near resting areas, wooded lots, and ponds are most vulnerable. Birds generally feed approximately 30 minutes before sunrise and generally conclude feeding about 30 minutes after sunset. Complete bird control is very difficult to attain even with the best managed bird scare devices. Birds are creatures of habit and can sense after a few days that a scare device is of no real threat.

Large flocks of birds can be persuaded to scare out of a field of strawberries much easier than a few group feeders. Feeding will occur on the first available fruit that ripens, and then other birds will fly in from a roosting site as far away as 12 miles. In some cases, birds begin feeding two weeks before harvest by investigating the strawberry fruit to determine if it is mature enough to feed on. Once the birds detect that the fruit is adequately ripe, larger flocks of birds will be attracted to the same field to begin feeding.

Types of Bird Repellent

Physical Barrier

Netting, either plastic or rope (known as tobacco netting), can be used; however, it takes a lot of labor to put in place, and birds can get under or eat through it. Nets offer nearly 100% protection, particularly in high-value crops. Placing the netting over the crop is best. Netting may be effective, but it is not typically used for strawberries except on a very small scale.

Sound Devices

Propane Cannons

These cannons give unexpected blasts and should be set at intervals greater than one blast per three minutes. Fully electronic, randomized, rotating multi-shot units are most effective since timing and direction of the blast keep birds off balance. However, neighbors who work early or late shifts and rest during the day may become angry if these are used. Timers can be used to provide flexibility and turn off the cannon during the off feeding periods.

When using propane field cannons, the following is suggested:

- Set intervals greater than three minutes.
- Time cannons to start 30 minutes before sunrise and to shut off 30 minutes after sunset.
- Operate on no more than five acres.
- Ensure propane tank valves do not leak.
- Move units around.
- Use electronic timers to shut off automatically.

Electronic Sound Devices

Some devices simply disrupt bird communications. Other devices use digital electronic sound to produce distress calls. Several "chips" of different calls are available on one device. Some reports say that these devices can attract hawks, and hawks scare birds away. These devices discourage birds from nesting in nearby trees in the spring. They tend to be less objectionable to neighbors.

Pistol Cartridges and Other Sound Devices

Special cartridges, launched from handguns, which explode high in the air near birds, can quickly clear a field or wooded lot and can be an effective manual scare device. Shotguns are often used but are generally ineffective. In some cases, protected species can be harmed.

Visual Repellents

Aluminum pie plates and Mylar humming lines may work for a few days and are best just before harvest. The same is true of artificial hawks, stuffed owls, or snakes.

Use an Integrated Approach

One deterrent system usually does not work; therefore, use a combination of methods. Creating random unexpected noise, positioning devices near perimeters and flight patterns, using scare devices near the fruit planting, and encouraging predators can be effective.

Here are some tips:

1. Start bird control methods 10 to 30 days before the crop ripens. Watch and be aware of the birds' habits and their reaction.
2. Change the method of control. Move devices once per week and change the type of noise.
3. Control birds 30 minutes before sunrise to early morning and into late afternoon to 30 minutes after sunset.
4. Consider the amount of fruit loss compared to the cost of equipment or material and labor to control birds.

Remember

Once birds start to eat the crop, they are difficult to remove. Control is based on knowing how birds behave. Start controls before the fruit starts to turn from green to red. Use several methods and change positions once per week.

Wild Turkey

Wild turkeys are appearing with ever-increasing numbers in fruit plantings, looking for food. Unless preventive measures are taken to restrict their entry into a field, little can be done to prevent them from decimating a strawberry planting. Wild turkeys, unlike domestic turkeys, can take flight and are often seen roosting in surrounding trees and brush. As with other birds, turkeys do not like loud and/or distressing sounds.

Types of Wild Turkey Repellents

- **Physical Barriers.** Standard bird netting can be used, although turkeys are more powerful and may tear the netting trying to get the fruit. High fencing can be used to turn back the turkeys.
- **Sound Repellent.** Propane cannons will have some effect in the short term, but, as with other fruit-eating birds, turkeys become accustomed to the sound and within a few days may pay little attention. Shotgun and pyrotechnic guns may provide some means of distraction to wild turkeys so they are less likely to settle in the strawberry field.

Deer

Deer, like other wildlife, pose a serious threat to Midwest fruit plantings. In early spring and late fall, deer have been observed foraging on tender, succulent strawberry leaves. Food sources are scarce in early spring, and deer are naturally attracted to any green tissue that emerges. Foraging deer are attracted to the naturally evergreen strawberry leaves in late fall as green grass and tree and shrub leaves become scare.

Deer have been observed feeding on strawberry plantings in late fall. This, normally, does not create undue stress and will usually have little effect on the overwintering capacity of the plants in matted-row production systems. Generally, adequate energy (carbohydrate) reserves are met by the first killing frost. Unless the deer have damaged the crowns of the strawberry plants while feeding on the leaves, new growth will emerge in the spring when warm weather returns.

In plasticulture plantings where the production of branch crowns is required in the fall, deer feeding can result in serious damage to the planting.

Several different kinds of approaches have been used to mitigate the damage that deer cause in fruit plantings.

- **Odor Repellents.**

  Materials (human hair, dog hair, and soap) that are commonly used to deter deer are used because they smell unnatural or have the smell of a predator. These materials can be used effectively to prevent deer from entering plantings.

  There is some interest in using coyote hair to create a negative environment for deer. Coyotes are the main predators of white-tail deer in the Midwest, and it has been reported that deer do not like to come near feeding areas that have been baited with coyote hair. As with the bird populations, deer can acclimate very quickly, and they can become familiar with a new odor. However, deer appear to avoid the area baited with coyote hair for several weeks, even when the bait is removed.

- **Sound Repellents.**

  Deer can be startled by unfamiliar sounds, and they are less likely to stay in an area in which strange, unnatural sounds are emanating. Propane cannons and distress signals can be used to send deer to flight.

  Moving the noisemakers around the inside and outside of the planting can help to dissuade the deer from entering and make the area somewhat less familiar. This should keep the deer on edge and less interested in foraging on the tender strawberry leaves.

- **Physical Barriers.**

  Fencing is one of the best means ofkeeping deer from entering a strawberry field; however, the expense can be cost prohibitive.

  Poly Tape electric fence, commonly used to keep horses and cattle in pasture, is being used to control deer around strawberry plantings. Some producers are using this in place of standard single-strand electrical fence. It has been observed that deer will not enter an area with this type of fence surrounding it.

  The Poly Tape (1-1/2-in. wide) works well at a height of 5 to 6 feet, with four to five strands from top to bottom. Generally, only the first through third stands from the ground are charged. Peanut butter on aluminum foil placed on the electrical wire is used to bate the deer. T-posts are used to fasten the tape in place within the fence row.

  With an electric fence, grass and weeds must be kept under control or the fence could short out. Weed whacker or burn-down herbicides can be used to keep vegetation under control.

Wildlife Control Summary

Strawberry growers may experience one or all of these wildlife predators feeding in their fields. The best approach is to watch carefully and determine which animals are causing the damage and then address the problem. Once you have found the predator, become proactive and place physical barriers, sound devices, and other detractors where they will do the most good. Wildlife can become accustomed to new sounds and motions so it will be imperative to continually move the devices around the field to avoid familiarity.

Chapter 9
Plant Tissue Analysis for Strawberry and Fertilizer Recommendations

Plant tissue analysis is an excellent means of monitoring nutrient levels in strawberries. Soil tests are very useful to determine the quantity of certain nutrients in the soil, and tissue analysis measures the levels of nutrients taken up by the plant. It is important to test both the soil and plant tissue to avoid any potential problems in a planting. Nutrient levels can be corrected when analysis indicates that abnormal levels exist. Target ranges of soil test results for strawberry are shown in Table 9-1.

Soil Test

A soil test should be taken one year before planting. Other than nitrogen, fertilizer and lime should be applied and incorporated into the soil. This application should be sufficient for a four- to five-year period or the expected life of a matted-row system.

Take a soil sample from the top 8 inches and take 10 or more samples in the field, particularly if there are more than 5 acres, and mix the samples. Send this to a soil testing laboratory that can provide recommendations for strawberries. The recommendations are estimates for each element but do not vary for different soil types and cation exchange capacity (CEC). Clays and soils high in organic matter tend to have a higher CEC where sands have low CEC. Also, limestone differs in purity and the time acquired for it to react in the soil.

Phosphorus can be limiting in strawberries. Keeping the pH near 6.5 will aid in maintaining the optimal uptake of phosphorus. After planting, monitor plant nutrient needs with a combination of tissue analysis, soil tests, and observation of leaf conditions. In the Midwest, clay soils with a pH of 7.0 or higher with high amounts of organic matter may show low zinc in the leaf. Applications of zinc sulfate at 15 to 20 pounds per acre prior to planting have shown good results when soil zinc levels are low. Compare your soil test results with those in Table 9-1.

Table 9-1. Desirable Range of pH, Organic Matter, and Elements from Soil Test for Strawberries.

	Strawberries[b]
pH	5.8 to 6.5
Organic Matter	2 to 3%
Phosphorus[a]	60 to 80
Potassium[a]	280 to 320
Magnesium[a]	250
Boron[a]	1.5 to 2.0
Zinc[a]	10 to 12

[a] Given in actual pounds of available phosphorus, boron, and zinc and as exchangeable pounds of potassium and magnesium, per acre.

[b] Desirable range will vary with soil type (sand, silt, or clay), organic matter already present in the soil, and pH. Soil levels may need to be changed to correct deficiencies or excesses as they are accessed.

Leaf Analysis

Leaf analysis is used to evaluate nutritional abnormalities in strawberries. Excessive levels of certain elements can be detected along with deficiencies. Tissue analysis allows a grower to detect macro and micronutrient deficiencies before a plant's health is impaired or yields are reduced.

Fresh whole leaves should be collected for analysis. Samples should be healthy and free of disease or damage. Plant material should be kept cool using an ice chest or refrigeration. If samples are contaminated with dust or soil, wash gently and quickly in flowing water. Do not prolong the washing, as this will leach nutrients out of the leaves. Air dry wet tissue samples on a paper towel in a cool area at least one day before mailing.

A soil sample should also be collected from the area where the plant tissue sample was collected to help in interpreting the results.

Ship to a lab as soon after sampling as possible. Record all foliar nutrient sprays in case the results are influenced by foliar fertilizer or pesticide applications.

Contact your county Extension office for information on where to send your leaf and soil samples for analysis. Be sure to read and follow all instructions regarding the completion of the record sheet submitted with each sample.

Sampling

Date, Location, and Number of Leaves to Sample

Try to collect all samples in the morning before temperatures heat up by mid-day. This will assure that turgor pressure is at its highest, and leaf tissue will be freshest for handling and shipping.

A minimum of 60 leaves should be collected by cultivar for analysis. Do not mix plant tissue samples from different cultivars. Leaves should be sampled from growth that is not too old or young. Samples should be gathered from fully expanded leaves.

Be sure to collect leaves randomly throughout the planting. A single sample should be from the same cultivar but should be taken from a number of plants. There may be a situation (*i.e.*, poor growing plants) in which you desire to collect individual samples for analysis. If you suspect that there may be a localized nutrient deficiency, try to keep this plant material separate from the rest.

Detach leaves from plants. Place leaves in a dry paper bag and label immediately. Be sure to include the date, cultivar, and field location.

Interpretation of Results

When you receive results from leaf or petiole tissue, consult the tables presented here for interpretation. The final decision requires a soil test taken from the same area as the tissue. Therefore, compare your results with Table 9-3.

These values are a composite of the best nutrition information currently available in strawberries. This assumes that the plant root system is healthy and that the soil pH is within optimal ranges for strawberries (5.8 to 6.5). If either of these assumptions is not true, do not attempt to use this information.

Remember these are guidelines, and additional information from a horticulturist may be required. For example, high organic matter plus a high pH may reduce zinc uptake even when the soil shows adequate zinc. Foliar zinc sprays may be the best choice. Soil-test results listed in ppm can be converted to lbs/acre by multiplying each number by two.

Table 9-2. Plant Tissue Sampling Periods and Crop Specifications.

Crop	Sampling Date	Leaf Number	Part Sampled
STRAWBERRY New and second season plasticulture plantings. Renewed matted-row plantings.	June 15 – July 1 July 15 – Aug. 15	60 60	Youngest fully expanded mature leaves. First fully expanded leaves.

