NRAES–88

# Strawberry Production Guide

*For the Northeast, Midwest, and Eastern Canada*

Northeast Regional Agricultural Engineering Service

Cooperative Extension

Cooperative Extension NRAES–88

# Strawberry Production Guide

## *For the Northeast, Midwest, and Eastern Canada*

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# Dedication

The *Strawberry Production Guide for the Northeast, Midwest, and Eastern Canada* is dedicated to Dr. Gene Galletta, strawberry breeder at the United States Department of Agriculture–Agricultural Research Service laboratory in Beltsville, Maryland. Through his tireless efforts, Dr. Galletta released many strawberry varieties to the industry, including Scott, Allstar, Lester, Lateglow, Tribute, Tristar, Mohawk, Northeaster, Primetime, Latestar, and Delmarvel. He has been a lifelong friend of the berry industry and has spoken at countless meetings to share information about the latest developments in berry breeding. Dr. Galletta continues to inspire and provide leadership for a new generation of scientists throughout North America. He is a gentleman and a scholar, and his influence will be felt for decades to come.

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# Introduction

The cultivated strawberry, *Fragaria ananassa* Duch., is a relative newcomer to agriculture. The varieties now grown in most parts of the world are derived from hybrids developed within the last two hundred years. The fruit of these varieties is quite different from that of the natural ancestral species that were harvested until the early 1800s.

The strawberry has become the basis of a large commercial industry and is one of the most popular small fruits in the United States. Annual per capita consumption of fresh strawberries is 5 pounds and growing. Most strawberries produced in the United States are grown as annuals in California and Florida over a long season and then sold in supermarkets. These two states supply much of the U.S. market from December through October, as the varieties grown there bear fruit that can survive long-distance shipping. Most strawberries from the Pacific Northwest and the remainder of the California crop are processed into juices, jams, and jellies or frozen whole or sliced for use in ice cream, yogurt, and toppings.

In the Northeast and Midwest, a market exists for locally produced strawberries for fresh consumption. Varieties grown in the Northeast are typically dark red in color, have a high sugar and acid content, and are intensely flavored. Many are resistant to soil and leaf diseases and tolerate a wide range of soil types. Fruits ripen over a three- to five-week period beginning in late May to mid-June, depending on the location.

Strawberries are usually grown as perennials in eastern Canada and the Northeast and Midwest, fruiting for several years before being replaced with new plantings. In the southern mid-Atlantic states and the Carolinas, many growers have adopted the annual plasticulture system and grow California varieties, but this system is less suitable for colder regions. (See chapter 4 for a description of the plasticulture system.)

Few farms grow strawberries exclusively — most strawberry growers produce other fruits and vegetables, because the strawberry season is usually very short. However, researchers are working to develop new methods and varieties to extend the season. Some of these methods, such as growing dayneutral varieties, planting in the fall on black plastic, using row covers, and growing plants in protected culture (greenhouses), are discussed in chapter 4 of this guide.

## About This Guide

This guide is intended as a comprehensive resource for both novice and experienced strawberry growers in northeastern North America. It provides information on all aspects of strawberry culture for the midwestern and northeastern United States and eastern Canada. The varieties mentioned either have performed well in this region or show the most promise. Pest management chapters emphasize cultural controls, since chemical use is regulated on a state-by-state basis. Sample budgets provided in chapter 14 are based on 1996 costs. Included on the floppy disks that accompany this guide is a spreadsheet template that allows growers to alter the sample budgets based on their own costs and capital; chapter 14 provides details about how to use the spreadsheets.

Two appendixes are included. Appendix A will help growers diagnose common strawberry pests and problems. Appendix B shows the ripening season for strawberries across the United States. Photographs referenced throughout the text are collected in the back of the book on pages 135 through 154. A glossary is included to define terms that might be unfamiliar to readers.

## Getting Started

Growing strawberries is not easy. To succeed, you must be a good horticulturist, pest manager, labor manager, and marketer. Below are some questions to consider before embarking in the strawberry business. Information in this guide will help you answer the questions.

1. How do you plan to market the berries?

2. Are your facilities adequate for the type of marketing you plan to do? For example, do you have cooling facilities for wholesaling or a parking area for pick-your-own customers?

3. Is the soil in your area appropriate for growing berries? Can it be amended to support berry production?

4. Is the soil sufficiently drained?

5. Do you have a large enough water supply for irrigation and frost protection?

6. Does your land slope enough to allow for air drainage, but not so much that it is difficult to work?

7. Do you have sufficient capital resources to invest in berries — about $3,000 per acre for matted rows to $6,000 per acre for annual plasticulture? (Keep in mind that a return on investment may be several years away.)

8. Do you have the personal skills necessary to manage laborers and greet customers?

9. Where will you obtain labor during the busy picking season?

10. Do you have land for future expansion and crop rotation?

11. Is your family willing to commit to berry production? Growing strawberries may entail foregoing a summer vacation; working during harvest; and, if retailing, tolerating the public on the farm.

12. Have you checked local ordinances regarding zoning, parking, signs, noise, riparian rights, etc., to see if they might conflict with your plans for berry production?

13. Are you set up to keep track of input expenses, payroll, pesticide applications, employee records, yield records, and perhaps customer mailing lists?

14. Have you started a library of resources?

15. Are you certified to apply pesticides?

16. If retailing, have you evaluated your farm's location in relation to population centers, off-road parking, visibility, and competition? Will customers be able to find your farm easily?

17. Have you inquired about membership in state and national grower organizations — for example, the North American Strawberry Growers Association? (See page 162 for membership information.)

For more information, you may want to read *Farming Alternatives: A Guide to Evaluating the Feasibility of New Farm-Based Enterprises,* NRAES–32. For a description of the book and ordering information, please see page 158.

CHAPTER 1

# The History and Biology of the Cultivated Strawberry

## A Brief History

The exact origin of the modern cultivated strawberry, *Fragaria ananassa* Duch., is unclear, but the best evidence indicates that it was derived from a cross between two American species, *Fragaria virginiana* Duch. and *Fragaria chiloensis* Linn. The former (photo 1-1) is a common inhabitant of the eastern coast of North America, and sixteenth-century colonists were greatly impressed by its size and flavor. Indigenous people used the fruit in breads and as a dried supplement to meats. Roger Williams, founder of Providence, Rhode Island, reported in 1643 that "the English have exceeded and make good strawberry wine." The species was introduced in England and became a favorite there in local gardens.

In 1712, while gathering information for the French navy about Spanish fortifications along the west coast of South America, Captain Amedee Frezier was struck by the large-fruited strawberries cultivated there by natives. Being an amateur botanist as well as a spy, he collected some plants for the voyage home. Two of the few specimens that survived the journey were given to the Royal Garden in Paris, along with the statement that they bore fruit "as big as walnuts." Antonine de Jussieu, director of the garden at the time, must have been disappointed, then, when the plants produced only a few small, deformed berries.

The plants Frezier had collected were *F. chiloensis*. This species is dioecious (having male and female plants), and unfortunately he had collected only females. The problem was simply a matter of pollination, but apparently this was not realized until many years later. Fortunately, the species was retained in some collections and later redeemed when, in Brittany, it was discovered that interplanting it with *F. virginiana*, a plentiful pollen producer, resulted in excellent crops.

*F. chiloensis* soon became the major species of commerce, although, despite its impressive size, the strawberry was pale, seedy, and faint of flavor. Brittany, the European center of production, shipped fruit to Paris and London.

Probably as a result of the cross pollination technique used to produce so-called Chilean strawberries, seedlings of *F. chiloensis* and *F. virginiana* crosses began to appear in European gardens. Some of the progeny bore large fruit with a deep red flesh. The flavor was somewhat reminiscent of pineapple, and for this reason the plant became known as the pineapple strawberry. The origin of this strawberry was initially shrouded in secrecy, probably by businesspeople hoping to earn high profits. But in 1766, Antoine Nicholas Duchesne published a hypothesis of its hybrid origin based on his experience with strawberry breeding and knowledge of the Brittany practices.

The pineapple strawberry was named *Fragaria ananassa* Duch. Crosses and selections between *F. chiloensis* and *F. virginiana* continued, and breeding among the progeny commenced as well. Eventually, selections from these crosses would lead to strawberries similar to those grown today — large, red fruit with exceptional flavor.

In America, the early commercial strawberry industry was dependent upon the European introductions of *F. virginiana* and *F. ananassa*. However, in 1838, Charles Hovey of Cambridge, Massachusetts introduced the 'Hovey' strawberry. This variety was the result of crossing a European pineapple strawberry with a native *F. virginiana* plant. 'Hovey' is credited as being the first variety of any fruit made from an artificial cross in the United States. The exceptional quality of both the fruit and the plant stimulated a great new interest in strawberries throughout the country. 'Hovey' and later U.S. introductions, such as 'Wilson' and 'Howard,' provided the basis for future breeding programs.

Many important varieties have been released this century from a number of breeding programs throughout North America. These programs have contributed varieties with regional adaptation, as well as outstanding characteristics such as size, firmness, red stele resistance, and dayneutrality (the ability to initiate flowers over a wide range of day lengths). Dayneutral varieties afford growers the opportunity to greatly extend the harvest season; they are discussed in more detail in chapter 4.

The hybrid nature of the cultivated strawberry provides breeders with the genetic variability to make substantial, consistent progress, and vast native populations still exist that exhibit useful horticultural traits. Plant breeders will likely make much more progress in the ensuing decades. Surely, many new delectable varieties are on the horizon.

## Growth and Development of the Strawberry Plant

A strawberry plant consists of a crown from which leaves, flowers, runners (stolons), branch crowns, flower clusters, and adventitious roots grow (figure 1-1). The leaves are arranged spirally, such that every sixth leaf is above the first. Each leaf has three leaflets with a thick cuticle layer. Stomata appear only on the leaf undersides. Older leaves (those that were produced in spring and early summer) die after exposure to hard frosts in the fall and are replaced by new leaves in the spring. Leaves produced late in the season overwinter until the following spring.

An axillary bud is produced at the base of each leaf and may develop into a runner or branch crown, depending upon environmental conditions. Runner development is stimulated by long days and warm temperatures. Runner plants are the primary means of propagating strawberries commercially. Runners that have rooted over the summer are dug between late fall and early spring and stored in coolers at about 32˚F until spring planting.

Plants can also be propagated by rooting runner tips. Runner tips are removed in early summer and placed into plug trays, where they are misted until they root. These are called "plug plants" in the industry and are used primarily for fall planting in the annual plasticulture system (see chapter 4 for more on plasticulture).

Branch crown development is promoted by short days and thus tends to occur late in the season. Being a very reduced stem with spirally arranged leaves, a branch crown has much of the same anatomy as the main crown. At one time, strawberry varieties that characteristically produced few runners were propagated by branch crowns. Whole plants would be dug in the fall, and the numerous branch crowns would be divided and stored for spring planting. This practice is labor intensive, however, and is not widely used today.

Each strawberry variety begins to initiate flower buds after exposure to a unique combination of day length and temperature. Most varieties begin flower bud initiation under conditions of shortening days and cool temperatures, which occur naturally in late September and October in the Northeast; such varieties are called short-day, or June-bearing, strawberries. Some varieties are not sensitive to day length and will initiate flower buds when temperatures are neither too hot nor too cold (between 40° and 85˚F); these varieties are called dayneutrals. Other varieties fall between these two extremes and exhibit a weak response to day length.

In short-day types in the Northeast, flower bud initiation is completed by November, but flowering does not occur until spring. In dayneutral types, flowering occurs about six weeks after bud initiation, which occurs continuously from late spring through fall.

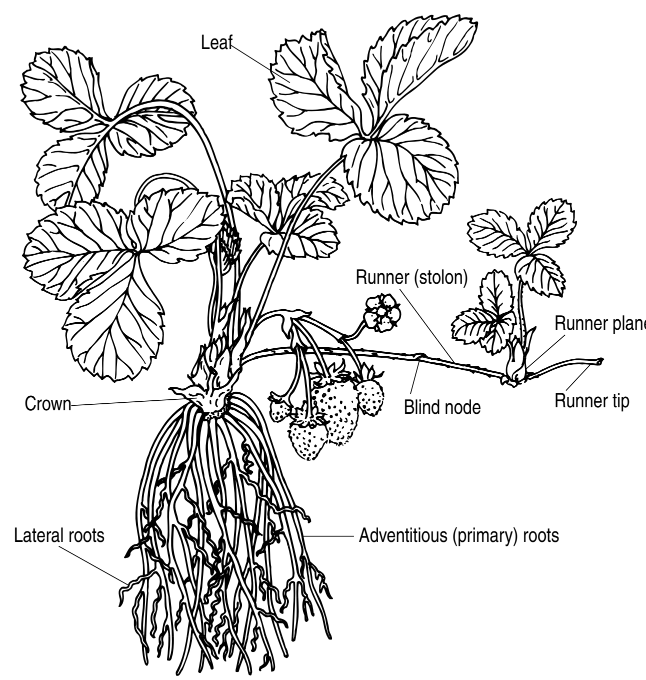


**Figure 1-1.** Parts of the strawberry plant

Adventitious roots arise from the crown primarily in late summer and fall. They extend several inches into the soil and form numerous lateral roots, which are the primary means of water and nutrient absorption. Lateral roots usually live one or two years; primary (adventitious) roots may live two to three years. The largest concentration of roots occurs in the upper 6 inches of the soil. The length and number of roots formed depend on soil conditions and plant density. Usually each plant maintains twenty to thirty primary roots, the average root length being 4 to 6 inches. Only after the development of numerous lateral roots (which is encouraged by proper soil moisture conditions) can runner plants become independent of the mother plant—that is, survive without support from the connecting runner.

## Flower Cluster and Fruit Development

The strawberry flower cluster, or inflorescence (figure 1-2), is a modified stem terminated by a primary blossom. Branches arise at nodes from buds in the axils of modified leaves, or bracts. Each branch is terminated by a blossom. Typically, two secondaries, four tertiaries, and up to eight quaternaries follow the primary (king) blossom. The exact scheme may vary among cultivars or locations.

An individual blossom typically has ten green sepals, five white petals, and twenty to thirty-five stamens arranged in a spiral pattern in three whorls. The pistils are arranged spirally on the receptacle and number anywhere from sixty to six hundred. Pistils occur in the greatest numbers on the primary blossom, and their numbers decrease successively down the inflorescence.

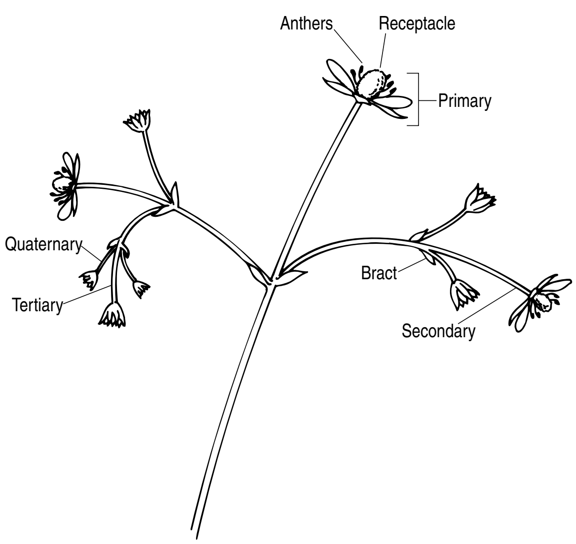


**Figure 1-2.** The strawberry inflorescence

Strawberries are self-fertile, but their size and yield have been shown to increase when they are cross pollinated by insects. Pollen is mature prior to the opening of the flowers but is not released for several days to encourage cross pollination. Stigmas remain receptive to pollen for eight to ten days. Fertilization occurs twenty-four to forty-eight hours after pollination.

The strawberry fruit is not a true berry, despite its name. A true berry develops from the ovary of a flower, whereas the strawberry develops from the flower receptacle. The ovaries are contained in the achenes (seeds) that are on the outside of the fruit.

Cell division accounts for only 15 to 20% of total fruit growth and occurs mostly before anthesis. (Anthesis marks the shedding of pollen from the anthers.) Approximately 80% of subsequent growth is from cell enlargement. Sugars, aromatic compounds, and pigments all increase as the receptacle tissue matures. Ripening, from anthesis to harvest stage, lasts approximately thirty days, depending on environmental conditions.

Development of the receptacle is controlled by growth regulators, primarily auxins, which are synthesized in the achenes. Auxin, which is produced in the endosperm and translocated into the receptacle tissues, stimulates growth via cell enlargement. Removal of achenes after fertilization results in a proportionate reduction in growth. For example, leaving only three achenes on a receptacle results in three areas of growth directly below and surrounding those achenes. A ring of achenes left on a receptacle results in a ring of growth. And so forth.

The ultimate size and shape of a strawberry are thus a function of the number of achenes on the receptacle, the area of receptacle tissue surrounding each achene, and the distribution of the achenes on the receptacle. Receptacles with few achenes will be small, as is observed for those receptacles lowest on the inflorescence. Berries that initiate more receptacle growth per achene will be larger. The location of the achenes on the receptacle will affect the distribution of growth and, therefore, berry shape. Figure 1-3 on the following page shows the types of berry shapes.

Lack of fertilization, or damage to the achenes by frost, insects, or disease, will prevent the synthesis of auxin and result in uneven development or malformation of

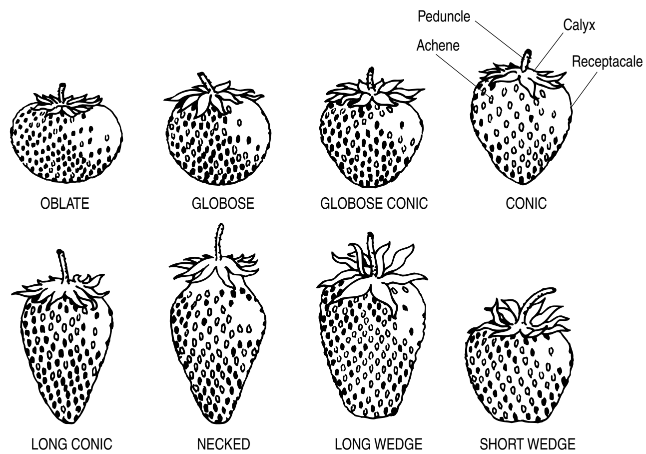


**Figure 1-3.** Strawberry shapes

the receptacle. The degree and character of the deformity will depend upon the number and location of damaged achenes.

Strawberries are extremely variable, and varieties have been developed for all parts of the world. They are perhaps the most widely grown fruit crop. But varieties tend to be narrowly adapted to specific regions. Varieties developed in one part of the world rarely grow well in another region.

## Further Reading

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CHAPTER 2

# Site Selection and Preparation

## Site Selection

Site selection is a major consideration for berry production. The site will affect not only yield potential but also marketing options. Pick-your-own (PYO) marketing is common in the Northeast and Midwest; but if your site is located far from a major highway or population center, then PYO marketing may not be successful in your location. If your site is ideally located for PYO, then you must keep in mind that not all of the land can be planted in berries—some must be reserved for customer parking and crop rotation. If you intend to sell berries through retail outlets, then your production fields should be close (preferably less than 1 mile) to the outlets to minimize the time strawberries will be in transit.

Do not grow strawberries for five or more consecutive years on the same site without some type of crop rotation. Plan to reserve at least 30% of your land (preferably 50 to 70%) for rotation in future years, because a minimum of three years should elapse between plantings on the same site. Land not planted in strawberries should be planted in soil-improving cover crops or cash crops that allow for easy weed management.

Another major consideration for site selection is the availability of water. Strawberries need a lot of water for both irrigation (see chapter 6) and frost protection (see chapter 5). So for successful berry production, the site must have access to an ample supply of high-quality water.

Equally important as having available water is having good internal water drainage. Strawberries cannot tolerate standing water or the diseases that thrive in wet conditions. If your site is too wet for strawberry production, then install subsoil drainage to alleviate problems with excess water. Sometimes strawberries can be grown successfully on wet sites if they are planted in raised beds (photo 2-1).

In general, strawberries are tolerant of a wide range of soil types and conditions. In most locations, the ideal soil for strawberry production is a well-drained, sandy loam (photo 2-2) with a pH of 6.0 to 6.5. Drainage and soil pH can be modified on less-than-ideal soils. In some acidic, sandy soils, certain micronutrients can become deficient if the soil pH gets above 6.0. Heavy clays should be avoided, but sandy soils are acceptable. Planting and cultivating strawberries is difficult in stony soils, and such soil is hard on equipment. In general, sites that produce good alfalfa crops tend to be good for strawberries.

Avoid steep slopes (greater than 5%), because they are erodible and difficult to cultivate and irrigate uniformly. Moderate slopes (3 to 5%) allow air to drain and, therefore, reduce the risk of frost injury. South-facing slopes tend to increase the risk of frost injury in spring because plants generally bloom earlier, and west-facing slopes present the greatest risk for winter injury because they are exposed to persistent, desiccating winds in winter.

Strawberry crowns are injured when their temperature approaches 20˚F, but the risk of winter injury can be

### *Checklist for a Good Site*

- ✔ a location close to market
- ✔ good soils
- ✔ good soil drainage
- ✔ a moderate slope (3 to 5%)
- ✔ a source of high-quality water

minimized by mulching properly or using row covers (see chapter 5). With these methods, strawberries can be grown on sites where air temperatures get as low as – 40˚F. With the proper selection of varieties, strawberries can be grown wherever the growing season is at least four months long. High temperatures (greater than 90˚F) significantly reduce flower bud initiation and root growth. Therefore, strawberries that are to be grown in a warm climate must first receive chilling in another location for satisfactory fruiting to occur. For example, plants can be propagated in cooler northern nurseries, then dug and shipped south for planting into production fields.

## Site Preparation

### *Weeds*

A major step in site preparation is eliminating perennial weeds. This is particularly important because few herbicides are labeled for use in strawberries, and these herbicides have a limited effect on perennial weeds. Weeds cause more economic loss than diseases and insects combined. Weeds also encourage the establishment of pest populations. Eliminating weeds the year before planting is much easier than controlling them after planting. Too many growers plant directly into a site where perennial weeds were not eliminated the previous summer, and then spend the next several years trying to find the right combination of herbicides to undo the damage. Starting site preparation two or three years in advance will be rewarded in future years.

Rotation, coupled with the use of a broad-spectrum postemergent herbicide the summer before planting, is an effective approach to eliminating weeds. Cover cropping the site again after applying herbicide will further suppress weed growth. Repeated cultivation or covering a site with black plastic for several months is also effective. Beginning site preparation two or three years before planting is especially important if the strawberries are going to be grown organically.