Table 9-3. Specific Element Recommendations for Strawberries from Leaves.

Element	Deficient	Below Normal	Normal	Above Normal	Excessive
N (%)	1.50	1.80	2.00	2.80	>2.80
P (%)	0.20	0.25	0.30	0.40	>0.40
K (%)	1.00	1.50	1.60	2.50	>2.50
Ca (%)	0.60	0.69	0.70	1.70	>1.70
Mg (%)	0.25	0.29	0.30	0.50	>0.50
Mn (ppm)	40	49	50	150	>250
Fe (ppm)	30	59	60	150	>150
Cu (ppm)	5	6	7	20	>20
B (ppm)	19	24	25	35	>35
Zn (ppm)	15	20	35	50	>50

Source: Ohio State University Extension Bulletin 436 and University of Kentucky (personal communication) for leaves taken after renovation, July 15 to August 15.

Recommendations for Matted-Row Strawberries

Nitrogen (N)

Low N (if N is below 1.8). Increase rate of nitrogen application by 10% for each 0.1 that the sample is below the desired level. Apply nitrogen at renovation and again in mid-August.

N within desired range, but N/K ratio >1.5. To improve the balance between N and K in the plants, decrease the N application by 10%. Apply nitrogen at renovation and again in mid-August.

High N (if N is above 2.80). Reduce the rate of N application by 10% for each 0.1% that the sample exceeds the desired level. Apply nitrogen at renovation and again in August.

Phosphorus (P)

Low P (if P is below 0.25). Apply 200 lbs/acre 45% superphosphate at any time to the soil surface.

High P (if P is above 0.40). Omit phosphate from fertilizer program.

Potassium (K)

Low K (if K is below 1.5). Apply 45, 50, 70, 90, or 100 lbs/acre actual potassium for soil management groups I (clay), II, III, IV, and V (sand), respectively. If Mg is also low, sulfate of potash-magnesia (sul-po-mag) can be used as a source of K at five times the above rates.

High K (if K is above 2.50). Discontinue use of K fertilizer for one year.

K within range, but N/K ratio > than 1.5 and K/Mg ratio <3.00. To improve the balance between N and K, increase K to a total of 80 lbs actual K.

K within range, but N/K ratio 4.00. To improve the balance between K and Mg, omit K from your fertilization program.

Calcium (Ca)

Low Ca (if Ca is below 0.70). Apply lime if pH is less than 6.0. See soil-test recommendations for adjustment of soil pH. If pH is greater than 6.0, then apply 1,000 lbs/acre calcium sulfate.

High Ca (if Ca is above 1.70). May indicate improper soil pH. See soil-test recommendations for adjustment.

Magnesium (Mg)

Low Mg (if Mg is below 0.30)

1. Apply magnesium sulfate (Epsom salts) to the soil surface in late fall or spring at 200 lbs/acre.

2. Use sulfate of potash-magnesia (sul-po-mag) if potassium is also low. Use at same rate as magnesium sulfate.

3. Apply dolomitic limestone according to soil-test recommendation if pH is below 5.5.

4. Make three foliar sprays of magnesium sulfate ($MgSO_4$) or magnesium oxide at two-week intervals beginning after renovation to temporarily correct deficiency (15 lbs $MgSO_4$/100 gal/acre or 3 lbs MgO/100 gal/acre).

Mg is within range, but K/Mg ratio >5.00. To improve the balance between K and Mg, increase Mg application to a total of 80 lbs/acre actual Mg.

High Mg (if Mg is above 0.50). Omit addition of Mg.

Manganese (Mn)

Low Mn (if Mn is below 50.0). Apply a foliar spray of manganese sulfate (2 lbs/100 gal/acre) or manganese chelate (6 lbs/100 gal/acre) prior to September 15. Check for high soil pH.

High Mn (if Mn is above 200.0). May indicate a low soil pH or contamination by fungicide or irrigation water. Consult soil-test recommendations to determine need for lime. Contamination from sprays may give artificially high readings.

Iron (Fe)

Low Fe (if Fe is below 60). Apply 4 lbs/100 gal/acre ferrous sulfate or 8 lbs/100 gal/acre iron chelate as a foliar spray prior to September 15. If condition persists for several consecutive years and the soil pH is within the desired range, apply 25 lb/acre iron chelate or 15 lb/acre ferrous sulfate to soil in early spring.

High Fe. May be toxic if levels exceed 500 ppm. Contamination from sprays may give artificially high readings.

Copper (Cu)

Low Cu (if Cu is below 7). Apply copper chelate (4 lbs/100 gal/acre) in a foliar spray prior to May 15. If the condition persists for several consecutive years and the soil pH is within the desired range, apply 20 lb/acre copper sulfate to soil in late fall.

High Cu (if Cu is above 20.0). May indicate a low soil pH or contamination from sprays. Consult soil-test recommendations to determine the need for lime.

Boron (B)

Low B (if B is below 30). Apply Solubor to the soil at the rate of 4.0 lbs/acre in early spring or late fall, or apply a foliar spray of Solubor (20% actual boron) at the rate of 1.5 lb product/100 gal/acre in early spring and after renovation.

High B (if B is above 70). Discontinue use of boron. Toxicity can occur if levels exceed 100 ppm.

Zinc (Zn)

Low Zn (if Zn is below 20). Apply zinc chelate (2 lbs/100 gal/acre) once after renovation and again in early May of the following year. If the condition persists for several consecutive years and the soil pH is within the desired range, apply 10 lb/acre zinc sulfate to soil in the fall.

Zn in desired range, but P/Zn ratio >140. To improve the balance between phosphorus and zinc, apply 2 lbs of zinc chelate/100 gal/acre four times during the growing season. Follow label instructions.

High Zn (if Zn is above 50). May indicate fungicide contamination. Toxicity can occur if levels exceed 300 ppm.

Chapter 10
Plasticulture in the Midwest

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Strawberry plasticulture is an annual hill training system in which freshly dug bare-root plants or plugs (transplants started from runner tips) are planted in late summer to early fall, depending on the climate. Plants are set out in double rows at densities of 15,000 to 17,500 plants per acre. Special equipment is needed to make the 8-inch-deep raised beds that are customarily fumigated with methyl bromide, Telone C-35, or metam sodium and covered with black plastic mulch (Figure 10-1).

Strawberry plasticulture in northern states is still quite limited, but matted-row growers in the Midwest and Mid-Atlantic states are taking a closer look at this production system because it has several advantages, including easier picking and earlier harvesting. Plasticulture berries can be harvested in seven to eight months after planting compared to 12 months for matted-row production.

Strawberries grown using the plasticulture system, however, must be intensively managed. Furthermore, daily production and pest management decisions can have a much greater effect on yields and profits than decisions made for matted-row systems. With a plasticulture system, there is considerably less margin for error in regard to soil treatments, timing, pest management, frost and freeze strategies, and marketing.

The strawberry plasticulture production system performs best in the milder areas of the Southeast, Northeast, and Midwest where temperatures rarely fall below 0°F (USDA Climate Zones 7 and higher). This isn't surprising: The plasticulture system evolved in the southern states and California.

But growers in USDA Climate Zone 6 (and warmer sites in Climate Zone 5), where temperatures can drop to -10°F, are achieving success with annual plantings of the Chandler variety using the plasticulture system. This zone includes the colder areas of North Carolina (the foothills and mountains) and similar climates in eastern Maryland, Delaware, and southern New Jersey. Similarly, southern Illinois, which was once called *Egypt* in Abraham Lincoln's time, is going to be better suited to strawberry plasticulture than northern Illinois and colder areas of the Midwest.

Figure 10-1. Sandy loam and clay loam soils are ideal for building and shaping the 8-inch raised beds that are a critical component to success in the strawberry plasticulture system. The raised beds are 8-inches high and 28- to 30-inches wide at the base. These beds are fumigated at least three weeks prior to transplanting, depending on the fumigant. As the fumigant is injected (shank injected), the beds are immediately tarped with an embossed 1.25 mil black plastic mulch film that can be stretched by the mulch-laying/fumigation unit to give an extra tight fit over the bed. The black plastic film needs to be in direct contact with the soil (for maximum soil warming to occur in the late fall and winter months). If there are air pockets between the film and the soil, the black plastic will actually serve to cool the soil, and plant top-growth and root development will be significantly reduced.

Based on research completed at North Carolina State University, strawberry growers need to achieve yields of at least 1 pound of berries per plant, or 15,000 pounds per acre, to make a profit using plasticulture (Safley and Poling, 2004). To achieve these yields in Zone 6, growers need to know the recommended cultivars and practices to use for successful production.

To meet that need, this publication provides an overview of the factors that growers in USDA Zone 6 should consider before deciding to use the plasticulture system for growing strawberries. It also describes recommended practices for the different stages of plasticulture production, from preplanting through harvest. Refer to *Producing and Marketing Strawberries for Direct Markets* by Safley and Poling (Publication No. AG-645, Raleigh: North Carolina Cooperative Extension, North Carolina State University) for in-depth information about the cost and returns of growing, harvesting, and marketing strawberries using plasticulture.

Preliminary Considerations Prior to Going into Plasticulture

Before deciding to use the plasticulture system for strawberries, a grower should carefully consider these factors:

- Site
- Soil
- Equipment
- Plant materials and sources
- Production challenges
- Production time.

Site

Attention to the specific site selection factors listed here will improve the likelihood of success in Zone 6.

Windbreaks. The most reliably productive strawberry plasticulture sites are almost always those with a wooded area or a windbreak on the north or northwest side of the field.

Row Orientation. A north-to-south orientation is recommended for more uniform plant stands and ripening. However, if the field is almost flat, facilitating soil drainage is the most important factor.

Crop Rotation. It is best to rotate strawberry field sites as often as possible, but the general practice in most areas is to crop strawberries continuously on the same land because of existing irrigation lines and market location. Avoid rotations with crops treated with herbicides or plant growth regulators (or a combination of these) that could carryover and cause crop losses in strawberries. Read all pesticide labels carefully for rotational restrictions.

Wildlife. Most strawberry plasticulture sites require protection from deer within a month or two of planting.

Soil

Soil Content. Strawberries grow and produce satisfactorily in a wide range of soil types, but sandy loam and sandy clay-loam soils are ideal for building and shaping the 8-inch-deep raised beds that are critical to the success of the strawberry plasticulture system. Soils with a high clay content or those that are rocky or very stony are more difficult for bedding, fumigation, and plastic-mulch operations.

As a general rule, growers should consider using plug plants on soils with a high clay content or soils that are rocky or very stony rather than bare-root freshly dug plants, which require hand transplanting. Sandy soils will require more careful irrigation and nutrient management.

Soil pH. Optimal strawberry production requires a favorable root environment and the availability of essential nutrients. Soil pH is a key factor in maintaining a favorable root environment. Soils with a pH between 6.0 to 6.4 promote the best growth. A soil test can indicate how much lime is needed.

Low pH is one of the most frequent problems identified on soil samples in Zone 6. Because the problem cannot be corrected after planting and low calcium (Ca) usually accompanies a low soil pH, testing and liming the soil as needed is especially important.

Soil Moisture. For all soil types and strawberry-growing regions in the Midwest, a drip irrigation system is required to meet the moisture requirements of the crop. See the section on *Equipment* for more details.

Soil Erosion and Surface Water Management. Although raised beds encourage water drainage within the soil, plasticulture growers frequently encounter problems with getting rid of excess surface water. Because 50 percent of a plasticulture strawberry field is covered with an impermeable plastic film, the field should have enough slope that surface water drains uniformly and gently from the field after periods of heavy precipitation, without causing erosion or leaving puddles.

On fields with more than a 2 percent slope (a 2-foot drop in 100 feet), continuous overhead sprinkling for freshly dug plant establishment may cause severe soil erosion. This is why it is often a good idea to broadcast annual ryegrass at a rate of approximately 50 pounds per acre over the entire field the same day you finish fumigating (before planting holes are punched). Ryegrass will reduce soil washing in the aisles after heavy rains or irrigation for establishing freshly dug plants on sloping terrain. Even in colder northern growing areas, the ryegrass should be killed or stunted by an application of post-emergence grass herbicide when it is about 6- to 8-inches tall (Figure 10-2).

Figure 10-2. Annual ryegrass should be killed or stunted by an application of post-emergence herbicide when it is about 6- to 8-inches tall and before row covers are applied for winter protection.

Equipment

Specialty equipment is needed for successful strawberry plasticulture production. This equipment includes:

- Equipment for bed-shaping, plastic-laying, and fumigation.
- An overhead sprinkler irrigation system.
- A drip irrigation system to meet the moisture requirements of the crop.

Shaping the Beds

New growers should consider hiring a contractor who has the necessary equipment and knows how to use it. Custom applicators can form beds, inject fumigant, apply plastic, and lay trickle tubes in one operation. Where custom services are unavailable for shaping beds, fumigating the soil, and laying plastic, you must either purchase equipment or make arrangements to lease it.

Overhead Sprinkler Irrigation

Strawberry plasticulture requires overhead sprinkler irrigation for establishing freshly dug bare-root plants, protecting blossoms from cold injury, and for evaporative cooling during occasional spring heat waves that cause open blossoms to abort. It is prudent to plan for at least 12 frost-and-freeze episodes per season.

The water requirement for an overhead sprinkler irrigation system is usually estimated on the basis of three consecutive frost or freeze nights. For example, 5.4 acre-inches of water (27,152 gallons equal 1 acre-inch) would be needed for sprinkling at the rate of 0.18 inch per hour (for control down to 24°F), for 10 continuous hours each night over three nights. Or, 1.8 inch per night (10 hours times 0.18 inch) for three nights equals 5.4 acre-inches.

An irrigation pond would need to hold about 150,000 gallons of water for each acre of plasticulture production under these conditions (5.4 inches times 27,152 gallons per acre-inch equals 146,620 gallons).

Several factors should be considered before installing an irrigation system:

- **Water supply.** Water may come from wells, ponds, lakes, and municipal lines. An irrigation pond would need to hold about 150,000 gallons of water for each acre of plasticulture production to provide protection on three consecutive frost or freeze nights.
- **Pumping capacity.** A pumping capacity of as much as 90 gallons per minute (gpm) or 0.2 inch per hour is recommended for severe frost and freeze conditions.

- **Pump.** An electric pump is recommended for reliability if you have a reliable electric power service.

- **Sprinkler type.** Low-impact sprinklers are preferred.

- **Sprinkler spacing.** A 40-foot by 40-foot triangular spacing will greatly improve the sprinkling distribution pattern under higher winds as compared to a conventional 60-foot by 60-foot spacing.

Drip Irrigation

The deep 8- and 10-inch beds require drip irrigation because capillary movement of water is poor. Drip irrigation provides the most efficient use of water and fertilizer. Many deep wells are fairly clean and require only a screen filter to remove particles. However, the presence of precipitates or other contaminants in the water should be determined by a water-quality test before considering the well for a drip system. Any surface water source, such as a stream, pond, pit, or river, will contain bacteria, algae, or other aquatic life, and sand or special filters are therefore a necessity.

For strawberries, a drip tape is used to wet a continuous strip along the row. A 12-inch emitter spacing is recommended for sandy loam and clay soils. For coarse sands, 8-inch emitter spacing is recommended. Drip emitter discharge rates are generally expressed in gallons per minute (gpm) per 100 feet of length for the selected emitter spacing. A common tape selection for plasticulture strawberries on sandy loam or clay soils uses 0.40 gpm emitters (24 gallons per hour, gph, per 100 feet). To determine field water requirements in gpm per acre, simply multiply 24 gph times 87.12 (the number of 100-foot row units per acre on 5-foot bed spacing) and divide by 60, which yields 35 gpm.

Because strawberries grown on plastic mulch are considered annuals and are grown for only one season, thin, disposable drip tape (4 to 8 mils thick) is commonly used. Once a drip irrigation system is installed, the crop can be fertilized using the drip system (fertigation). The drip system also can be used to establish plug transplants in the late summer, but some overhead sprinkler irrigation should still be applied for the first two to three days after transplanting (see the section on ordering and handling tips and plugs).

Plant Materials and Sources

Growers in Zone 6 should use a cultivar recommended for colder climates and choose planting material (freshly dug plants or plugs) that best suits their growing conditions and operation. Planting material should be obtained from reliable sources that provide disease-free material.

Cultivars

These cultivars are recommended:

Chandler

This cultivar is the "old reliable" for northern plasticulture. It is possible to grow and successfully market two or three different varieties for strawberry plasticulture in the Southeast to extend the harvest season over a six-week period. However, growers in Zone 6, including southern Illinois and milder sections of the Midwest, should concentrate on planting plug plants of Chandler.

Chandler plugs are being grown by the North Carolina State University research team at an elevation of nearly 3,000 feet in western North Carolina at one of the coldest locations in the state (Laurel Springs). This demonstrates how well adapted this cultivar is to a Zone 6 region (-10°F to 0°F). In the colder areas of Virginia, several matted-row cultivars have been evaluated by Professor Emeritus Charles O'Dell at Virginia Polytechnic Institute and State University. Chandler continues to be the most reliable producer in the plasticulture system for colder areas.

Sweet Charlie

Sweet Charlie is an early ripening strawberry adapted to the mid-Atlantic and southern United States and has a large orange-red fruit color and is moderately firm. Easy to harvest. Good flavor. Flowers early. Tolerant to anthracnose. Yields are about 1/3 lower than Chandler. Patented by the University of Florida.

Darselect

Plasticulture trials have been conducted in Ohio with both dormant frozen plants and plug plants of Darselect. This cultivar was introduced by

Darbonne, a private French breeding-program company. It is reported to be a highly productive, widely adapted variety for plasticulture, and it has been rated very highly for flavor and firmness. Based on recent reports, its fruiting season will be comparable to Chandler (early midseason to midseason).

Ovation

Trials of the cultivar Ovation will be included in the 2005-2006 Mountain Trials for North Carolina. According to USDA trials, Ovation may be well adapted to plasticulture, but further evaluation is needed. It is a late-midseason, disease-resistant variety. According to the USDA, the plant is vigorous, resistant to five strains of red stele, and shows good tolerance to foliage diseases.

Plugs vs. Freshly Dug Plants

Freshly dugs are not usually available until the final week of September, and this is too late for transplanting in northern regions. However, if good quality freshly dugs can be obtained in the third week of September, growers in warmer sections of Zone 6 may wish to evaluate freshly dugs from the standpoint of their relative cost savings and the possibility of enjoying a harvest season that is not quite so concentrated in picking.

Plant Source

The success of a strawberry plasticulture planting, in large part, depends on the health and vigor of the runner tips used for plug propagation. Purchase your runner tips from a reputable supplier. Runner tips must be true-to-variety and free of insects, diseases, nematodes, and viruses.

If you are purchasing plugs from a commercial source, be sure to verify that their runner tips came from a reputable supplier. The Web site **www.ncstrawberry.org** (maintained by the North Carolina Strawberry Association, Inc.) keeps a current listing of U.S. and Canadian plant sources of Chandler, and important details about their respective propagation programs.

Production Challenges Unique to Plasticulture

As noted in the introduction to this publication, decisions made throughout production can make a big impact on the success of plasticulture strawberries. In particular, the system requires close attention to plant size, density, and weather conditions.

Plant Size

Controlling plant size is a very important objective in the plasticulture system regardless of the location. One of the most important influences on plant size and, ultimately, fruit quality is planting date. Select a planting week for your area that will result in the development of four branch crowns, in addition to the main crown, by harvest (Figure 10-3). Four branch crowns are needed to produce a desirable number of berries per plant (around 35 to 40).

But do not plant so early that you end up producing six or more branch crowns per plant. Plants with six or more branch crowns can produce so many blossoms that fruit size will be depressed to the point where both harvesting and marketing the small berries will be a problem.

Plants that are transplanted late will have inadequate cropping potential due to lower branch crown production. Thus, plant density, planting date, and weather conditions must be considered.

Figure 10-3. Strawberry plant with four branch crowns (branch crowns removed) in addition to the main crown. The development of four branch crowns is needed by late winter and before bloom in order to produce a desirable number of berries per plant.

Plant Density

Based on trials with Chandler in western North Carolina (USDA Plant Hardiness Zone 6), plants should be spaced at least 14 inches within each row for a double-row plant bed on 5-foot center. A 14-inch within-row spacing will require 15,000 plants per acre; it is normal to have a 12-inch spacing between the double-rows of plants for standard width plastic mulch beds (28 to 30 inches wide on the top).

Optimum plug planting dates for Chandler in western North Carolina are the first week in September for high elevations and the second week in September for lower elevations. Based on these planting dates, growers in Zone 6 may wish to evaluate planting right around Labor Day, as this has turned out to be the best planting time in North Carolina's coldest mountain areas.

Growers in warmer areas of Zone 6, such as southern Illinois, may find that a suitable time for planting is during the second week of September. If you find that you are producing more than two to three runners per plant in an average fall, this is probably a good indication that you are planting too early.

Warm Fall Conditions

Other factors besides the planting date have an important influence on the final number of branch crowns produced. Fall weather conditions following planting in early to mid-September can play a very important role in determining ultimate plant size. Fall temperatures may be so warm as to produce excessive plant size by harvest (more than six branch crowns).

In North Carolina, growers, who are especially interested in optimizing fruit size and shape, will purposely set out a portion of their crop several days to one week later than recommended for their area in case of an unseasonably warm fall. By planting slightly later in an unseasonably warm fall, you will encounter fewer problems with plants producing runners.

Chandler plugs set at the normal planting date may produce two to three runners per plant in a warm fall, and removing these runners can involve a significant labor expense. In northern plasticulture regions, such as southern Illinois, it may be better to delay the winter row-cover application until late November or early December if you are experiencing an unusually warm fall season.

Cool Fall Conditions

If fall temperatures are cooler than usual, you may encounter difficulties in achieving adequate plant size. Plants that end up developing only two or three branch crowns may have a cropping potential of less than 1 pound per plant. If the fall is unseasonably cool, row covers should be applied earlier to enhance plant growth and branch crown formation. In our coldest regions in western North Carolina, the earliest that row covers would be applied is in the last week of October (around Halloween).

Getting Started in Plasticulture

Plasticulture Production Schedule

Growing strawberries with the plasticulture system is a year-round activity. Just as berries are harvested in the spring, supplies must be ordered for the coming year so the beds can be prepared in late summer. These activities can be organized into the following stages of production:

- Preplanting
- Planting
- Postplanting
- Dormancy
- Preharvest
- Harvest
- Postharvest.

Table 10-1 provides an overview of production by month for Zone 6. A successful harvest depends on the decisions made during production, and timing is essential for success. As noted under *Production Challenges Unique to Plasticulture,* a bountiful harvest depends on plant size and density, which are directly related to the tasks completed during the preplanting and planting stages.

Table 10-1. Plasticulture Strawberry Calendar for USDA Climate Zone 6.

Stage	Month	Activities
DORMANCY	January	Begin a leaf sanitation schedule in late January to early February. Remove dead foliage. If possible, delay this procedure until after the period of greatest likelihood of windborne freeze(s) in January as the older foliage surrounding the crown can provide a beneficial mulching effect. Snap off old leaf petioles at their base. Remove any unwanted runners and weeds.
	February	Leaf sanitation must be completed before the onset of new growth from the crown.
PREHARVEST	February	When new growth emerges from the crowns in mid February to early March, roll back the row covers. Leave row covers in the field in case they are needed for a frost or freeze. After new growth begins, pull up side crowns that are caught beneath the mulch. Remove weeds in the planted holes. Hook up drip irrigation within a week or two after new growth has started. Make the first nitrogen fertilizer injection. Check out the overhead irrigation system to be sure it is ready for use when temperatures fall and row covers become impractical as plants grow.
	March	Main blossoming period begins 4 to 5 weeks after new leaf growth starts and continues for a month. Inspect plants for botrytis and anthracnose. Begin a control program if needed. Stay alert for conditions that favor frost formation at the ground level. Apply overhead sprinkling for frost protection when row covers become impractical. Maintain a weather journal for future reference. Scout for weeds until harvest.
	April	Make sure a farm liability insurance policy is in effect for pick-your-own and fruit stand operations.

Table 10-1 (continued). Plasticulture Strawberry Calendar for USDA Climate Zone 6.