Fumigation at high rates will suppress weeds (photo 2-3), although its use worldwide will likely be restricted because of environmental concerns, availability, and expense. In some situations, nematodes, soil diseases, soil insects, or intense weed pressure may justify fumigation. For fumigation to work properly, the soil should be friable, warm (greater than 50˚F), and devoid of decomposing plant material. The best time to fumigate a strawberry field is late summer or early fall of the year prior to planting. Chapter 10 provides more details on weed management.

### *Nutrient Amendments*

Before planting, test the soil for pH, potassium, phosphorus, magnesium, calcium, and boron. Sample soil in a V-shaped pattern within the field (figure 2-1), and collect from at least ten locations. The sample should represent the profile of the top 10 to 12 inches of soil. After testing, plow the site, add the amount of nutrients recommended by the soil-testing laboratory, and then disc. Because soil-testing procedures are not standardized, follow the recommendations from the laboratory where the samples were analyzed. Do not use test results from one laboratory and sufficiency ranges from another.

It takes one year for lime to raise soil pH and for sulfur to lower soil pH, so these nutrients must be applied one year before planting. The more finely ground the sulfur or lime, the faster it will react with the soil.

To increase soil pH, apply a liming agent such as calcite or dolomite. Liming agents differ from one another in two important ways, both of which will influence their effectiveness: (1) chemical composition, which affects acid-neutralizing potential and fertilizer value, and (2) particle size, which determines liming efficiency and ease of application. Consider the relative importance of these when selecting a liming agent. For example, even though dolomite has a lower neutralizing value than calcite, it is often used on sites that require supplemental magnesium for adequate fertility. Moreover, finely ground lime is more difficult to apply than coarse particles, but it changes the soil pH more quickly.

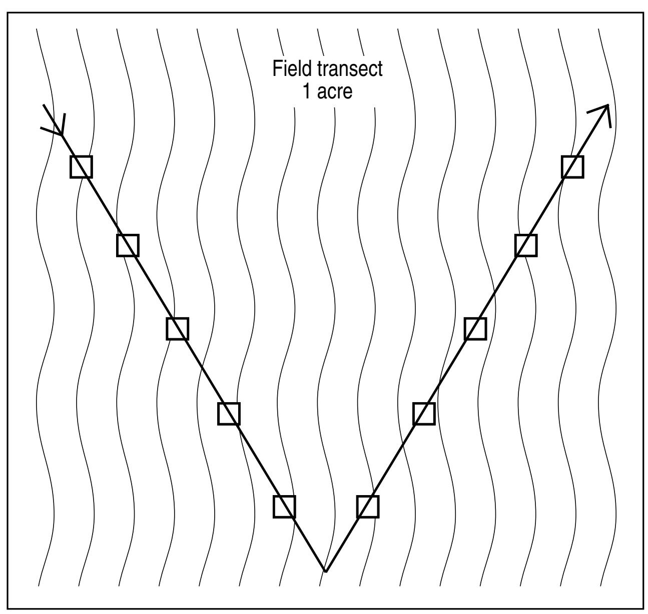


**Figure 2-1.** "V" pattern used for sampling a field

Sulfur is effective at lowering soil pH, but it takes time for bacteria to oxidize the sulfur into a usable form. Sulfur comes as a wettable powder or as prills, with the former reacting faster to lower the soil pH. Aluminum sulfate is sometimes recommended for acidification because it provides an already oxidized form of sulfur; but it is expensive, and six times as much is required to do the same job as sulfur. Also, aluminum toxicity can occur when large amounts of aluminum sulfate are used, so the authors of this book do not recommend it.

Certain nutrients, like phosphorus, are very insoluble in water and move very slowly through the soil. It may take years for phosphorus applied to the soil surface to reach the root zone of the plant and be taken up. For this reason, it is imperative to apply sufficient phosphorus before planting and to mix it into the root zone. Chapter 7 provides more details on nutrient management.

Animal manures and legumes offer a good source of slowly released nitrogen when they are incorporated into the soil prior to planting. Animal manures are a potential source of weed seeds, however. Manure applied to fields should be well-composted and worked into the soil prior to planting to minimize any risk of fruit contamination from pathogenic bacteria (see chapter 7).

## Irrigation

The irrigation system should be in place and operational before planting for two important reasons: (1) transplants will probably require immediate watering, and (2) any preemergent herbicide applied after transplanting will need to be watered in by rain or irrigation to be effective. Also, in early spring, the irrigation system will be a necessary tool for frost protection. Chapter 6 provides details for irrigation design and management.

## Preplant Cover Crops

Seeding a cover crop on the site the year before planting is an excellent way to improve soil structure; suppress weeds; and, if the proper cover crop is chosen, suppress nematode populations. Benefits of a cover crop are greatest when the soil is sandy and/or the soil organic matter content is low. Most cover crops grow under the same soil conditions as strawberries; it is unlikely that you will need to add anything other than nitrogen (40 pounds per acre) and perhaps phosphorus prior to seeding.

Use minimum seeding rates for cover crops when the objective is to supply a harvestable stand of grain or straw. But when a vigorous, dense stand is desired for weed suppression and organic matter, use a higher seeding rate.

Preplant cover crops are usually plowed under in the late fall or early spring prior to planting. Unless the soil and site are prone to erosion, crops with low nitrogen contents (grains and grasses) should be plowed under early in the fall to allow enough time for decomposition. Legumes contain more nitrogen and decompose quickly, so they can be turned under within a month of planting.

Some growers are experimenting with planting strawberries into a mowed or killed sod of grain rye, rather than planting into bare soil. This method reduces the requirement for herbicides and is discussed more fully in chapter 4.

Many plant species are suitable as preplant cover crops, and each has its own advantages. In some cases, mixtures of crops are used to realize the benefits of several species. Listed below are some cover crops that perform well in cooler climates; the list is by no means comprehensive.

### *Alfalfa*

Alfalfa is a perennial legume that requires a well-drained soil with a high pH (6.0 to 7.0). The most desirable periods for planting are early April to late May or late July to mid-August. The recommended seeding rate is 14 pounds per acre. Alfalfa grows tall enough to become difficult to incorporate if allowed to overwinter from a spring seeding. The cost of alfalfa seed is much greater than the cost of clover seed. It is recommended that alfalfa seed be inoculated when seeded on an area for the first time.

### *Buckwheat*

Buckwheat can be seeded successfully on sites with low soil pH. While there is fast growth of the top portion of this grain, there is little organic matter contribution from the roots. The plants should not be allowed to mature, since reseeding will readily occur. Early seedings in late May or early June are better than summer seedings in late July. Buckwheat may be seeded at 60 pounds per acre.

### *Canola/Rape/Brassicas*

Mustards are becoming increasingly popular as a preplant cover crop because they contain certain chemicals (allyl isothiocyanates) that suppress weeds, nematodes, and soilborne pathogens. They also have an extensive root system. Grass suppression is notable with a *Brassica* cover. Varieties and species with a high glucosinolate content (*Brassica nigra* and *B. juncea*) are preferable over those bred for oil production. Mustards are adapted to cool, wet conditions and are easily established if they are planted in late August and weed pressure is not too severe. Once established, they can outcompete many weeds because of their exceptional cold-hardiness. A seeding rate of 2 to 4 pounds per acre is recommended.

### *Alsike, Ladino, and White Clovers*

All of these clovers have low to moderately upright growth and tend to establish a good legume stand in about ten weeks. Alsike clover, a very short-lived perennial, can be established in low-pH soils. Ladino and other common white clovers respond to high soil fertility (notably phosphorus) and high soil pH. All of these clovers are fair to moderately good nitrogen-producing crops. They establish best when seeded in early April to late May or from late July to mid-August. Early seedings in either season are more successful. A late fall or late winter broadcast application to open ground may be another effective method of seeding these crops, depending on the soil-seed contact that follows.

The cost of seed varies with the type of clover. Common white clover and alsike clover are cheaper than ladino. The cost of seed per acre is low for clover preplant cover crops, since the recommended seeding rate is only 4 pounds per acre for alsike and common white clover and 2 pounds per acre for ladino. Volunteer clovers grow naturally in most fields, so it may not be necessary to inoculate clover seed. However, several pounds of seed can be treated with inoculant for only a few dollars.

### *Red Clover*

Red clover produces a top growth of 12 to 18 inches and establishes relatively quickly, depending on soil moisture and seed bed conditions. Red clover grows best in a soil pH of 5.6 or higher. Like other clovers, red clover should be seeded in early April to late May or from late July to mid-August. Early seedings in either season are more successful. As with white clovers, a late fall or late winter broadcast application on open, unfrozen soil may produce a successful seeding. Red clover is a good nitrogen-producing crop and is adapted to a broader range of soil conditions than alfalfa. The seeding rate for red clover is 8 pounds per acre.

### *Sweet Clover*

Sweet clover is a slow- to moderately fast-establishing biennial legume that responds better to higher soil pH than other clovers. It also responds well to soils with good phosphorus levels and is most easily established when seeded from early April to mid-May or during the first half of August. Large, deeply penetrating roots and heavy top growth make large contributions of nitrogen and organic matter to the soil when incorporated. Second-year top growth may exceed 50 inches. However, this growth must be cut at a lower height and incorporated after cutting. The seeding rate is 12 pounds per acre.

### *Fescues*

The fescues are perennial cool-season grasses that are adapted to a wide range of soil types and pHs (although a pH of 6 to 7 is best). They are susceptible to few diseases and insects. They are used as both a preplant and permanent cover crop in fruit plantings, often in combination with white and red clover, or alfalfa. Plantings are made in fall from mid-August to October, with a seeding rate of 20 pounds per acre for pure stands and 10 pounds per acre for a legume mixture. Kentucky 31, the most popular variety of tall fescue, is quick to establish. When provided with nitrogen, it grows vigorously and outcompetes most weedy species. Sheep fescue and red fescue are two less vigorous types of fine-leaf fescues used for permanent covers.

### *Annual Field Brome*

This fast-establishing winter annual grass has a much more extensive and fibrous root system than most other green manure crops. Seedings made during July and August tend to be much more successful than seedings made in late spring. The following year's spring growth is rapid and, after the seeds ripen in July, the crop will die. If the soil is disced when the seeds start to fall, the crop can be easily reestablished with no further seeding. Since this is not desirable with a preplant cover crop, thoroughly disc or plow down the heavy root system early in the spring. This seed is not readily available, so plans for obtaining it should be made well in advance of the seeding date. Annual field brome is usually seeded at a rate of 20 pounds per acre.

### *Hairy Vetch*

This legume is adapted to a range of soil conditions. It is a moderately fast-growing winter annual when seeded in August or very early September. In the Northeast, the best practice to ensure good growth is early establishment. This vetch can supply much nitrogen to the soil when grown under ideal conditions. In the mid-Atlantic states, hairy vetch can provide up to 125 pounds of nitrogen for the next crop. Hairy vetch is a true vetch with purple flowers and viny growth, and it should not be confused with another legume known as crown vetch, which is commonly seeded along highways for bank establishment. Hairy vetch is seeded at a rate of 40 pounds per acre.

### *Marigolds*

Marigold is a relatively new cover crop that has generated much interest among strawberry growers for its ability to suppress weed and nematode populations. Marigolds are used as a preplant cover crop in Northern Europe and to some extent in North America. A warm-season crop, marigold germinates only when soil temperatures exceed 65˚F. Plants do not have to flower to pro vide benefits, and they can be plowed under after growing for ninety days or more. Little is known about the suitability of various varieties of marigold as a preplant cover crop.

Use open-pollinated seed rather than the expensive hybrid seed. Open-pollinated seed currently sells for about \$30 per pound. Seed at the rate of 5 pounds per acre and shallowly incorporate the seed to a depth of $^1/_2$ inch. Overhead irrigate to promote germination.

### *Japanese Millet*

Japanese millet is a fast-growing summer annual that competes well with weeds and establishes faster on cooler soils than sudan grass. If planted between late May and mid-July, millet will grow 4 feet high in seven to eight weeks. Unlike small-seeded legumes and grasses, the large millet seed should be covered with $^3/_{10}$ to 1 inch of soil in a firm seedbed. The planting may be cut back and allowed to regrow at any time after reaching 20 inches of growth. Millet should not be allowed to mature and drop seed. Millet seed is relatively inexpensive; seed at a rate of 20 pounds per acre.

### *Spring Oats*

When used as a very early spring green manure crop, oats should be planted in early to mid-April. Because of the fast spring growth, plan to incorporate the planting in early to mid-June. Oats will grow on soils with relatively low pH (5.5) and moderately good fertility; however, this crop requires good soil drainage. A mid-August seeding will provide good growth and ground cover for protection against soil erosion during the fall and winter months. Oats will be gradually killed back by successive frosts and will not grow again in the spring. The dead plant residue is easily incorporated with very light tillage equipment. Three bushels of oats (approximately 100 pounds) are usually seeded per acre.

### *Annual Ryegrass*

Annual ryegrass seedings establish very rapidly in spring or late summer. Ideal dates for spring seedings range from early April to early June; late summer seedings are more successful when made from early August to early September. Heavy root growth and rapid seeding development make annual ryegrass a very desirable green manure cover crop in areas when good soil-water relations can be maintained. Ryegrass will die out early in the second year, leaving a heavy root system and a moderate top growth residue to incorporate into the soil. A seeding rate of 30 pounds per acre is suggested.

### *Perennial Ryegrass*

Seedings of perennial ryegrass become established more quickly than seedings of other common perennial grasses such as timothy, bromegrass, and orchard grass. The fibrous root system is extensive and, with the vigorous top growth, provides substantial material for incorporation into the soil in early spring. The dry matter root growth of perennial ryegrass is approximately equal to the top growth. For many other crops, the top growth represents 60 to 70% of the material turned under at plowing. A seeding rate of 25 pounds per acre is recommended.

### *Winter Rye*

Winter rye, a cereal grain, establishes quickly from late summer and early fall seedings. However, fall seedings made after October 1 are likely to provide only winter cover and are slower to produce heavy spring growth. Excessive early spring top growth can create tillage problems if the crop is not incorporated by early to mid-May. This date will vary with the location and season. The seed is readily available and is usually sold in bushel quantities of 56 pounds. Use a seeding rate of 2 bushels per acre to establish.

### *Sudan Grass*

Sudan grass is a summer annual that requires much heat for good growth. Seedings made in late May or early June will guarantee a more vigorous growth than seedings made in late June or early July. Hybrid sudan grasses may have larger seeds and should be planted at heavy rates. Like millet and sorghum-sudan hybrids, which also have large seeds, sudan grass should be seeded to a depth of $^1/_2$ to 1 inch into a firm seedbed. This summer annual will recover after being cut. Because of its tall growth habit, sudan grass should be cut back when growth exceeds 20 to 25 inches or plowed down if a second growth is not desired. Use a seeding rate of 80 pounds per acre.

*Sorghum-Sudan Grass Hybrids*

This summer annual requires more heat for growth than sudan grass. It is more expensive to establish and fails to adapt to most soils as readily as Japanese millet. This crop will grow to a greater height than sudan grass under ideal conditions of heat, moisture, and fertility; but the 4- to 6-foot growth is very difficult to incorporate with small or moderately sized tillage equipment. Like sudan grass, this crop will make a second growth if climatic conditions permit. Growth will cease by mid-September if night temperatures drop to near freezing. The seeding rate will vary from 35 to 50 pounds per acre, depending on seed size.

## Further Reading

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United States Department of Agriculture (USDA). *Managing Cover Crops Profitably.* 342 Aerospace Center, Washington, DC: Sustainable Agriculture Publications, USDA.

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CHAPTER 3

# Plant Selection

The selection of strawberry varieties available to small fruit growers has increased greatly in recent years, thanks to introductions from both new and established breeding programs. Many varieties have desirable characteristics such as large, glossy fruit and high yields; but many other factors are involved in making a good selection.

Ripening season is one factor. Early-ripening berries tend to bring the highest price in a local market, but they are more susceptible to frost damage and may not provide good yields or produce large fruit. Midseason berries supply the bulk of the market; but there is a great deal of variation in quality, flavor, and growth habit among these varieties. Late-season fruit can be higher quality, but it tends to find a slower market. In all cases, consider where each variety has been developed and how extensively it has been tested prior to release.

Disease resistance should always be an important factor in variety selection. Red stele *(Phytophthora fragariae),* a root rot fungus, is prevalent in many soils, especially those that hold water because of poor drainage. Plant resistance is the primary method to combat this disease. When ordering strawberry plants, give priority to varieties resistant to red stele if you will be planting into a field that is known to be infested. Planting exclusively nonresistant varieties could lead to total crop failure, especially during a wet year.

The performance of an individual variety can vary depending on soil type, fertilization, weather, season, or renovation practices. For example, some varieties develop an off flavor under high temperatures. Others are more tolerant to drought-prone soils, while others grow well only in light soils. Always plant several varieties to stretch out the marketing season and reduce disease and frost problems.

Evaluate the performance of new varieties in small test plantings before placing large orders for plants. Progressive growers provide samples of new varieties to customers for feedback. Often a berry will perform well for the grower, but the customer does not like the flavor. Ultimately, the superior taste and flavor of eastern berries motivate the consumer to buy locally.

The predominant plant type is the dormant crown. These are dug in the fall (or early spring) and shipped in the spring with bare roots. They must be kept cold until planting. These plants are usually one to three generations removed from tissue culture. Strawberry plants direct from tissue culture are too vigorous and vegetative to be used for fruit production. Fresh-dug and plug plants are available for some varieties for the fall-planted annual plasticulture system (see chapter 4).

Always order plants from a nursery that offers certified virus-tested material; this indicates that plants are free of common viruses that may decrease productivity. Propagation from fruiting fields is not recommended, because the disease status of the plants is unknown.

Not all available varieties are listed in this chapter. Those listed are widely used by growers throughout the northeastern United States and eastern Canada, are increasing in acreage, or appear to be the most promising. Varieties declining in acreage are not listed. Characteristics of the varieties listed here are summarized in table 3-1 on page 17.

# Strawberry Variety Descriptions

## *June-Bearing*

### *Early Season*

**Annapolis** [(Micmac x Raritan) x Earliglow]: From Nova Scotia in 1984. This variety has a compressed ripening season. Fruit are large, globose, and somewhat soft with a light color and mild flavor. Plants are very vigorous, producing lots of runners. Plants are resistant to red stele but very susceptible to powdery mildew.

**Cornwallis** (Earliglow x Kent): From Nova Scotia in 1984. This variety is very productive and matures three days after Earliglow. Fruit are medium-sized and attractive with good flavor and a glossy, red color. Plants are vigorous and produce many runners. Plants are resistant to red stele.

**Earliglow** [(Fairland x Midland) x (Redglow x Surecrop)]: From the U.S. Department of Agriculture in Maryland in 1975. Recognized throughout the Northeast and Midwest as a superior commercial variety, Earliglow produces an early, symmetrical berry of exceptionally high quality. The fruit is firm with excellent flavor and color throughout and freezes well. Yields may be low because fruit size tends to decrease as the season progresses. Plants are vigorous runner producers and somewhat resistant to gray mold, red stele, and *Verticillium* wilt diseases. They are susceptible to powdery mildew and leaf spot.

**Mohawk** (MDUS 4587 x Earliglow): From the U.S. Department of Agriculture in Maryland in 1994. This is a high-quality variety with large, firm fruit that have a good, sweet flavor but somewhat asymmetrical shape. Plants are vigorous and cold-hardy and resistant to red stele and *Verticillium* wilt. Mohawk ripens with Earliglow.

**Northeaster** (MDUS 4380 x Holiday): From the U.S. Department of Agriculture in Maryland in 1994. Northeaster is a uniquely flavored berry with a strong aroma. Fruits ripen about three days after Earliglow and are large, light red in color, and firm. Plants are adapted to heavier soils and resistant to red stele and *Verticillium* wilt but susceptible to powdery mildew. This variety exhibits high vigor with heavy foliage.

**Veestar** (Valentine x Sparkle): A Canadian introduction from Ontario in 1967. The conical fruits tend to have a dark flesh color and are soft. Plants are vigorous but have no resistance to red stele and only moderate resistance to *Verticillium* wilt. This variety is used primarily in southern Canada for pick-your-own markets and jam production.

### *Early/Midseason*

**Cavendish** (Glooscap x Annapolis): From Nova Scotia in 1990. This is a highly productive variety with large, firm, dark red, glossy fruit and good flavor but an uneven ripening habit (white shoulders) in hot weather. Fruit does not store well but is suitable for pick-your-own markets. Plants are moderately vigorous and resistant to red stele and *Verticillium* wilt but susceptible to powdery mildew.

**Delmarvel** (Earliglow x Atlas): From the U.S. Department of Agriculture in Maryland in 1994. These berries are highly flavored and aromatic with dark red flesh, symmetrical shape, and firm skin. Fruit size is large but decreases as the season progresses. The fruiting season is more compressed than with most varieties. In some years, pollination of the berry tip may be poor. Plants are vigorous and productive and resistant to red stele and anthracnose.

**Honeoye** (Vibrant x Holiday): A 1979 New York release that is among the most widely planted and highest yielding varieties in northern climates. This variety is generally early ripening and very high yielding, and its fruit size is maintained throughout the season. The fruit is firm and attractive with somewhat recessed seeds but may develop a sugar-acid imbalance (that is, high acid content and low sugar content), which results in poor flavor. Also, off flavors may develop under high temperatures during ripening. Under cooler conditions, fruit quality is good. Plants are vigorous and winter hardy and produce many runners. Honeoye is very susceptible to soil diseases and is intolerant of wet soils.

**Kent** [(Redgauntlet x Tioga) x Raritan]: From Nova Scotia in 1981. This is the most widely grown variety in eastern Canada. Plants are very high yielding with large, attractive fruit that have a mild flavor and good postharvest qualities. Plants are vigorous and good runner producers, but beds tend to run down after two or three seasons. Kent is susceptible to red stele, *Verticillium* wilt, and leaf spot.

**Lester** (Raritan x MDUS 3413): From Maryland (U.S. Department of Agriculture) in 1985. This variety produces large, firm fruit with good color and flavor. Berries are excellent for shipping. Plants are vigorous, moderate runner producers but may lack adequate hardiness for northern New England. This variety is resistant to red stele and *Verticillium* wilt.

**Primetime** [Sunrise x (Redchief x Guardian)] x Earliglow: From Maryland (U.S. Department of Agriculture) in 1995. This variety produces large, conic-shaped, very light red, attractive fruit with medium firmness and a mild acidic flavor. Plants are high-yielding across a range of soil types and are resistant to red stele but susceptible to leaf diseases, especially powdery mildew.

**Raritan** (Redglow x Jerseybelle): From New Jersey in 1968. This variety produces attractive, medium-sized fruit with excellent flavor but poor freezing quality. Raritan requires good water management. Plants are fairly vigorous but may lack adequate hardiness for northern New England. This variety is very susceptible to red stele and *Verticillium* wilt.