Stage	Month	Activities
HARVEST	April	Harvest begins 9 weeks after the first new growth emerges and continues until about 12 weeks after the new growth emerges.
	May	Order tips and plugs for the next growing season by the first of May. Peak harvest usually occurs around Mother's Day.
POSTHARVEST	June	Destroy plants when harvest ends. Incorporate lime when existing beds are broken down.
PREPLANTING	July	Begin soil preparations. Irrigate overhead to soften soil as needed. Subsoil completely.
	August	Have fumigant cylinders delivered by early August. Check fumigation rig safety. Cut tips for rooting plugs in early August if you are rooting your own. Stick pre-ordered tips or cut tips by mid-August. Broadcast N-P-K fertilizer and disk it into the soil by mid-August. Form and fumigate beds. Lay plastic. Install drip tape.
	September	Inject mefenoxam through the drip system a week before planting if the site has a history of Phytophthora root rot.
PLANTING/ POSTPLANTING	September	Transplant and irrigate plugs during the second or third week of September. Put up electric fences for deer protection.
	October	Check plants carefully for mites three to four weeks after transplanting. Apply miticide if needed before laying down row covers for late fall and early winter. Check for signs of botrytis crown rot when fall temperatures are warm. Begin a fertilization program now if fertilizers were not applied in the preplant stage.

Table 10-1 (continued). Plasticulture Strawberry Calendar for USDA Climate Zone 6.

Stage	Month	Activities
DORMANCY	November	Lay a row covering down five to six weeks after transplanting if planting was delayed by one or two weeks, if plants are small, or if temperatures are unseasonably cool. Otherwise, lay down row covering in late November or early to mid-December so plants will accumulate greater winter hardiness. If a row covering is used early in November, stunt the annual ryegrass in the aisles with a post-emergent herbicide before the covers are applied. Check leaves for presence of spider mites and aphids. Take control steps as needed.
	December	Remove runners as needed beginning four weeks after transplanting to create 7- to 8-inch diameter plants by mid-December with one or two branch crowns and eight to 10 leaves.

Preplanting Activities

Ensure Fertility: Test the Soil

Complete a soil test several months before planting to determine how much dolomitic lime is needed to raise the soil pH and how much potash (K_20) fertilizer to apply before bedding. If a soil test was not taken prior to shaping the beds, use these standard recommendations: Apply 60 pounds nitrogen (N) per acre, 60 pounds phosphate (P_2O_5) per acre, and 120 pounds potash (K_20) per acre. Broadcast these fertilizers and lightly incorporate before bedding and fumigation.

Ammonium nitrate is recommended for the preplanting N application. A broadcast application of 175 pounds per acre of ammonium nitrate will deliver 60 pounds of nitrogen per acre. In general, a P_2O_5 application of 60 pounds per acre should be incorporated even on soil with a high P index. However, on soils that have ultra high levels of phosphorus (typically areas where large amounts of poultry manure have been applied), this application can be deleted. A prebedding broadcast application of 120 pounds triple superphosphate (50 percent) can supply 60 pounds of P_2O_5 per acre.

Soil testing also determines the need for potash (K_20). Potassium sulfate is a very good source of K_20 for strawberries (50 to 53 percent), and it provides some sulfur as well (18 percent). If the soil test recommends 60 pounds K_20 per acre, then a broadcast application of 120 pounds of potassium sulfate fertilizer (50 percent K_20) can be applied to meet the crop's potash requirement. Other nutrients can be injected as called for (preferably as the result of tissue testing) through the drip system.

Shape the Beds

Avoid using a vegetable bed-maker. Instead, stick with the bed-making equipment that is specifically designed for deep strawberry plasticulture beds. A deep bed will produce higher yields and fruit with less soil splash. The eight-inch deep beds mulched in plastic are typically 30 to 32 inches wide at the base and 28 to 30 inches wide on top. Beds are slightly crowned so water will run off and not rest on the plastic. For example, a bed with a 28- to 30-inch top should slope from the center to the edge with a drop of 1.25 inches. Bed centers are usually 5 feet, and **60-inch-wide plastic film is recommended** (54-inch rolls are not satisfactory).

Most machines have some specific advantages, and it is worthwhile to investigate these differences. Almost all of the machines sold will form the bed, fumigate, lay plastic mulch, and install drip tape in one operation. In general, the single-row bed-making and plastic-laying machines are appropriate for most strawberry operations. Be sure that enough soil is pulled up so that the bed has good, sharp corners and no depression in the center (it is not usually possible to get these sharp corners on clay soils).

You may find it beneficial to pre-bed the rows to make sure that enough soil will be pulled up for the bed-shaper — the same disk hillers used for making tobacco beds work nicely for strawberry pre-bedding. The extra pains involved in getting your land just right for forming beds, laying plastic, and fumigating will pay off in better plant growth in the fall and winter season and higher yields in the spring.

Install Plastic Mulch

Excellent strawberry beds have the plastic mulch in direct contact with the soil beneath. If there are air pockets beneath the plastic, plant growth will be slow in the fall and winter. Heat from the black plastic will not be conducted into the soil if there are air pockets — in fact, the black plastic will have a cooling effect if it is not in good contact with the soil beneath.

Use embossed 1-mil to 1.25-mil black plastic mulch for strawberry plasticulture production. On 5-foot row centers there are 8,712 linear feet of row per acre, so you will need about 3.5 rolls (2,400 feet) of plastic mulch per acre. For 6-foot centers, three rolls of plastic mulch will be required per acre. It is important that the plastic fit tightly on the bed and that the edge of the plastic, or the tuck, be held firmly in the soil. These measures reduce the chance of wind getting under the plastic and causing it to blow off or float up and down, which injures plants.

Install Drip Tubing

Install drip tubing with the orifices facing upwards. The tubing is typically buried 1 or 2 inches deep in the bed center. During installation, several workers should be watching to ensure that the tubing maintains its orifice-upwards orientation, to assist if the tubing becomes tangled in the injector, and to signal when the drip tape reel is empty. Tubing ends should be closed off by kinking or knotting until the tubes are hooked up to the system. Growers have the option of using only overhead sprinklers in the fall, but the drip system should be functional by late winter.

Fumigate

New land that has been subject to good crop rotations and best management practices (such as cover cropping and good drainage strategies) can, under optimum conditions, generate yields that are 85 to 95 percent of the yields in fumigated soil. Weed control, however, can be a serious problem. Strawberry plasticulture production on the same site year after year is not advisable without preplant fumigation because of potential weed and disease problems.

Schedule fumigation far enough in advance to allow for plant-back restrictions for the particular chemical used as well as unexpected setbacks that can occur with weather. If the site is fairly free of noxious diseases and weeds, such as nutsedge, it may be better to plant on time and not fumigate than to fumigate and plant extremely late.

Currently, the preplanting fumigant with the shortest plant-back interval of 14 days is methyl bromide:chloropicrin (67:33), but this fumigant may not be available for use in your area unless your state received a Critical Use Exemption (CUE) granted by the EPA to the Eastern Strawberry Consortium (2006, 2007). Other registered fumigants for strawberries have plant-back intervals of 21 days or more.

As a general rule, you should begin land preparation for bedding and fumigation at least six weeks ahead of planting with the use of methyl bromide:chloropicrin (67:33) and seven weeks ahead of planting for Telone C-35.

It Is Important to Stay on Schedule

Here is a sample schedule for a grower in Zone 6 who wants to set out Chandler plugs in the second week of September and wants to use methyl bromide. For fumigants requiring a 21-day plant-back, plan on starting at least one week earlier (also refer to Table 10-1).

- **July — Week 4.**

  Whenever there is adequate soil moisture, begin preparing the soil so you can shape the beds and fumigate in early August. In an unusually dry July, you may be forced to overhead irrigate to get the land ready for chisel plowing and sub-soiling, if needed.

  Sub-soiling is needed every few years on heavy soils. This needs to be done in two directions, north-south and east-west, and it needs to be done deeply to loosen the soil and break up the plow layer (at 10 to 12 inches deep). Breaking up this layer will require setting the draft control so the V-ripper doesn't come up easily when it hits the hard spots. This operation requires extra horsepower!

  Be sure to incorporate your lime at this stage if you haven't done so already. Ideally the lime should be spread in June, just after the plastic is pulled and the beds are knocked down.

- **August — Week 1.**

  Have fumigant cylinders delivered to the farm and complete fumigation rig safety checks. Check with your fumigant supplier to be sure the cylinders are delivered on time and to ensure that the proper safety checks are used.

- **August — Week 2.**

  Broadcast N-P-K fertilizers and disk them into the soil to prevent nitrogen loss. Disk to a depth of 6 inches, breaking up clods until the soil has a "fluffy" texture.Don't use equipment that will compact the soil (a rotary hoe or rototiller may cause compaction).

- **August — Week 3.**

  Shape the beds and fumigate with methyl bromide + chloropicrin. Lay plastic mulch and drip tape.

  As the fumigant is injected, the beds should be immediately tarped with an embossed 1-mil black plastic mulch film that can be stretched by the mulch-laying and fumigation unit to give an extra tight fit over the bed. Also, stick tips (if you are rooting your own plugs). This is also the time to seed annual ryegrass.

- **September — Week 2.**

  Transplant plugs. Always try to allow three weeks between fumigation and planting, even though methyl bromide:chloropicrin (67:33) is a two-week plant-back material. This extra week will provide a cushion for possible weather delays that may occur.

  Likewise, for a 21-day plant-back fumigant, you really need to allow a four-week waiting period between fumigation and planting. Thus, fumigation with Telone C-35 should be done in the third week of August for an area that will be planted in the third week of September.

Order Planting Material and Handle Tips and Plugs Properly

Order runner tips or plugs on time. You must order your tips or plugs well before planting season (early to mid-September in Zone 6 for Chandler). Usually, the cutoff for placing these orders is in May. Tips should be shipped to your farm for plug rooting one month ahead of transplanting. For example, tips will need to be cut in the first week of August for transplanting plugs in the first week of September.

Store and handle runner tips carefully. Extended storage of the runner tips is generally not needed. Commercial tip nurseries can harvest fresh tips weekly starting in late July and continuing through mid-October. The tips are shipped by refrigerated truck to the grower's farm for delivery approximately 35 days prior to field transplanting. Tips may be stored up to two weeks at 34°F without deterioration in quality, but you should try to stick them as soon as possible after arrival.

The boxes containing approximately 1,000 plantlets must be stacked loose so that the cool air can circulate freely around the boxes. The strawberry tips are living, respiring plants and must be kept cool until the grower is ready to root them under mist. The humidity in the cooler should be kept at around 75 to 80 percent relative humidity.

Root Tips With Moisture

Prior to rooting tips, additional plantlet preparation is needed to trim away excess runner-cords. An approximate 3/8- to 1/2-inch runner stub serves to anchor the plantlet until new roots develop. Fresh strawberry tips are best rooted under a fine mist that will wet the foliage yet put very little excess water on the soil. Keep moisture on the leaves until the plant is well rooted, about seven to 10 days.

As the roots form, the plants can be weaned from the mist and allowed to draw their moisture from the soil. Gradually reduce the mist over two to five days. Two weeks after sticking, you should be able to pull most plants from the cell with the root ball remaining intact. When that occurs, misting can be terminated.

This is a suggested misting schedule for greenhouse rooting:

- **Days 1 – 3:** Mist from 8:30 a.m. to 6:30 p.m. for 7 to 10 seconds of mist every 5 minutes.
- **Day 4 – 5:** Mist from 9:30 a.m. to 5:30 p.m. for 10 seconds every 7 minutes.
- **Day 6:** Mist from 10 a.m. to 5 p.m. for 10 seconds every 15 minutes.
- **Day 7:** Mist from 10 a.m. to 5 p.m. for 10 seconds every 15 minutes.
- **Days 8 –10:** Mist from 10 a.m. to noon and from 2 p.m. to 5 p.m. for 10 seconds every 15 minutes.
- **Days 11 – 13:** Mist from 10 a.m. to 3 p.m. for 10 seconds every hour. Move the plugs outdoors at the end of day 13.
- **Days 14 – 28:** Sprinkle for 5 minutes at 1 p.m. and possibly again in the late afternoon if temperatures are high.

Use the right rooting medium. Strawberry plugs should be grown in a specially prepared medium. Many different media are available, but a soil-less media composed of peat, sand, grit, vermiculite, perlite, polystyrene, or other materials is recommended. You will need about 4 cubic feet of media for approximately 1,000 tips, in 50-cell rigid plastic trays measuring 2 and 3/8 by 12 by 20 inches.