### *Midseason*

**Governor Simcoe** (Guardian x Holiday): From Ontario in 1985. Governor Simcoe produces large, light red, sweet, flavorful berries with a uniform, blunt, conic shape. Plants are adapted to lighter soils and have no resistance to root diseases or powdery mildew. This variety is widely grown in Ontario because of its quality and light red color. Berries have a good postharvest appearance.

**Guardian** (NC 1768 x Surecrop): From Maryland (U.S. Department of Agriculture) in 1969. Berries are large, rough in appearance, and sometimes hollow. They are light red to orange in color with fair flavor and freezing quality. Plants runner well and are resistant to red stele and *Verticillium* wilt.

**Redchief** (NC 1768 x Surecrop): Released from Maryland (U.S. Department of Agriculture) in 1968. Fruit are glossy, attractive, and medium-sized with moderate texture and flavor. Plants are vigorous and productive but prefer heavier soils. They are resistant to red stele and *Verticillium* wilt.

**Scott** (Sunrise x Tioga): From Maryland (U.S. Department of Agriculture) in 1979. Fruit are large and light-colored with mild flavor. Plants are vigorous runner producers but may lack adequate hardiness for northern New England. They are resistant to red stele and *Verticillium* wilt and perform well in heavier soils.

**Settler** (Guardian x Holiday): From Ontario in 1986. This variety produces large, moderately firm, flavorful, light red fruit and adapts to growth in heavier soils. It is not resistant to root diseases.

### *Mid/Late Season*

**Allstar** (complex parentage): From Maryland (U.S. Department of Agriculture) in 1981. Berries are large, conical, and light red to orange in color with a mild, sweet flavor. The plants are vigorous and produce many runners. Allstar is a very dependable producer, and the berries ship well. Plants are resistant to red stele and *Verticillium* wilt but tend to be susceptible to gray mold.

**Glooscap** (Micmac x Bounty): From Nova Scotia in 1983. Fruit are medium to large, firm, and very dark red with good flavor. Plants are highly productive and very winter hardy but susceptible to red stele and *Verticillium* wilt.

**Jewel** (NY 1221 x Holiday): From New York in 1985. Jewel is among the most widely planted varieties in the northeastern United States. It produces large, glossy, attractive fruit with firm texture and excellent flavor. Berries are good for freezing and jams and have excellent postharvest qualities. Size is maintained throughout the season, and production is high. Plants have moderate vigor and runner production, so renovation should be less vigorous than with other varieties. Plants have no resistance to red stele or *Verticillium* wilt but are resistant to leaf diseases.

**Micmac** (Tioga x Guardsman): A Nova Scotia introduction in 1976. Plants produce good yields of large, light red, firm fruit with good flavor. Plants are vigorous and produce many runners but have no known resistance to red stele or *Verticillium* wilt.

**Seneca** (Holiday x NY 1261): A 1991 release from New York. This is a high-yielding variety with large, blunt, conically shaped, bright red, firm fruit with wide shoulders. Fruit is somewhat acidic with a mild flavor. Plants are moderately vigorous and have no resistance to red stele or *Verticillium* wilt.

**Sparkle** (Fairfax x Aberdeen): These fruit have excellent flavor, a dark red color, and very soft flesh. Fruit size tends to decrease as the season progresses. Plants are vigorous, copious runner producers and have some resistance to red stele. This variety is an old-time favorite but is too soft for the commercial market.

**Startyme** (V77053 x GU66Q50) From Ontario in 1995. These large, pale red fruit are easy to hull and somewhat soft with mild flavor and good postharvest qualities. Plants are large and vigorous but have no known resistance to red stele or *Verticillium* wilt. This variety is narrowly adapted to the Lake Ontario region.

### *Late Season*

**Bounty** (Jerseybelle x Senga Sengana): A 1972 release from Nova Scotia. The fruit are dark red with good flavor, but they are small in size—especially later berries. Plants show good vigor and runner production but have no resistance to red stele or *Verticillium* wilt. This variety is used primarily for pick-your-own markets and jam making.

**Idea** (79-12-13 x Etna): From the Italian breeding program in Cesena. This is the latest ripening commercial June-bearing variety available. It produces large, orange, flavorful fruit. It is resistant to red stele and tolerant of anthracnose but susceptible to leaf diseases.

**Lateglow** (Tamella x MDUS 3184): From Maryland (U.S. Department of Agriculture) in 1988. This variety produces medium to large, bright red, attractive, firm fruit with good flavor. Plants are vigorous and resistant to red stele and *Verticillium* wilt. This variety may lack adequate hardiness for northern New England and eastern Canada and lacks resistance to anthracnose fruit rot.

**Latestar** (Lateglow x Allstar): From Maryland (U.S. Department of Agriculture) in 1995. Fruit are large with firm, light red skin and mild flavor. Plants are very productive and resistant to red stele and leaf diseases. Plants do not produce many runners, so they may require a closer plant spacing. Latestar is among the latest to ripen.

**Vesper** (Utah Shipper x Jerseybelle): Released in 1962 from New Jersey. Fruit are very large, dark red, and soft with good flavor. Plants are relatively weak and produce few runners. This variety has no resistance to red stele or *Verticillium* wilt.

**Winona** [Earliglow x (Lateglow x MDUS 4616)]: Released in 1996 from Minnesota. This variety is resistant to five races of red stele and has performed well in black root rot–infested soils. It is not susceptible to leaf diseases. Fruit is bright orange-red and firm with a conical shape and good flavor. Berries hold their large size well during the season. Plants have good winter hardiness.

## *Dayneutrals*

**Evita:** From Italy. This productive plant produces moderately sized fruit that are light red in color and have good flavor. Fruit may be soft under hot conditions.

**Tribute:** From Maryland (U.S. Department of Agriculture) in 1981. Berries are firm and rounded and reach full flavor one or two days after turning red. Plants are resistant to soil diseases but susceptible to leaf diseases.

**Tristar:** From Maryland (U.S. Department of Agriculture) in 1981. This sibling of Tribute produces smaller but more conical and flavorful berries. Plants are susceptible to leaf diseases but resistant to soil diseases.

## *Annual Varieties*

Chandler and Camarosa (from California) and Sweet Charlie (from Florida) were developed specifically for annual plasticulture and are used for annual strawberry production even in the Northeast. Each of these varieties produces large fruit that is easy to harvest and, when allowed to ripen fully, has very good flavor. Camarosa is the most flavorful of the group. Sweet Charlie appears to ripen earlier than the other two by about one week and is anthracnose-resistant. Chandler is an older but widely adapted variety and is the standard variety for annual systems in the East.

Although less winter hardy than the typical perennial varieties, these annuals can overwinter in the Northeast when cared for properly. Many of the northern varieties described above are suitable for use in the annual plasticulture system. See chapter 4 for more information about annual plasticulture.

**Table 3-1.** Ratings of varieties for important characteristics (1 = top ranked, 2 = average, 3 = bottom ranked)

| Variety | Flavor | Yield | Berry Size | Firmness | Resistance To Leaf Diseases | Resistance To Root Diseases |
|---|---|---|---|---|---|---|
| Annapolis | 2 | 2 | 1 | 3 | 3 | 1 |
| Allstar | 1 | 2 | 1 | 1 | 1 | 1 |
| Bounty | 2 | 1 | 3 | 3 | 2 | 3 |
| Cavendish | 2 | 1 | 1 | 3 | 1 | 1 |
| Cornwallis | 2 | 2 | 2 | 2 | 2 | 1 |
| Delmarvel | 1 | 3 | 2 | 2 | 1 | 1 |
| Earliglow | 1 | 3 | 3 | 2 | 3 | 1 |
| Evita | 1 | 3 | 2 | 3 | 3 | 3 |
| Glooscap | 3 | 2 | 1 | 2 | 2 | 3 |
| Governor Simcoe | 1 | 2 | 2 | 1 | 2 | 3 |
| Guardian | 2 | 2 | 2 | 2 | 1 | 1 |
| Honeoye | 3 | 1 | 2 | 2 | 1 | 3 |
| Idea | 2 | 2 | 1 | 2 | 3 | 2 |
| Jewel | 1 | 1 | 1 | 1 | 1 | 3 |
| Kent | 2 | 1 | 2 | 2 | 3 | 3 |
| Lateglow | 2 | 2 | 2 | 2 | 2 | 1 |
| Latestar | 2 | 2 | 1 | 1 | 1 | 1 |
| Lester | 2 | 2 | 1 | 2 | 2 | 1 |
| Micmac | 2 | 1 | 2 | 2 | 1 | 3 |
| Mohawk | 1 | 2 | 2 | 2 | 2 | 1 |
| Northeaster | 1 | 3 | 2 | 1 | 2 | 1 |
| Primetime | 3 | 2 | 1 | 2 | 3 | 1 |
| Raritan | 1 | 3 | 2 | 3 | 2 | 3 |
| Redchief | 2 | 2 | 2 | 2 | 1 | 1 |
| Scott | 2 | 2 | 2 | 1 | 2 | 1 |
| Seneca | 3 | 2 | 1 | 1 | 2 | 3 |
| Settler | 2 | 2 | 1 | 2 | 2 | 3 |
| Sparkle | 1 | 3 | 3 | 3 | 3 | 2 |
| Startyme | 3 | 2 | 2 | 2 | 2 | 3 |
| Tribute | 2 | 3 | 3 | 2 | 3 | 1 |
| Tristar | 1 | 3 | 3 | 2 | 3 | 1 |
| Veestar | 3 | 3 | 3 | 3 | 2 | 3 |
| Vesper | 2 | 2 | 1 | 3 | 2 | 3 |
| Winona | 2 | 2 | 2 | 1 | 1 | 1 |

CHAPTER 4

# Production Systems

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

Which system you should choose depends on the time of year you wish to produce strawberries, the quality of the market in your area (Are consumers willing to pay top dollar for high-quality, off-season produce?), and your aversion to risk. Several options are presented in this chapter with their advantages and disadvantages. Consider each one carefully.

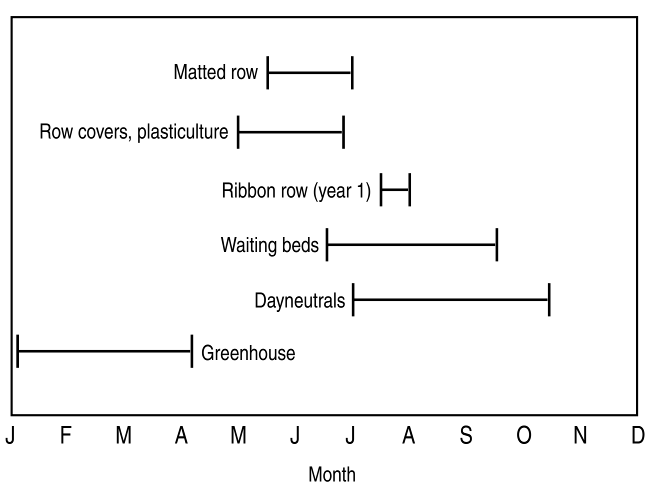

Figure 4-1. Production methods and seasons

## The Matted Row System

### *Synopsis*

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

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

### *Details*

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

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

TABLE 4-1. Planting year summary schedule

| ACTIVITY | APPROXIMATE TIMING |
|---|---|
| Plant dormant crowns | April or May |
| Weed control | May |
| Remove flowers | June or July |
| Fertilize | June |
| Position runners | July through September |
| Weed control | August |
| Fertilize | September |
| Weed control | November |
| Mulch | late November |

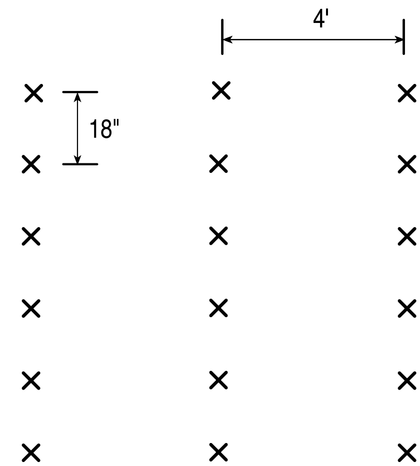


FIGURE 4-2. Spacing diagram for the matted row system

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

**SINGLE ROWS**

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

**DOUBLE ROWS**

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

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

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

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

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

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

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

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

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

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

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

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

**Table 4-3.** Renovation summary schedule

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

### *Organic Matted Rows*

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

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

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

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

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

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

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

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

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

## The Ribbon Row System

### *Synopsis*

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

### *Details*

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

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

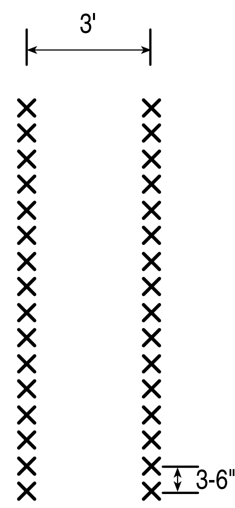


**Figure 4-3.** Spacing diagram for the ribbon row system

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

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

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

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

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

### *No-Till Strawberries*

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

## Waiting Beds

### *Synopsis*

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

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

### *Details*

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

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

## Annual Plasticulture

### *Synopsis*

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

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

## *Details*

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

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

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

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

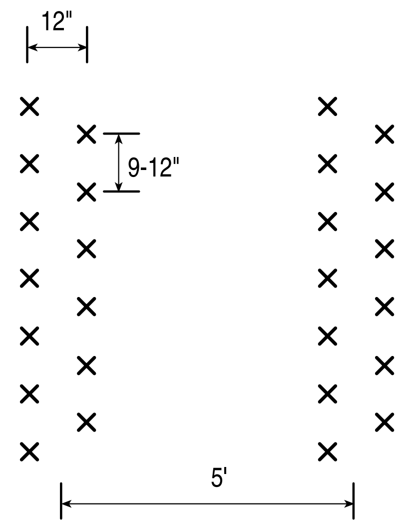


**FIGURE 4-4.** Spacing diagram for the annual plasticulture system

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

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

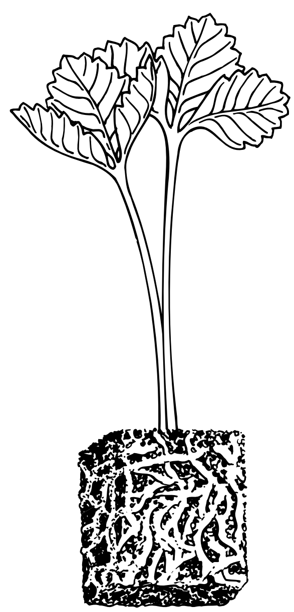

**FIGURE 4-5.** Plug plant

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

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

Purchase plug plants directly from nurseries (although varieties are limited), or produce them on the farm. Collect runner tips in the field in July and hold them at 32°F under high humidity in plastic bags. Tips should have one or two leaves with roots less than $^3/_8$ inch long. Place the tips into plug trays filled with potting soil in a shaded greenhouse, and keep them under intermittent mist for about seven to twelve days until rooting occurs.

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

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

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

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

By spring, flowers have been initiated. They will develop over the next several months. Soluble calcium nitrate has proven to be a good nitrogen source during this period. Apply it weekly at $3^1/_2$ pounds per acre nitrogen for a total of eight weeks. Bear in mind that excessive nitrogen reduces the flavor of Chandler and produces tall, lush plants that are more prone to disease.

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

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

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

## Dayneutral Strawberries

### *Synopsis*

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

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

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

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

### *Details*

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

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

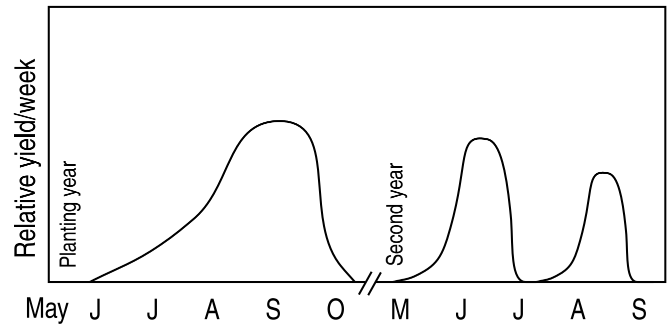


**FIGURE 4-6.** Production cycle of dayneutral strawberries

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

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

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

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

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

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

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

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

### *Pests*

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

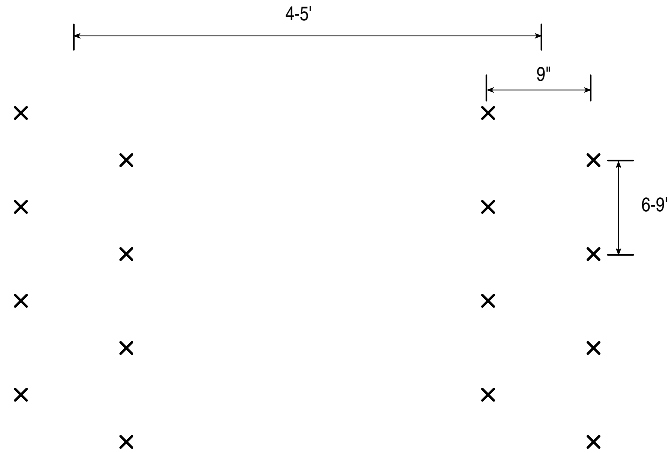


**Figure 4-7.** Spacing diagram for dayneutrals

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

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

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

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

### *Harvest*

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

### *Overwintering and Second-Year Production*

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

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

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

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

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

### *Special Problems*

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

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

## Plastic Tunnels and Greenhouses

### *Synopsis*

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

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

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

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

## Details

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

### Plastic Tunnels

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

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

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

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

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

### Day Length–Insensitive (Dayneutral) Varieties in Greenhouses

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

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

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

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

## Greenhouse Management

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

### Lighting/Heating

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

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

### *Vertical Hydroponic Systems*

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

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

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

### *Fertilization/Irrigation/Growing Media*

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

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

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

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

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

### *Pollination*

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

### *Pest Management*

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

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

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

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

## Economics

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

CHAPTER 5

# Temperature Regulation: Mulches, Row Covers, Frost Protection, and Evaporative Cooling

Strawberry growers can enjoy a full crop of berries only if they practice some type of temperature control during the year. Temperature control is especially important during the winter and early spring when flowers are susceptible to frost. Cool spring temperatures can delay growth, flowering, and fruiting. Excessive summer temperatures inhibit growth as well. This chapter describes strategies for temperature management at critical stages during the year.

## Winter Temperatures and Cold Injury

Cold temperatures coupled with high winds can injure strawberry plants during winter, especially if the plants are grown on raised beds. Strawberries are considerably less cold-tolerant than most other fruit crops grown in the Northeast. But because the plants are low-growing and can be protected from the cold by snow cover and/or some type of mulching material, they can be grown on a commercial scale in northern regions.

The severity of winter injury incurred by strawberry plants depends on many factors, some of which have a much greater impact than others. The first group of factors relates to how much cold tolerance the plants develop. The cultivar, plant nutritional status, plant age, and autumn hardening conditions such as temperature, moisture, and light all affect a plant's tolerance to cold. Other factors directly influence the amount of injury during or immediately after the hardening process. These include the timing and severity of minimum temperatures, the rates of temperature change, repeated freezes, the amount of snow cover, the type and amount of mulch used, and the type of cultural practice being implemented (for example, raised beds versus conventional beds). Each of these factors is discussed in more detail in the following sections.

### *Plant Acclimation and Cold Tolerance*

Strawberry plants acclimate to cold over a six- to eight-week period in the autumn in response to shortening day lengths and lower temperatures (figure 5-1). With most cultivars, plant injury begins when the crown temperature (not air temperature) reaches 23°F, and death can occur if the crown temperature drops to 4°F. Within this temperature range (4° to 23°F), the amount of injury increases and subsequent yield decreases proportionally with decreasing crown temperature.

### *Cultivar Hardiness*

Differences in hardiness among cultivars are slight—the crown temperatures at which injury occurs vary by only a few degrees. In some years, however, a few degrees

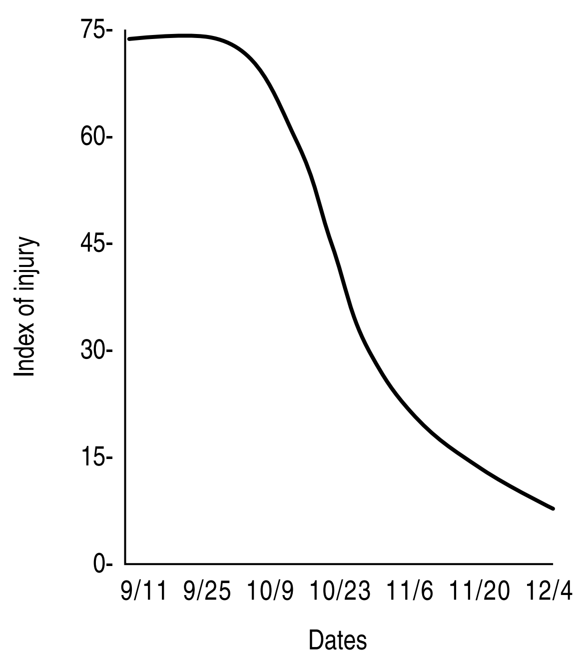


**Figure 5-1.** Seasonal acclimation of strawberries to cold temperatures

may result in a substantial change in yield. Field observations and laboratory studies have shown that some of the hardier cultivars include Honeoye, Jewel, Kent, Catskill, Sparkle, Micmac, Cornwallis, and Bounty.

## *Time of Injury*

Although cold injury may occur any time during the late fall, winter, or early spring, it is frequently associated with lack of snow cover during winter. Plants are usually injured after the ground is frozen. Straw mulches that offer good protection when first applied lose much of their insulating value if they become matted down or filled with ice. Likewise, low areas in a field may collect standing water that will create a layer of ice if it freezes. Since ice is not a good insulator, the plants in these areas would be more prone to winter injury.

## *Symptoms of Injury*

Strawberry plants respond to winter injury in several ways, depending on the severity of the injury. Tissue discoloration or the degree of browning revealed by cutting crowns longitudinally is often used as a field indicator of the seriousness of injury (photos 5-1 and 5-2). Injury begins with browning of the cells at the base of the crown. As the amount of injury increases, the browning extends toward the top of the crown and becomes more intense in color. The last tissues to be killed are the leaf primordia (the small leaves that are just beginning to develop in the crown) and the vascular tissue. A slight amount of browning may cause reduced leaf size, deformed leaves, reduced blossoms, or smaller fruit. These latter symptoms may go undetected if the injury is mild.