If the tips you receive from your supplier are quite variable in plantlet length, it is well worth the extra step to grade the tips by size into large, medium, and small lots. The large tips should be rooted in 38-cell trays, the medium tips rooted in 50-cell trays, and the smaller tips rooted in 60-cell trays. Sticking large tips (longer than 5 inches) in the same tray with small tips (2 to 3 inches long) will result in light competition and irregular root growth of the smaller, shaded tip plants. During misting, shaded tips are susceptible to botrytis infection.

Acclimate the plants. After the misting cycle is complete, move the trays to a fully exposed gravel pad for another two to three weeks of growth and acclimation before field transplanting. During this final field-conditioning phase, a single daily watering is suggested along with a weekly supplemental drench of a complete fertilizer material. A root-bound plug is desirable for mechanical transplanting; plugs for hand transplanting can be set before this stage is reached.

Planting

The ideal age of the plug for field transplanting is four weeks. Plugs held for six weeks in the trays are not as desirable and may have a slower initial growth rate in the field following transplanting.

Transplant Plugs to the Field

Plug plants pose less serious problems than freshly dugs for field transplanting. Pot-mulch planters or vegetable water-wheels can be used to mechanically transplant and water strawberry plugs. Careful size-grading of tip plants will produce more uniform plugs for efficient machine transplanting.

Depth

Do not bury the growing point of the plug plant by setting too deeply. Plug plants are not very deep; the rootballs are only 2 and 3/8 inches in depth for 50-cell trays. Your planting hole should not be quite as deep as the plug rootball: A 2-inch hole is recommended for a plug from a 50-cell tray. Press the plug into the hole so that the top of the rootball is about even with the soil surface.

Even if you are mechanically setting plugs with a water wheel, it is a good idea to have one or two workers following the transplanter to brush a light layer of soil around the top of the plug's rootball without covering the growing point. This soil layer is helpful in keeping the plugs from wicking out. Without this slight soil layer, the exposed artificial soil media will wick moisture out of the plug very rapidly on sunny, windy days.

Starter Solution

Tray-grown transplants that have been under a plug propagation nutritional program do not require a starter solution at transplanting. A typical feeding program for plug transplants while they are still in the trays is to apply 1 pound of 20-20-20 per 100 gallons of water (in weeks three and four) before transplanting. This supplies roughly the equivalent of 240 parts per million (ppm) N.

Irrigation

A few hours of overhead sprinkler irrigation immediately following transplanting of plugs is recommended. A number of commercial growers in North Carolina use light overhead sprinkling (1/10 inch per hour) for the first, second, and possibly third day following transplanting for approximately 5 hours, 3 hours, and 2 hours per day, respectively.

Postplanting

Monitor the Plants

Plants should have three or more fully green leaves remaining at the end of the initial three- to four-week establishment period, regardless of whether they are fresh-dug plants or plugs. If the original leaves on a bare-root, fresh-dug plant or plug are lost to drought stress, plant establishment will be significantly delayed or set back, and spring yields will be significantly reduced. The number of leaves and total plant leaf area in the late fall/early winter can be correlated with fruit production the following spring.

Runners that develop in the fall can be removed to prevent competition with crown formation and floral bud development:

- Avoid removing runners until about three to four weeks following transplanting.
- Complete a follow-up runner removal operation at six weeks following transplanting if necessary.

It is also very important to achieve an adequate plant canopy by early winter as a good leaf canopy acts as an important crown insulator in winter. A 7-inch plant diameter is about ideal in mid-December. For good berry production, each plant should form one or two side stems (the branch crowns) and about eight leaves by mid-December (Figure 10-4).

Rooting is active throughout the fall and early winter as long as soil temperature is above 45°F and roots remain healthy. The roots also serve as storage sites for starch reserves during winter. Growers who push fall top-growth with extra nitrogen feeding may be doing so at the expense of starch accumulation in the roots. The stored starch is needed for vigorous growth and flowering the following spring, which will enhance berry size.

Figure 10-4. Plants should have about eight leaves by mid-December.

Ensure Fall and Early Winter Fertility

If beds were prepared as described under *Preplanting*, no fertilizer should be needed after transplanting. It takes strawberry plants (especially freshly dugs) two to three weeks to establish a new root system, and you should not expect the plant's top-growth to look that healthy and vigorous during this initial period.

Once a new root system is established, the plants will be able to take advantage of the nitrogen, phosphate, and potash fertilizers that were applied prior to bedding. After three weeks, you should see the plants color up and begin to produce healthy new leaves. If preplant fertilizers were not applied, then it will be necessary to begin a fertigation program starting in the third week following transplanting.

Monitor for Diseases and Insects and Treat When Needed

A miticide application may be needed in the early fall to prevent two-spotted spider mites from reaching damaging levels in the late winter.

- Check plugs carefully for mites three to four weeks after transplanting.
- Make the miticide application before the late fall or early winter application of row covers if row covers are being used for winter protection.

Dormancy

Strawberry plants are dormant from late fall to early winter. The challenge during this stage of production is to protect plants from cold without creating conditions that encourage them to break dormancy too soon. To overwinter plants successfully, use row covers and windbreaks as needed. Monitor your plants for signs of early bloom and prevent diseases by removing dead leaves.

Use Row Covers

A fully dormant Chandler plant is quite cold hardy in midwinter, and it is usually grown without row covers in areas with average annual minimum temperatures of 5°F or higher. In zones colder than USDA Plant Hardiness Zone 7a, where average annual minimum temperatures can drop to less than 5°F, row covers must be used to overwinter plants successfully. Determining when to apply and remove them for your particular situation can be tricky, and it is important to consider both temperature and plant size (Figure 10-5).

Figure 10-5. Spunbonded row covers that weigh 1.5 ounce per square yard are ideal for the Midwest and are necessary for overwinter protection (applied in late fall); the covers are left in place until new leaves begin to develop in late winter. After they are removed, they can be re-applied for cold protection. The 1.5-ounce material can confer about 6 to 8 degrees of cold protection. Under severe wind-borne freeze conditions, the covers can be used in conjunction with overhead irrigation for maximum cold protection.

Delay covering for maximum plant hardiness. Delay the application of row covers until late November or early to mid-December. If you wait until late fall, plants should accumulate greater winter hardiness from exposure to lower temperatures than plants that are covered earlier in the fall for growth enhancement.

Apply covers early for growth enhancement. If the planting stage was delayed by one or two weeks, row covers can be applied as early as five to six weeks after transplanting to enhance fall growth and development. If row covers are not applied at this juncture, late plants will not have enough time to develop an adequate number of branch crowns for a full crop in the spring. In some cases, it also may be beneficial to apply covers in the early fall if temperatures have been unseasonably cool, and plant size is relatively small.

If covers are applied in early fall, the following steps are critical:

- Stunt the growth of the annual ryegrass in the aisles with a post-emergent herbicide — this must be done before the covers are applied.

- Inspect the undersides of leaves carefully for spider mites and aphids and take control steps if needed.

Remove covers early to slow crop development. Once covers are applied in the fall, they should remain in place until the end of dormancy when new leaf growth emerges from the crowns. New leaves begin to push out of the crowns by the middle of February in Zones 6 and 7. In the mountains and foothills of North Carolina, this is typically when the overwinter row covers are pulled off. Leave the covers rolled up in the field in case they are needed for a windborne freeze from late February through early March.

By removing the covers when the new leaf growth begins, you can slow down the crop in terms of how quickly it progresses from a tight-flower-bud stage to an open-blossom stage. If row covers stay on the crop for an additional two to three weeks, the crop comes out of dormancy and advances to the open-blossom stage while the weather is still very prone to Arctic clippers, wind currents that often lower temperatures to the midteens and gust to 20 miles per hour (mph) or greater.

Of course, row covers can be re-applied for windborne freeze protection. But there is little likelihood of saving open blossoms if more than 8 degrees of protection is required (spunbonded row covers that weigh 1.5 ounce per square yard [oz/sq yd] can confer about 6 to 8 degrees of protection, while 1.0 oz/sq yd covers can provide 4 to 6 degrees of protection).

Consider delayed removal for increased yields. Researchers in the North Carolina mountains are currently investigating the effect of leaving row covers in place for two to three weeks past the start of new leaf growth. A significant increase in Chandler yields was achieved in one season by leaving covers in place for two or three weeks after the start of new leaf growth.

The covers were then removed just before the open-blossom stage when buds have formed and appear white but have not opened — the popcorn stage. Although this ongoing research may prove to be quite valuable, it is based on just one season. Growers who wish to experiment with this strategy should do so only on a portion of their crop.

Use the most effective material. Research in North Carolina's mountains indicates that a 1.5 oz/sq yd spunbonded row cover material is the best all-round choice for colder plasticulture regions (USDA Zone 7a and colder). The covers come in various lengths and widths, and growers typically order covers in widths that can cover five or six rows.

Anchor the covers in place. Use gravel hold-downs to keep the row covers from blowing away and to preserve the cover. Shoveling soil on the edges of the row cover or using wire hooks will cause more rapid deterioration of the cover than using gravel hold-down bags placed every 5 to 6 feet along the cover edges (sometimes as close as 4 feet on high wind sites). Hold-downs can be placed even closer together on very windy fields.

The hold-downs are nylon mesh bags filled with enough gravel to weigh about 15 to 17 pounds each. The nylon mesh is available in 3,000-foot rolls. To make a hold down, pull off about 36 inches of the nylon to make one bag. Tie a knot at one end of the bag, fill the bag with the gravel (about two round-point shovels full), and tie off the other end. The stones at the bottom of the bag will flatten out nicely when dropped on the edge of the row cover. At the end of the season, collect the hold-down bags from the field and store until next year.

Remove Dead Leaves

In milder winters, strawberry leaves remain green. Where winters are more severe, the desiccating effects of cold winds will cause many dead leaves that need to be removed at the end of the dormant period. Many growers refer to this as leaf sanitation. Dead-leaf removal reduces botrytis pressure in March and during the early bloom stage. Leaf sanitation should not be done too early in the winter because a full plant canopy may be needed to protect plant crowns under severe freeze conditions.

Mid-February is usually the best time to schedule leaf sanitation following row cover removal. But when winters are warm, you may have to start this practice in January. Cold injury to leaves can be quite serious after a series of freezes. Plants that are covered during these freeze periods in winter will often not sustain any leaf injury and may remain green throughout most of the winter.

Preharvest

In the preharvest stage, strawberry plants break dormancy, make new growth, and begin to bloom. The prebloom phase begins as dormancy ends and new leaves emerge. New leaves begin to push out of the crowns by mid-February in Zone 6. This is typically when the overwinter row covers are removed — at the start of new leaf growth.

It is usually too late for leaf sanitation operations with tractor-drawn mechanical brushing equipment once new strawberry leaf growth has started because new leaf growth is very succulent and easily injured by rotary brushes. This is the time to pull up side-crowns that are caught beneath the plastic mulch and to remove weeds in the planting holes that were missed in earlier passes through the field. It is also time to hook up the drip irrigation system.

The main blossoming phase starts approximately four to five weeks after the beginning of new leaf growth in late winter, and continues for about one month. This is generally the most complex period in the crop cycle for the protection of blossoms from various pathogens and cold injury.

It Is Important to Maintain Proper Fertility

Make the first N fertilizer injection within a week after new growth has started. Research indicates that approximately 120 pounds per acre is an optimal N rate for Chandler strawberry production under plasticulture in sandy soils over the complete production season. Apply approximately one-half the N during the preplanting stage, and the remainder through drip irrigation starting in late winter soon after new growth begins.

Recommended N rates vary depending on the soil type. Deep sandy soils require the highest rates, followed by medium-textured soils; heavy-textured soils require the lowest rates. Do not wait too long after plants commence new leaf growth before initiating the prebloom N application. The general N recommendation to begin the season is 0.50 pounds per acre per day, which represents 3.50 pounds per acre on a weekly injection basis. The best way to determine the appropriate N rate for your plants, however, is to use a tissue analysis (Figure 10-6). Consult your local Extension service for information on where to get tissue analysis in your area or region.