Controlled freezing studies have shown that reduced yields can occur even with only a slight amount of browning. In a laboratory study using Catskill, one of the older but hardier cultivars, injury was detected at a crown temperature of 23˚F, and the number of blossoms was reduced by about half at a crown temperature of 18˚F.

## *Snow Cover*

Strawberry plants are not very winter-hardy, so they must be protected from the cold in northern regions. Although snow cover is by far the best protection, it is not dependable in most areas, so mulches are used to keep winter injury to a minimum. Snow depths over 6 to 8 inches usually keep crown temperatures sufficiently warm, even when air temperatures drop as low as –25˚F. Cold, desiccating winds are extremely harmful to uncovered strawberry plants. Take measures to reduce wind (for example, erect snow fences) to help avoid winter injury.

## *Mulching*

Mulching plants in late fall is the only practical way to prevent cold injury. Grain straw mulches are the most common. Other materials—such as black and clear plastic, spun-bonded row covers, and artificial snow—have also been used as winter mulches. Although these materials can reduce winter injury, they do not have thermal properties as good as straw. Rye and sudan grass straw are satisfactory, but wheat straw is usually preferred because it is more resistant to compaction. Oat and barley straw tend to break down quickly and provide little insulation. Straw also helps hold the snow, particularly on raised beds where snowfalls are subject to drifting. During the production season, straw mulch prevents soil from splashing on the developing fruit, which reduces culls and the incidence of leather rot.

Straw should be clean and free of any seeds. Strawberry growers often produce their own straw and bale it before seeds form. Straw mulch is applied over the tops of strawberry rows, usually with machines that chop the straw and spread the mulch. Newer machines can accommodate large, round bales (photo 5-3) rather than just small, rectangular bales. The objective is to cover plants with enough straw to prevent desiccation of the crown (photo 4-9). A minimum of 2 to 3 tons per acre (a 2- to 3-inch layer) is recommended in areas with regular snowfall and moderate temperatures, but 4 to 5 tons may be necessary in cold, windy climates or where plants are grown on raised beds (which tend to be colder).

Row covers (photo 4-19) can be used for winter protection along coastal areas of New Jersey south through the Carolinas and are essential for overwintering annual plasticulture strawberries in the Northeast. For the most part, however, row covers provide insufficient protection during midwinter in most areas of the Northeast and Midwest unless snow cover is dependable.

### *Mulch Application*

Strawberry leaves are photosynthetically active well into late autumn (figure 5-2) and in early spring as well. Because straw mulch is opaque, do not apply it too early in autumn or remove it too late in spring, as this would compromise the plant's ability to manufacture carbohydrates. Do not apply mulch while the plants are in their hardening process, either, or they may not acclimate properly. About the time strawberry plants are acclimated, the leaves attached to the crown begin to flatten. Wait until after several frosts occur and the leaves flatten before mulching. Mulch must be applied before tempera-

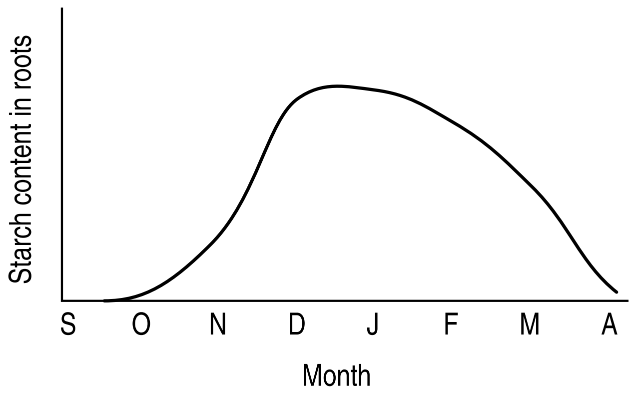


**Figure 5-2.** Seasonal pattern of starch content in roots

tures become cold enough to cause injury and before snow cover makes applying it impractical. In most northern locations, this is usually the last of November. Delaying mulching until just before the ground freezes results in the highest yields.

### *Mulch Removal*

Move mulch from the top of plants to the row middles in the spring. Although the primary purpose of mulch is winter protection, it also keeps the fruit clean. Leave enough mulch around the plants so the berries will not touch the soil. The plants will grow through a light layer of straw. Placing mulch between the rows also helps control weeds, conserves soil moisture, and makes picking more comfortable. Mulch can be removed early in the spring (late March in most northern locations), unless you plan to delay bloom to reduce the possibility of frost damage. In a three-year study where mulch was removed periodically over six weeks, the highest yields came from plants that had the mulch removed as early in the spring as was practical following snow melt (mid-March in Vermont). Removing mulch after April 15 may reduce yield significantly.

## *Care of Injured Plants*

Cold injury reduces the number of fruit on a plant and adversely affects fruit size. Any additional stress suffered by injured plants during the fruiting year will magnify the problem. Once injury occurs, the number of fruit cannot be increased, but further losses can be minimized by providing ample moisture and controlling weeds, insects, and diseases. Supplemental fertilizer has little impact. Consider the severity of plant injury when deciding whether or not to renovate after harvest.

## Early Spring Temperatures and Row Covers

Synthetic spun-bonded row covers are a useful tool for growers who want to accelerate harvest with a portion of their crop (photo 5-4). Growers often use row covers on early varieties, such as Earliglow, and leave midseason and late varieties uncovered. This extends the harvest season for the June-bearing varieties, in some years to as much as six weeks.

Row covers can provide a degree of winter protection, but for matted row growers, their primary benefit is realized in early spring. Row covers allow light and moisture to penetrate but trap in heat, so the microclimate under the cover is favorable for early growth. With cool, sunny spring weather, row covers can accelerate flowering by up to two weeks with early varieties. Furthermore, most studies have documented yield increases with the use of row covers.

Matted row growers can manage row covers in two ways. The first is to apply an herbicide in autumn, then cover the planting with row cover until spring. Mulching between the rows is done either in autumn before the cover is applied or in spring after the cover is removed. The cover will not provide much insulation, but it will trap heat during the day, and the soil will slowly release the heat at night. In addition, the barrier will provide enough protection to significantly reduce wind speed at crown level. In warmer parts of the Northeast, this strategy can be successful.

The second management strategy is used in colder areas where straw mulch is required for reliable winter protection. If covers are to be used, the mulch must be removed from the plants early and replaced with row cover. Early March is generally a good time to remove straw and apply the row cover. If snow still covers the planting, then obviously it is best to wait until the snow has melted. Similarly, if unseasonably cold weather persists in early March, then wait for warmer weather before removing the straw.

Perhaps the biggest challenge with row covers is applying them. Although they are lightweight, do not attempt to apply them under windy conditions. The material must be firmly anchored around the edges. Many ingenious anchoring devices have been tried, but one successful option is using large U-pins and positioning a popsicle stick between the pin and the cover. The sticks will bend just enough to keep the cover from tearing, and they are inexpensive and easy to install. In windier areas, bags of gravel are the best option. Some growers purchase UV-protected nylon bags, fill them with a small amount of gravel, and use them to anchor the row cover every 6 to 10 feet.

Remove the covers soon after flowers appear; if wind or bees cannot reach the plants, pollination will be reduced and fruit will be deformed. If cold temperatures (less than 30˚F) occur when the covers are still in place and flower trusses have emerged, apply water directly over the covers for frost protection.

Row covers can offer a small degree of frost protection when plants are near bloom, but do not rely on them for complete frost protection, especially if the day preceding the frost event was cold. Irrigation applied directly over row covers will provide remarkable frost protection to the plants underneath. Frost damage can occur under the covers without irrigation, especially when the upright flowers are close to the cover.

Since row covers accelerate flowering, they increase the risk of frost damage. However, this disadvantage is somewhat offset by the extended season of harvest that occurs with row covers. If a short harvest season coincides with a period of rainy weather, harvest results can be disappointing. However, if the same period of rainy weather occurs during an extended harvest, the rain will have less of an impact on total harvest.

Research has shown that row covers can reduce the incidence of tarnished plant bug damage, provided fields are not weedy. If the flowers open before tarnished plant bug adults emerge from surrounding fields, feeding on flowers will be minimal. Strawberry clippers will overwinter within strawberry plantings, especially if weeds are present, so monitor carefully for this insect if it has been a pest in previous years. Covers can make looking for clipped buds difficult.

Covers can be reused several times, although it is difficult to roll the material back into a compact form. Before removing the covers from the field, consider spray painting the edges so they can be found easily. Carefully removing and storing row covers are essential to ensure multiple seasons of use. A word of caution—mice love to overwinter in stored row cover.

Several companies manufacture covering materials. The most useful materials are lightweight (0.5 to 1.5 ounces per square yard) and spun-bonded with sewn seams. The cost ranges from $800 to $1,200 per acre. Although this may seem expensive, the cost is not that great if prorated over three to six uses. Many growers find that using row covers on at least a portion of their acreage is a profitable choice, because they receive a higher price for early berries and yields are generally higher.

## Spring Frost Protection

Of all the factors that negatively affect strawberry production, frost is the most serious. Frost can eliminate an entire crop almost instantly. Strawberries often bloom before the last frost, and if a frost occurs during or just before bloom, it can cause significant loss. The strawberry flower opens toward the sky, which makes it particularly susceptible to frost damage. A black rather than yellow flower center is an indicator of frost damage (photo 5-5).

Strawberry growers occasionally delay removing straw mulch in spring to delay bloom and avoid frost. Research has demonstrated, however, that this results in reduced yields. Also, applying straw between the rows just before bloom will insulate the soil from the air. This will increase the incidence of frost injury, because it prevents soil from absorbing heat as solar radiation and reradiating it at night. If you plan to apply additional straw between the rows in spring, delay applying it for as long as possible before fruit set.

Overhead irrigation is necessary for frost control, be-cause flowers must be wet during a freeze to be pro-tected. As long as water is present on a flower, the temperature of the ice will stay at 32˚F, because the transition from liquid to ice releases heat. Strawberry flowers are safe from injury until their temperature falls below 28˚F. Because of this 4-degree margin, a strawberry field can be completely covered with ice and yet the plants will sustain no injury from frost (photo 4-11). However, if insufficient water is applied to a field during a freeze, the plants might sustain more injury than they would if no water were applied.

Several principles help explain why ice protects strawberry flowers from injury. First, pure water freezes at 32˚F. But the liquid in the strawberry plant is a solution of sugar and salt, which lowers the freezing point to below 32˚F. Also, ice crystals cannot begin to form without a nucleator, and certain bacteria serve as nucleators. Sometimes the bacteria that allow ice to form are absent in a strawberry flower, which lowers the freezing point.

The temperature of the applied water is usually greater than the temperature of the plants, and this serves to warm the flowers before heat is lost to the air. As long as water is continually applied to the plants, the temperature under the ice will not fall below 32˚F. When 1 gallon of water freezes into ice, 1,172 BTUs of heat are released.

Several factors affect the amount of water required to provide frost protection and the timing of application. At a minimum, apply water at 0.1 to 0.15 inch per hour with a fast rotating head (one cycle per minute). Water must be applied continuously to be effective. A water capacity of 45 to 60 gallons per minute per acre is required to provide this much water. Choose a nozzle size capable of delivering the amount of water needed for frost protection under typical spring conditions in your area (see table 5-1).

### *Wind*

Windy conditions accelerate heat loss from water, so more water is required for frost protection. For every gallon of water that evaporates, 7,760 BTUs are lost. The application rate then depends on both air temperature and wind speed (see table 5-1). Under windy conditions, there is less chance of flower temperatures falling below air temperature because of the mixing of air that occurs at the boundary of the flower. Winds are beneficial if the temperature stays above the critical freezing point but detrimental if the temperature approaches the critical point. Less evaporation (and cooling) will occur on a still, humid night.