Figure 10-6. Collecting leaves for tissue analysis. Randomly collect 20 to 25 trifoliates with petioles (leaf stalks) attached. (The leaf blades of strawberries are divided into smaller units called leaflets. The strawberry blade has three leaflets, thus the term trifoliate.) Next, snap off the petiole (right) from the leaf blade (left). At this time of year (late February), the petioles are about 2 inches long (earlier in the winter they are simply too short for sampling). Use a rubber band or bread ties to hold the 20 to 25 petioles together. Place both the 20 to 25 leaf blades along with the petioles in the pouch provided by the test lab.

Apply boron if needed on deep sandy soils. Wait until late winter or early spring to inject boron (B) through the drip system. Typically about 10 ounces per acre of solubor (20 percent B) is used if a tissue analysis shows deficient or near-deficient boron levels in the leaves. Apply solubor well before any blooms appear. Take care to apply boron accurately because it is extremely toxic if applied in excess. The difference between enough B and too much is small.

Continue to apply nutrients when plants begin to blossom. During the early bloom and main blossom phases, a weekly or bi-weekly schedule of N fertigation is recommended based on the results of a leaf tissue analysis. If leaf tissue analysis is not available, inject 0.75 pounds N per acre per day, the equivalent of 5.25 pounds N per acre per week.

With a weekly or bi-weekly feeding schedule, you can take corrective actions based on tissue sampling and petiole nitrate analysis during the prebloom period. Injecting N fertilizer every three or four weeks is not recommended.

Table 10-2. Petiole Nitrate N for New Growth, Prebloom, Bloom, and Harvest (ppm).			
Stage of Development (weeks after dormancy breaks)		**Low (ppm)**	**High (ppm)**
New growth	Week 1	1,500	1,600
Prebloom	Weeks 2 to 3	4,000	6,000
Early bloom	Week 4	3,500	6,000
Mid-to-late bloom	Weeks 5 to 8	3,000	5,000
Harvest	Week 9	2,000	4,500
Harvest	Week 10	2,000	4,000
Harvest	Week 11	1,500	3,000

The petioles (leaf stalks) from trifoliate leaves are the best indicator of N status (nitrate N). The initial petiole nitrate levels before any drip fertilization is usually 600 to 1,500 parts per million (ppm). After the initial N feeding, these levels go up quite significantly (Table 10-2).

Tissue analysis can indicate whether any supplemental potash (K_20) or sulfur (S) is required at this stage. Tissue analyses and soil tests indicate that low sulfur is a real concern in numerous crops, including strawberries. Nitrogen levels are often elevated in the leaf tissue during the blooming and fruiting periods. This high concentration causes an imbalance between nitrogen and sulfur (the N:S ratio).

In turn, additional sulfur may be needed to offset the high level of N. Supply only as much N as required. If sulfur is needed during the spring, magnesium sulfate (Epsom salts) or potassium sulfate are good sources for drip injection. Sufficiency ranges for nutrients in the most recent mature trifoliate are given in Table 10-3.

Table 10-3. Sufficient Nutrient Ranges for Healthy Strawberry Plant Tissue.	
Nutrient	**Sufficiency Range**
	%
N	3 – 4
P	0.2 – 0.4
K	1.1 – 2.5
Ca	0.5 – 1.5
Mg	0.25 – 0.45
S	0.15 – 0.40
	ppm
Fe	50 – 300
Mn	30 – 300
Zn	15 – 60
Cu	3 – 15
B	25 – 50

Provide Cold Protection

Strawberry flower buds begin to emerge from the end of February through early March in Zone 6. Unfortunately, in late winter, the entire zone is subject to advective or windborne freezes of various types (see Table 10-4). Throughout the blooming cycle, growers need to stay alert to conditions that favor frost formation at the ground level. Even when forecasts indicate that dew point temperatures and air temperatures will be in the upper 30s at the weather shelter

Table 10-4. Types of cold events.	
Type of Event	**National Weather Service Definition**
Freeze	Wind speeds of more than 10 mph and air temperature below 32˚F.
Frost/freeze	Wind speeds are less than 10 mph and air temperature is below 32˚F.
Frost	Wind speeds are less than 10 mph and air temperature is above 32 F.
Hoar frost or white frost	Atmospheric moisture freezes in small crystals on solid surfaces.
Black frost	Few or no ice crystals form on the plant because the air in the lower atmosphere is too dry.

height (5 feet), a killing frost is still possible at the strawberry canopy level. Windborne freezes can cause devastating crop losses and delay the harvest by one or two weeks.

Row covers are usually the safest method of cold protection during the early bloom period. Under freeze conditions, overhead sprinkler irrigation is very risky due to a phenomenon known as evaporative cooling. Strawberry plants are most effectively protected during the early-bloom period when flower buds emerge with floating row covers of medium to heavy weight (0.9 or 1.0 to 1.5 oz/sq yd). Row covers of medium weight (1 oz/sq yd) can provide several degrees of cold protection, and this is usually adequate to keep emerged flower buds above their critical temperature of 22˚F when air temperatures are in the upper teens (Tables 10-5 and 10-6).

Losses of the earliest open blossoms (which have a critical temperature of 30˚F) will not be prevented with row covers when temperatures are in the low 20s and upper teens. However, the loss of the first three to four blossoms per plant with Chandler and Camarosa has little economic consequence because the earliest flowers typically develop into berries that are poorly shaped and hard to sell.

Use overhead irrigation during the main blossom period. A variety of cold events still can occur at the main blossom stage, including windborne freezes. But the majority of cold events during the main blossom period are frost/freezes (see Table 10-4). Overhead sprinkler irrigation is the most effective method for frost/freeze and frost protection of popcorn-size and fully open-blossoms.

Row covers are inconvenient during the main blooming period because they must be pulled back each morning following a night of cold protection (for bee and insect pollination), and a medium weight row cover (1 oz/sq yd) is not reliable for more than 3 to 4 degrees of cold protection.

These guidelines provide a basic overview of cold protection strategies for the preharvest stage. You will need special resources, however, to use these strategies effectively.

For detailed information on effective frost control using overhead irrigation, see: *Strawberry Plasticulture Advisory on Cold Protection,* Barclay Poling, April 2005, **http://www.smallfruits.org/SRSFC_News/StrawberryPlasticulureAdvisoryApril1505.pdf**

Harvest

After the blooms begin to bear fruit, the plasticulture strawberry harvest normally lasts around six weeks. But in cooler-than-average spring temperatures, the harvest can last up to two months. Because of high input costs for strawberry plasticulture production (about $10,000 per acre),

Table 10-5. Protection Effectiveness by Cold Event, Flower Stage, and Control Method.			
Weather Event	**Flower Stage**	**Row Cover Alone**	**Sprinkling Alone**
Windborne freeze	Emerged flower bud	Good to Excellent[1]	Not recommended
	Open blossom	Fair	Not recommended
Frost/freeze	Emerged flower bud	Excellent	Excellent
	Open blossom	Fair	Excellent
Frost	Open blossom	Good	Excellent
	Popcorn	Good	Excellent

[1] The protection effectiveness of row covers alone will depend on cover weight, minimum temperature, and humidity.

Table 10-6. Critical Temperatures for Strawberries by Stage of Development.	
Stage of Development	**Approximate Critical Temperature (˚F)**
Tight bud	22.0
Popcorn	26.5
Open blossom	30.0
Fruit	28.0

it is difficult to realize a profit unless you achieve a yield of 1 pound of marketable fruit per plant (15,000 pounds per acre) (Safley *et al.*, 2004). In favorable seasons, yields of 1.2 to 1.5 pounds per plant (18,000 to 22,500 pounds per acre) are possible with good management practices.

Postharvest

When the harvest is over, it is time to begin thinking about the next growing season. Destroy plants as soon as the harvest ends and incorporate lime when the beds are broken down. Although some growers reuse the plastic-covered beds for growing summer vegetable crops, July is the ideal time to begin preparing beds for the next plasticulture strawberry season.

Recommended Reading

Safley, C. D., E. B. Poling, M. K. Wohlgenant, O. Sydorovych, and R. F. Williams. 2004. *Producing and Marketing Strawberries for Direct Markets.* Publication No. AG-645. Raleigh: North Carolina Cooperative Extension, North Carolina State University.

The following web sites also contain a great deal of information related to the plasticulture of strawberry:

http://www.smallfruits.org/SmallFruitsRegGuide/Guides/2006/StrawberryIntegMgmtGuidefina12Jan06.pdf

2006 Southeast Regional Strawberry Integrated Management Guide

http://www.ca.uky.edu/agc/pubs/ho/ho16/ho16.htm

Chapter 11
Economics of Midwest Strawberry Production and Marketing Systems

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The production and marketing of strawberries in the Midwest require a large investment per acre over the life of the crop. In the matted-row system, returns may not equal costs of field preparation and planting for one to two years after planting. New systems of culture may cost twice as much as the matted row. Larger investments per acre carry larger financial risks if cultural practices or weather causes a crop failure. On heavy soils, raised beds or tile drainage may improve yields. Each grower must decide on a system of culture that can produce high and early yields and must be able to carry a large initial investment.

Strawberry Systems Compared

An economic comparison of three strawberry production and marketing systems was made using early 2005 prices. For all systems, an estimated overhead cost per acre per year was calculated for all systems used on a 30-acre farm with five acres of non-productive land (Table 11-1). Estimated labor and equipment costs for all systems are shown in Tables 11-2 and 11-3. Selected material, chemical, and supply costs are shown on a per-acre basis (Table 11-4). In all systems, 60% of berries are sold as pick-your-own and 40% as hand-harvested berries.

The estimated costs and returns for the typical irrigated matted row are shown in Tables 11-5 to 11-9. Year zero constitutes the preparation year and year one is the planting year. This comparison has no fumigation, raised bed, or plastic. Yields begin in year two with 8,000, 6,000, and 5,000 pounds per acre in years two, three, and four. In year four, the planting is destroyed.

The costs and returns for an annual plasticulture system are shown in Table 11-10. This system uses plastic, raised beds, fumigation, and a double-row system. Row covers and overhead irrigation are used for frost control.

Table 11-1. Estimated Overhead Costs per Acre for Midwest Strawberry Production, 2005.

Item	Cost /Year/ Farm[1] ($)
Electricity	1,200
Signs, advertising, postage	850
Pickup	4,500
Telephone, communications	800
Buildings	3,000
Pond/pump/well	700
Road and gravel	450
Clothes, protective clothing	425
Tools[2]	500
Taxes	1,000
Education	600
Professional fees[3]	800
Insurance[4]	1,200
Computer, printer, fax	525
TOTAL	**$16,600**
COST / ACRE / YEAR[5]	**$664**

[1] Farm is 30 acres with 5 acres nonproductive land; 25 acres produces fruit, vegetables, and other horticultural crops.
[2] For repairs, planting, welding, air compressor, etc.
[3] Accounting fees.
[4] Insurance is fire, disability, etc.
[5] Tax base is 25 acres.

Table 11-2. Estimated Labor Costs for Midwest Strawberry Production, 2005.				
Type of Labor	Hourly Rate	Social Security	Others[1]	Total Hourly Cost ($)
Minimum wage	5.15	0.39	0.39	5.93
Unskilled labor	8.25	0.63	0.63	9.51
Semi-skilled labor	9.50	0.73	0.73	10.96
Skilled Labor	14.00	1.07	3.39	18.46

[1] Unemployment insurance, workers comp. (health insurance: skilled labor only @ $200/month).

A modified strawberry plasticulture production system, which uses raised beds, plastic, one row, and straw mulch, is described in Tables 11-11 to 11-14. In year zero the field is prepared and in year two a single row of plants is set with drip irrigation and plastic. Estimated yields of 8,000 and 6,000 pounds per acre are harvested in year two and three, respectively.

Economic Summary of Strawberry Production Systems

Estimated costs and returns for three strawberry production/marketing systems were calculated based on 2005 costs and prices. In all systems, returns were based on 60% of the estimated yield for pick-your-own and 40% for hand-harvested berries. These systems have different estimated costs and returns over several years.

An internal rate of return analysis was used to determine the relative profitability of the three systems. A fair rate of return on investment is defined to be above the current rate for borrowed money. This rate or higher rate of return should be in relation to the financial risk because larger investments carry a higher risk than smaller investments.

Three strawberry production systems are compared as to their potential economic returns in Table 11-15. The matted row and annual plasticulture systems have four years of cost and return streams, and the modified plasticulture system has three years. Based on the estimated cost and return, the matted-row, annual plasticulture, and modified plasticulture had a rate of return of 24, -2.5, and 15 percent, respectively. If the grower increased the return by $0.10 per pound of fruit, then the rate of returns would be 37, 4.5, and 25 percent, respectively.

Generally, any return under 10% does not present a reasonable level of financial risk. Secondly, a net profit below $1,000 per acre for each year over the life of the planting is considered to be low. In general, the plan or goal is to produce a high and early yield and establish a price to have a positive return.

If your costs are similar to those in this study and if interest rates for a certificate of deposit are below 10 percent, then the prices that were used for 2005 are reasonable for a fair return. However, as costs increase, either yield, prices, or yields and price must increase over the life of the planting.

Table 11-3. Estimated Equipment Cost for Midwest Strawberry Production, 2005.[1]

Equipment[1]	Initial Cost ($)	Hours/ Year	Years Dep.	Cost/Hour ($)
Tractor				
30 - 4D	18,000	200	15	14.01
60 - 2D	36,000	300	15	20.74
90 - 2D	54,000	250	15	34.60
Plow — 3-16”	1,800	10	20	16.21
Rototiller — 60”	1,950	20	10	17.22
Sprayer — 110 gal.	8,300	50	15	22.67
Weed Sprayer — 50 gal.	2,100	20	15	12.08
Transplanter — 1 row	1,320	20	20	8.18
Bedder, plastic irrigation tube	4,400	10	15	48.45
Water wheel planter — 2 row	2,800	20	15	18.32
Wagon	1,100	50	20	2.97
Seeder — 6 ft.	3,500	10	20	37.10
Fertilizer spreader	1,250	10	15	14.53
Mower — 6 ft.	2,000	25	15	10.98
Straw spreader	4,680	20	15	34.86
Irrigation — Overhead	18,720	100	15	25.57
Irrigation — Drip	3,625	100	10	6.40

[1] Equipment costs such as transplanters and bedders include shipping charge.

Table 11-4. Estimated Cost of Materials, Chemicals, and Supplies for Midwest Strawberry Production, 2005.

Item — Description		Unit Cost	Cost/ Acre ($)/ Application
Fumigation — custom			2,000.00
Fertilizer / 50 lbs	34-0-0	$7.00	14.00
	19-19-19	$7.70	15.40
	45-0-0	$8.40	8.40
	0-0-60	$8.50	34.00
Foliar / 20 lbs	20-20-20	$40	4.00
Lime — spread		$45/ton	90.00
Lime — pelletized		$90/ton	90.00
Black Plastic — 1.25 ml embossed 4′ x 4,000		$115/roll + $18 shipping	300.00
Row cover, medium — 26′ x 800′		$670/roll + $100 shipping	1,700.00
Row cover, heavy — 25′ x 500′		$700/roll + $100 shipping	3,000.00
Drip tube, 4 ml (15,000 ft 12″)		$175/roll + $25 shipping	120.00
Drip tube, 15 ml (9,000 ft 12″)		$120/roll + $25 shipping	150.00
Straw — 40 lbs/bale		$2.50 x 100 bales, delivered	250.00
Rye — 1 bushel			10.00
Lay flat — 2″ x 300 ft			101.00
Values, brass gate — 1-1/2″			12.30
Injector — 1-1/2 - 70 gph			84.50
Sinbar		$37/lb	18.60
Spartan		$115/gal	7.20
Stinger		$283/0.5 gal	35.40
Devrinol		$85/8 lb	64.00
Dacthal		$206/12 lb	206.00
Roundup		$180/2.5 gal	36.00
Captec		$68/2.5 gal	13.60
Topsin		$91/5 lb	18.20
Elevate		$75/2 lb	56.50
Nova		$88/20 oz	17.60
Quadris		$327/gal	20.50
Ridomil		$111/ pt	111.00
Cabrio		$137/5 lb	23.75
Switch		$127/28 oz	54.60

Table 11-4 (continued). Estimated Cost of Materials, Chemicals, and Supplies for Midwest Strawberry Production, 2005.

Item — Description	Unit Cost	Cost/ Acre ($)/ Application
Endosulfan	$39/5 lb	19.50
Sevin	$87/2.5 gal	17.40
Guthion	$566/5 lb	11.20
Brigade	$103/2.5 lb	41.00
Admire	$88/1 pt	88.00
Savey	$208/12 oz	520.00
Deadline Bait	$97.50/50	48.75
Poast	$200/2.5 gal	25.00
Select	$211/gal	27.00
2,4-D	$45.50/2.5 gal	11.00
Crop oil	$13.50/2.5 gal	1.35
Nufilm/spreader	$33.50/gal	1.70
Plants - all systems	$140/m	1,540.00

* Prices are estimated and do not include shipping, delivery charge, nor discount for large quantities unless indicated.

Table 11-5. Estimated Costs per Acre for Matted-Row System in the Midwest in Preplant Year (0), 2005.

Operation[1]	Year 0	Cost ($)/ Acre[2]
Soil sample (0.33 hr x 18.46 + 18.00)		24.09
Apply herbicide (0.5 hr) x (18.46 + 14.01 + 12.08) + 36.00		58.28
Plow (1.0 hr) x (18.46 x 20.74 x 16.21)		55.41
Apply lime, nutrients (0.5 hr) x (14.01 + 14.53 + 18.46) + 90.00 + 30.80		144.30
Rototill (1.5 hr) x (18.46 + 17.22 + 14.01)		74.54
Seed cover crop (0.5 hr) x (18.46 + 14.01 + 37.10) + 20.00		54.78
Overhead		664.00
Land charge (irrigated land)		250.00
Management — 10% (4.3)		7.94
Sub Total		**1,333.34**
Interest		93.33
TOTAL		**$1,426.67**

[1] Operation includes labor, equipment, materials, etc. See Overhead Costs, Table 11-1.
[2] No fumigation; dormant plants; single row; 12-inch spacing; 4-ft. row spacing; irrigated.

Table 11-6. Estimated Costs per Acre for Matted-Row System in the Midwest in Planting Year One (1), 2005.

Operation[1]	Year 1	Cost/Acre ($)
Herbicide, cover crop — (0.5 hr.)		58.28
Rototill (1.5 hr.)		74.54
Plants — 11,000 @ $140/m		1,540.00
Planting/Replanting — 10 hr.		298.35
Irrigation — 4 hr., Install		43.84
15 hr. — Operation		260.40
Drip material — 1.0 hr.		150.00
Fertilizer, twice (18.96 + 14.01 + (4.53) + 28.00)		75.00
Weed Control		
Hand — 12 hr.		114.12
Chemical — 3 applications		381.21
Insect/Disease — 1.0 hr.		159.70
Straw — Material		250.00
— 12-hr. Application		469.74
Overhead		664.00
Land Charge		250.00
Management — 10% (59)		111.86
SUB TOTAL COST		**4,901.04**
Interest 7%		343.07
TOTAL COST		**$5,2445.11**

[1] Rows are four feet wide and plants are set at 12 inches with drip irrigation expected to operate for five years.

Table 11-7. Estimated Costs and Returns per Acre for Matted-Row Strawberry Production in Year Two (2) in the Midwest, 2005.

Item — Description[1]	Year 2	Cost ($)/Acre
Remove straw — 6 hr.		65.76
Herbicide	0.5 Spring	86.28
	1.0 Renovation	66.65
	0.5 Summer	228.28
	0.5 Fall	52.25
Weed control — hand + rototill (74.54) — 16 hr.		228.24
Frost control — 20 hr. (9.51 + 25.57)		700.60
Drip irrigation — 4 hr.		43.84
Insecticide[2] / Fungicide — 2.0 hr. (22.67 + 20.74)		379.12
Harvest Labor	PYO — 12 hr.	131.52
	Hand — 160 hr.	1,521.60
Transport fruit — 4 hr.		43.84
Refrigerate — 1/2 volume — 2.0 hr.		53.12
Containers	PYO — 480 x 0.68	326.40
	Hand — 320 x 0.82	262.40
Fertilizer — 1.0 hr. twice		75.50
Straw mulch — 12 hr. (plus material + equipment)		719.74
Overhead		664.00
Land charge		250.00
Management — 10% (24.6)		467.36
COST	**Sub Total**	**6,366.50**
	Interest 7%	445.66
TOTAL COST		**$6,812.16**
RETURNS		
PYO — 4,800 @ 1.10		5,280.00
Hand — 3,200 @ 2.00		6,400.00
TOTAL RETURN		**$11,680.00**
NET RETURN		4,867.84
NET RETURN / lb		0.61

[1] Year 2 is the first harvest year with 8,000 pounds harvested; 60% PYO, 40% Hand.
[2] Insecticides (2) are combined with fungicide sprays.

Table 11-8. Estimated Costs and Returns per Acre for Matted-Row Strawberry Production in Year Three (3) in the Midwest, 2005.

Item — Description[1]	Year 3	Cost ($)/Acre
Remove straw — 6 hr.		65.76
Herbicide — 4 applications		499.22
Weed control — hand + rototill		228.28
Frost control		700.60
Drip irrigation		139.84
Insecticide/Fungicide		379.12
Harvest Labor — PY0 12 hr.		131.52
Hand labor — 120 hr.		1,141.20
Transport fruit — 3 hr.		32.88
Refrigerate — 2.0 hr.		45.92
Containers	PYO — 360 @ 0.68	244.80
	Hand — 240 @ 0.82	196.80
Fertilizer		75.50
Straw mulch		719.74
Overhead		664.00
Land charge		250.00
Management 10% (20)		371.20
COST	**Sub Total**	**5,886.38**
	Interest 7%	412.05
TOTAL COST		**$6,298.43**
Return	3,600 lb @ 1.10	3,960.00
	2,400 lb @ 2.00	4,800.00
TOTAL RETURN		**$8,760.00**
NET RETURN		2,461.57
NET RETURN / lb		0.41

[1] Year three has similar items and operations as Year 2 (Table 11-7) with 6,000 pounds of berries harvested; 60% PYO, and 40% Hand.

Table 11-9. Estimated Costs and Returns per Acre for Matted-row Strawberry Production in Year Four (4) in the Midwest, 2005.

Item — Description[1]		Year 4	Cost ($)/Acre
Remove straw — 6 hr.			65.76
Herbicide — 1 application			86.28
Weed control — 1 application 8 hr. (no rototill)			76.08
Frost control			700.40
Drip irrigation			139.84
Insecticide/Fungicide			379.12
Harvest labor — PY0 (12 hr)			131.52
Hand labor — 100 hr)			951.00
Transport fruit — 2 hr.			21.12
Refrigerate	2 hr. ($21.12 + 20.00)		41.12
Containers	PYO — 300 @ 0.64		204.00
	Hand — 200 @ 0.82		164.00
Fertilizer — none			—
Straw mulch — none			—
Overhead			664.00
Land charge			250.00
Management 10% (15)			284.40
COST	**Sub Total**		**4,158.64**
	Interest 7%		291.10
TOTAL COST			**$4,449.74**
Return	3,000 @ 1.10		3,300.00
	2,000 @ 2.00		4,000.00
TOTAL RETURN			**$7,300.00**
	NET RETURN/acre		2,850.26
	NET RETURN / lb		0.57

[1] In year four, 5,000 pounds are harvested, and the planting is terminated after harvest; 60% are PYO and 40% Hand.

Table 11-10. Estimated Costs and Returns per Acre for Strawberry Plasticulture Production for One Year in the Midwest, 2005.

Item — Description[1]	Year 1	Cost ($)/Acre
Land preparation		
Soil sample		24.09
Herbicide old crop — 0.5		58.28
Remove old plastic and dispose — 16 hr.		152.16
Disking and lime fertilizer 2.5 hr.		139.01
Cover crop — 1.0 hr.		54.78
Preplant		
Rototilll — 1.5 hr.		74.54
Fertilizer		75.50
Fumigate[2]		2,000.00
Plastic		300.00
Drip tube (4 mil)		120.00
Raised bed 1.5 hr. (18.46 + 34.60 + 48.45 + 10.96)		168.70
Plant		
Herbicide		86.28
Plants — 17,600 @ 140/m		2,464.00
Transplant-double row — 6 hr (18.46 + 10.96(2) + 20.74 + 18.32) 21.92		476.64
Deer control — 3 hr. labor + materials		192.88
Preharvest		379.12
Insecticide/fungicide		
Floating row cover — 5 hr. (2)		109.60
— material[3]		850.00
Frost control — replace row cover		109.60
Drip irrigation — 6 hr + 3 injections		77.76
Tissue samples		24.00
Overhead irrigation — frost control		700.40
Harvest		
Labor — 280 hr		2,662.80
Containers — PYO - 425 @ 0.68		289.00
Hand - 280 @ 0.82		229.60
Harvest supervision — 33.5 hr.		353.76
Transport — 7 hr.		73.92
Refrigerate — 7 hr.		137.92

Table 11-10 (continued). Estimated Costs and Returns per Acre for Strawberry Plasticulture Production for One Year in the Midwest, 2005.

Item — Description[1]	Year 1	Cost ($)/Acre
Overhead		664.00
Land charge		250.00
Management 10% (41.5)		756.86
COST		**$14,055.20**
Sub Total		
Interest 7%		983.86
TOTAL COST		**$15,039.06**
RETURN[4]		
PYO — 8,500 @ 1.10		9,350.00
Hand — 5,600 @ 2.00		11,200.00
TOTAL RETURN		**$20,550.00**
NET RETURN/acre		5,510.94
NET RETURN / lb		0.39

[1] An annual system at 5 ft between rows; plastic; raised bed with drip irrigation; fumigation.
[2] Custom operator applied.
[3] Row cover usable for 2 seasons.
[4] Yield estimated at 14,000 lb/acre or approximately 0.8 times 17,600 plants.

Table 11-11. Estimated Costs per Acre for Modified Strawberry Plasticulture Production System in the Midwest, 2005.

Item — Description[1]	Year 0	Cost ($)/Acre
Soil sample — 0.33		24.09
Apply Herbicide — 0.5		58.28
Plow — 1.0 hr.		55.41
Apply lime, nutrients — 2.5 hr.		144.30
Rototill — 1.5 hr.		74.54
Raised bed — 1.5 hr.		168.70
Plastic — 1.5 hr. (300.00 material)		468.70
Drip tube (15 mil) — 12 inch		150.00
Herbicide — 0.5		6.28
Seed cover crop — 0.5		54.78
Deer control — 3 hr.		182.88
Overhead		664.00
Land charge		250.00
Management — 10% (1.0)		18.46
SUB TOTAL COST		**$2,392.42**
Interest 7%		167.47
TOTAL COST		**$2,559.89**

[1] Raised bed at 48 inches between rows; plastic; drip irrigation; no row cover or fumigation; expected two harvests or three-year rotation with eastern strawberry red stele-resistant plants.

Table 11-12. Estimated Costs per Acre for Modified Strawberry Plasticulture Production System in the Midwest, 2005.

Item — Description[1]	Year 1	Cost ($)/Acre
Plants — 11,00 @ 140/m		1,540.00
Planting/replanting — 10 hr.		298.35
Irrigation operation — 15 hr.		164.40
Fertilizer — foliar, drip		28.00
Weed control — hand, 12 hr.		114.12
Insect/disease — 1.0 hr.		159.70
Straw		
— material		250.00
— application, 12 hr.		469.76
Deer control		192.88
Overhead		674.00
Land charge		250.00
Management — 10% (5)		92.30
SUB TOTAL		**$4,233.49**
Interest		296.34
TOTAL COST		**$4,529.83**

[1] Dormant plants spaced 12 inches between plants and 48 inches between rows; planted in April with sod between rows; raised bed; plastic and drip irrigation installed in fall before spring planting.

Table 11-13. Estimated Costs per Acre for Modified Strawberry Plasticulture System in the Midwest, 2005.

Item — Description[1]	Year 2	Cost ($)/Acre
Remove straw — 6 hr.		65.76
Weed control — hand, 8 hr. @ 10.96		87.68
Runner control — 8 hr. @ 10.96		87.68
Frost control — 20 hr.		700.60
Drip irrigation — 4 hr. labor + 15 hr.		139.84
Deer control – 3 hr.		192.88
Insecticide/fungicide — 2.0 hr.		379.12
Harvest labor		
PYO — 12 hr.		131.52
Hand — 160		1,521.60
Transport — 4 hr.		43.84
Refrigerate — 1,600 lb — 2 hr.		53.12
Containers		
PYO — 480 x 0.68		326.40
Hand — 320 x 0.82		262.40
Fertilizer — 1.0 hr. twice		75.50
Straw mulch — 10 hr.		719.74
Overhead		664.00
Land charge		250.00
Management (24)		440.64
COST		
Sub Total		6,142.32
Interest 7%		429.96
TOTAL COST		**$6,572.28**
RETURN		
PYO — 4,800 @ 1.10		5,280.00
Hand — 3,200 lb @ 2.00		6,400.00
TOTAL RETURN		**$11,689.00**
NET RETURN		5,107.72
NET RETURN/LB		0.64

[1] This system utilizes overhead sprinklers for frost control. Plastic is expected to last three seasons. Hand weeding only.

Table 11-14. Estimated Costs per Acre for Modified Strawberry Plasticulture System in the Midwest, 2005.

Item — Description[1]	Year 3	Cost ($)/Acre
Remove straw — 6 hr.		65.76
Weed control — 4 hr. hand		43.84
Insect/disease — 2.0 hr.		379.12
Frost control — 20 hr.		700.40
Drip irrigation — 6 hr. + injection		77.76
Deer control — 3 hr.		192.88
Containers		
PYO — 360		244.80
Hand — 240		196.80
Harvest		
Labor PYO (12 hr.)		131.52
Labor Hand (120 hr.)		1,141.20
Transport — 3 hr.		32.88
Refrigerate — 2.0		45.92
Remove plastic, dispose		152.16
Overhead		664.00
Land charge		250.00
Management — 10% (18)		332.28
COST		
Sub Total		4,651.32
Interest 7%		325.59
TOTAL COST		**$4,976.91**
RETURN		
PYO — 3,600 lb @ 1.10		3,960.00
Hand – 2,400 lb @ 2.00		4,800.00
TOTAL RETURN		**$8,760.00**
NET RETURN		3,783.09
NET RETURN/LB		0.63

[1] Sprinkler irrigation used for frost control. Plastic is removed because this is the last harvest — second harvest. Spring weed control only.

Table 11-15. Estimated Internal Rate of Different Strawberry Systems in the Midwest, 2005.

System[1]	Year	Cost($)/ Acre	Return/acre[2] ($)		IRR[3] — %	
			60%	40%		
Matted Row						
	0	1,427	0	0		
	1	5,244	0	0		
	2	6,812	11,680	12,480		
	3	6,298	8,760	9,360		
	4	4,159	7,000	7,800		
	Total	23,940	27,440	29,640	24%	37%
	Difference	—	3,500	5,700		
Annual Plasticulture						
	1	15,039	20,550	21,960		
	2	11,678	0	0		
	3	14,020	17,520	18,720		
	4	12,980	14,600	15,600		
	Total	53,717	52,670	56,280		
	Difference	—	-1,047	+2,563	-2.5	+4.5
Modified Plasticulture						
	0	2,560	0	0		
	1	4,530	0	0		
	2	6,366	11,680	12,480		
	3	4,977	8,760	9,360		
	Total	18,433	20,440	21,840	15	25
	Difference	—	2,007	3,407		

[1] Please refer to Tables 11-5 to 11-14 for cost/returns and description of systems. Costs are rounded to nearest dollar.

[2] Returns are 60% pick-your-own at $1.10 or $1.20 and 40% hand harvested at $2.00 or $2.10 per pound.

[3] IRR — Internal rate of return analysis indicates the percent return on total investment over the entire time of planting.

Table 11-16. Estimated Total Cost per Hour for Specific Equipment and Labor for a Small Midwest Strawberry Farm, 2005.

Item	Hours/Yr.	Cost/Hr. ($)	Labor[1] ($)	Total Cost/ Hr. ($)
Tractors[2]				
30/4D	200	14.01	9.23	23.34
60/2D	200	20.74	9.23	29.97
90/2D	250	34.60	9.23	43.83
Sprayers				
Weed	20	12.08	9.23	21.31
Air Blast	50	22.67	9.23	31.90
Bed Shaper, etc.	10	48.45	9.23	57.68
Transplanter	20	8.18	28.25	36.43
Rototiller	20	17.22	9.23	26.45
Water Wheel Planter	20	18.32	28.25	46.57
Fertilizer Spreader	10	14.53	9.23	23.76
Mower	25	10.98	9.23	20.21
Straw Spreader	25	34.86	28.25	63.11
Irrigation				
Overhead	100	25.57	10.96	36.53
Drip	100	6.40	10.96	17.36
Wagon	50	2.97	9.23	12.20
Pick-up	150	30.00	18.46	48.46

[1] Labor is one skilled person for most operations, except two unskilled people for water wheel planter, transplanter, straw spreader. Labor is 50% tractor and 50% attached equipment.
[2] See Table 11-3 for additional information.

Chapter 12
Marketing

The area of marketing is challenging for many growers. They are producers first, managers second, and marketers last. Profit will be affected by giving marketing a greater priority. Competition from new, inexperienced growers for retail and pick-your-own sales and wholesale California berries in local supermarkets will always provide a serious challenge or opportunity for growth. Those who can adapt and interpret change and take corrective action will become stronger as a result of adversity.

Potential customer needs must be a priority. The emphasis is no longer on trying to sell what you can produce but on trying to produce what you can sell. Successful growers recognize that customers' needs are more than just purchasing a good quality berry.

The pick-your-own industry is making a rapid shift from production emphasis to a marketing emphasis. A marketing concept emphasizes planning the total business around the specific needs of a target customer group while maximizing volume within a short picking season. The marketing plan develops around product, price, promotion, and place.

In pick-your-own, the product is not only quality but also fresh fruit of the season, produced in clean fields with friendly people. The product can be part of a family outing as recreation or fun at home making jam and jelly (Figure 12-1).

Determine the price per pound by developing a budget showing all costs. However, it should be as the customer sees the value of a fresh berry. Volume pricing or offering coupons are other ideas for determining price. One price through the season is best.

Promotion of pick-your-own has brought different degrees of success, but word-of-mouth is widely accepted as the best and least expensive advertisement. If customers have been treated warmly and fairly, they'll tell others. Radio, newspapers, and free television exposure are used. Generally, 3 to 5 percent of the budget is used for promotion. Timing of advertising is critical. Weather plays an important part in people coming to the farm.

Location is vital to success. A location near a large metropolitan population is best, but 50 percent or more of the customers may come from a 25-mile radius when they are assured of a good supply of berries. Aggressive, market-oriented growers are considering moving their locations or adding locations to their operations to be more accessible to the growing market. Specialty stores and other outlets may be looking for hand-harvested berries.

Pick-Your-Own Considerations

Pick-your-own offers savings in picking, packing,

Figure 12-1. Pick-your-own strawberry plantings offer fresh, high-quality berries as well as an outing for families.

and delivery. However, costs for supervision, advertising, parking space, check-out people, and liability insurance can be high. Generally, profits are higher, particularly if the average customer purchases 20 pounds per person.

It is best to sell fruit by weight. Most operators furnish the container and charge a fee per container to reduce the labor and time for weighing the fruit. The grower must acquaint the customers with operating procedures such as price, weighing, and children in the field. Signs (Figure 12-2) and supervisors expedite the picking and checkout process. Signs are also useful in attracting customers and providing directions to the planting. It is important to remember that any signs you post represent your business; therefore, they should present the desired information and should be attractive.

More importantly, growers must monitor, review, and evaluate their marketing plan to be effective. At the end of the season, review all activities. Were they accomplished on time? Goals should be measurable in numbers, when possible.

Use key people in your organization to discuss their ideas with you. Their involvement increases their commitment. Seeking outside help from a local marketing expert can pay big dividends.

Successful businesses do not concentrate on fighting competition. Instead, they concentrate their time, efforts, and finances on managing and developing their own business. Successful growers understand their costs, develop a marketing plan, and act accordingly.

Successful growers belong and participate in professional associations to improve their marketing efforts. An intentional, well-planned, well-executed marketing effort generates significant returns to the aggressive grower.

Figure 12-2. Attractive signage plays an important role in drawing customers to pick-your-own strawberry plantings. In addition, quality signs promise a quality food product for the consumer.


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