Under extremely windy conditions, it may be best not to irrigate because the heat lost to evaporation can be greater than the heat released from freezing.

### *Stage of Development*

Strawberry flowers are most sensitive to frost injury immediately before and after they open. At this stage, temperatures lower than 28˚F will usually cause injury. However, when strawberry flowers are in tight clusters (as when emerging from the crown), they will tolerate temperatures as low as 22˚F. Likewise, once the fruit begins to develop, temperatures lower than 26˚F may be tolerated for short periods.

The length of time that plants are exposed to cold temperatures before a frost also influences injury. Plants exposed to a period of cold temperatures before a frost are more tolerant than those not yet exposed to cold weather. A freeze event following a period of warm weather is most detrimental.

### *Flower Temperature*

The temperature of all flowers in a field is not the same. Flowers under leaves may not be as cold as others, and those near the soil may be warmer than those higher on the plant. On a clear night, the temperature of a flower can be lower than that of the surrounding air. This is because radiational cooling causes leaves and flowers to lose heat faster than it accumulates through conduction from the air.

**Table 5-1.** Water application rate (inches/hour) for a given humidity and wind speed

| | Wind Speed (MPH) | | | | |
|---|---|---|---|---|---|
| **Air Temperature (˚F)** | **0–1** | **2–4** | **5–8** | **10–14** | **18–22** |
| **Relative Humidity of 50%** | | | | | |
| 27 | 0.10 | 0.20 | 0.30 | 0.40 | 0.45 |
| 24 | 0.10 | 0.30 | 0.35 | 0.45 | 0.60 |
| 20 | 0.15 | 0.35 | 0.45 | 0.60 | 0.75 |
| 18 | 0.20 | 0.40 | 0.50 | 0.65 | 0.80 |
| **Relative Humidity of 75%** | | | | | |
| 27 | 0.05 | 0.10 | 0.20 | 0.25 | 0.25 |
| 24 | 0.10 | 0.20 | 0.30 | 0.35 | 0.40 |
| 20 | 0.10 | 0.25 | 0.40 | 0.45 | 0.60 |
| 18 | 0.15 | 0.30 | 0.45 | 0.55 | 0.70 |

*FROSTPRO model from North Carolina State University.*

### *Rules of Thumb*

- store sufficient water for two or three consecutive nights of frost protection
- use small-diameter nozzles ($^1/_{16}$ to $^3/_{16}$ inch in diameter) for better coverage
- preferably use a 30-foot-by-30-foot staggered spacing of nozzles
- use metal sprinklers to minimize icing
- use a minimum rotation of once per minute

Soil also retains heat during the day and releases it at night. On a calm, cloudy night, the air temperature can be below freezing yet the flowers will be warm. Wet, dark soil has better heat-retaining properties than dry, light-colored soil.

## *Using Row Covers*

Row covers modify the influence of wind, evaporative cooling, radiational cooling, and convection (photo 5-4). Wind velocity is lower under a row cover, so less heat is lost from the soil and less evaporative cooling occurs. Relative humidity is higher under a row cover, so less heat is lost from evaporation. Convective heat loss and radiational heat loss are also reduced because of the physical barrier provided by the cover. Plant temperatures under a cover may eventually equal air temperature, but this equilibration takes longer than with uncovered plants. In other words, row covers do not provide additional degrees of protection, but they do buy time on a cold night, because flower temperatures fall slower inside a cover. Often temperatures fall so slowly under a row cover that irrigation is unnecessary. If irrigation is necessary, less water will be needed to provide the same degree of frost protection under a row cover. Water can be applied directly over the row covers to protect the flowers inside.

## *Turning on the Water*

Since cold air falls to the lowest spot in the field, a thermometer should be located there. Place it in the aisle at the level of the flowers, exposed to the sky and away from plants. Air temperature measured at this level can be quite different from the temperature recorded on a thermometer at the back of the house.

The dewpoint temperature measured in the evening is often a good indication of how low the temperature will drop on a clear night. The dewpoint is that temperature at which moisture condenses from the air to form dew. The dewpoint is related to relative humidity: When the air is humid, the dewpoint occurs at a higher temperature than when the air is dry. Once dew begins to form, the air temperature tends to drop more slowly. Frequently, the night temperature drops to the dewpoint, but it does not go much below it.

Air temperature will fall less if the humidity is high. If the air is very dry (there is a low dewpoint), evaporative cooling will occur when water is first applied to the plants, so irrigation must be started at a relatively warm temperature. Table 5-2 shows the recommended temperature for starting irrigation at various dewpoints. Most local weather forecasters can provide the current dewpoint, or it can be obtained from weather information services on the World Wide Web.

If the air temperature falls below 34°F on a clear, calm night, especially before 3:00 A.M., it would be wise to start irrigating since flower temperatures could be several degrees colder. On the other hand, if conditions are cloudy, it may not be necessary to start irrigating until the temperature approaches 31°F. If conditions are windy or the air is dry and if irrigation is not turned on until the temperature approaches 31°F, then damage can occur due to the drop in temperature that occurs when the water first contacts the blossom and evaporates.

The air temperature at which irrigation should start at flowering is normally between 31° and 34°F but can be as high as 40°F. The exact temperature depends on cloud cover, wind speed, and humidity. Admittedly, these numbers are conservative. Flowers can tolerate colder temperatures for short periods of time, and irrigation may

**TABLE 5-2.** Dewpoint and corresponding suggested air temperatures for starting irrigation

| Dewpoint (°F) | Suggested Starting Air Temperature (°F) |
|---|---|
| 30 | 32 |
| 29 | 33 |
| 27 | 34 |
| 25 | 35 |
| 24 | 37 |
| 22 | 38 |
| 20 | 39 |
| 17 | 40 |

be unnecessary if the sun is about to rise. Do not irrigate too soon, since pumping is expensive and excess water in the field can cause disease problems.

### *Turning off the Water*

Once irrigation begins, do not shut it off until the sun comes out in the morning and the ice begins to slough off the plants, or until the ice begins to melt without the applied water.

### *Waterless Frost Protection Agents*

Future solutions to frost protection could lie in waterless methods, such as genetically engineered bacteria that do not promote the formation of ice. However, these materials have not been consistently effective to date, so they are not recommended as the sole basis for frost protection.

## Hot Summer Temperatures and Evaporative Cooling

Strawberry plants can benefit from sprinkling during hot afternoons to reduce stress. Sprinkling is used routinely in hot, arid climates like Australia's to maintain fruit quality (size and firmness) and improve overall plant health. In the Northeast, evaporative cooling benefits plants most in hot, dry years; but even in cool summers, the plant canopy and berries can be kept cooler with evaporative cooling.

Set automated sprinkler systems to apply water during very hot afternoons (greater than 85˚F) for about ten minutes every hour. So as not to promote disease, make the last application early enough so that moisture will evaporate before evening.

CHAPTER 6

# *Water Management*

Strawberry tissues contain a relatively high percentage of water. Roots and stems range from about 75 to 90% water; healthy strawberry fruits contain from 88 to 93% water. Plants require a continuous supply of water throughout the fruiting period. The increase in berry size from fruit set through ripening is due primarily to an increase in cell size, rather than to division of existing cells in the undeveloped fruit. This increase in cell size (called cell expansion) is highly dependent on water availability.

Runner rooting and development also require an adequate, consistent water supply. In the first few weeks of runner establishment, the moisture supply to the mother plant is responsible for the rate and quantity of top growth of the daughter plant. In addition, secondary root growth, which enables the plantlet to acquire independence from the mother plant, is inhibited by either very wet or very dry soil conditions.

Excessive moisture must be avoided as well. Wet soils and plants often encourage disease. Furthermore, strawberry plants that receive excessive moisture produce softer, less flavorful fruit.

## The Need for Irrigation

Strawberries should not be planted without an irrigation system in place. While total rainfall statistics in many regions might prompt one to believe that irrigation is unnecessary, rainfall distribution is often uneven, with long, dry periods occurring in the summer months in most of the eastern and midwestern United States (figure 6-1).

Problems associated with water deficits can occur even during years of normal, abundant rainfall. For high-value crops, irrigation is beneficial even in humid climates and is cheap insurance against catastrophic loss. For example, in the Northeast, there are on average five days between significant rains. In one out of every two years, a ten- to fifteen-day period without rainfall is likely. As a result, just one water application could provide significant yield benefits to strawberries in at least half of the years, particularly if water stress occurs during blossom and fruit set or the berry enlargement period. Periods of twenty to thirty days without significant rainfall may occur two or three times every twenty years somewhere in northeastern North America. A drought lasting this long during the prime growing season would result in catastrophic yield losses. In the upper Midwest, the average number of days between rains is six or seven, and the drought frequency is greater. In the lower Midwest and the South, significant periods of drought occur nearly every year.

In addition, the strawberry plant is shallow-rooted, with up to 90% of its roots located in the top 6 inches of soil.

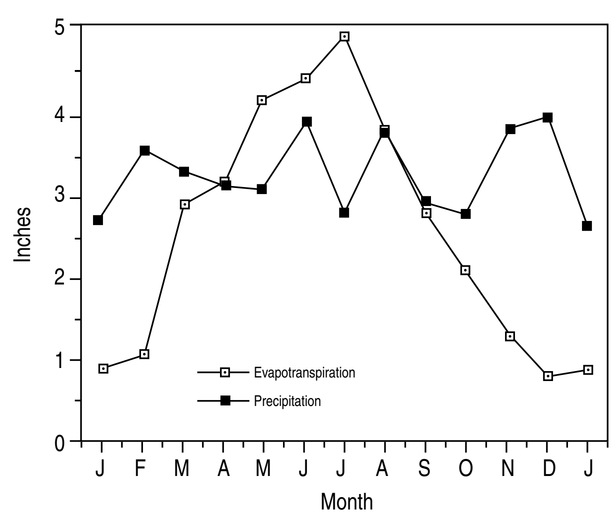


**FIGURE 6-1.** Average monthly precipitation and potential evapotranspiration at Aurora, New York, based on five years of data

This small rooting area holds little moisture, so available water can be depleted within just a few days after a heavy rainfall. Moreover, because the strawberry plant is short in stature, it is not a vigorous competitor with weed species. These factors all contribute to the susceptibility of the strawberry plant to water stress.

Along with soil, markets, and terrain, be sure to consider water management during the initial site selection process to minimize future problems. In many cases, the availability of water for irrigation determines whether a site is suitable for strawberry production.

## Irrigation Systems for Frost Protection, Evaporative Cooling, and Chemical Injection

Irrigation systems for strawberry production are used routinely for frost protection, evaporative cooling, and chemical injection. Separate descriptions of irrigation management for frost protection and evaporative cooling are contained in chapter 5.

### *Chemical Injection*

Any chemical that is soluble in water can be applied through an irrigation system (see table 7-8 on page 65), but most pesticides are not labeled for this application method in strawberries. The exception to this is certain fungicides, which are labeled for injection.

Nutrients, particularly nitrogen fertilizer, are frequently injected through irrigation systems. There are several advantages to this method of nutrient application. It is often less expensive, since the cost is limited to placing the nutrient solution in an injector. The soil compaction that results from driving machinery over a field is avoided as well. Fertilizer distribution is highly dependent on the injector and flow rate used. A comparison of injectors is detailed in table 6-1 on page 40.

Backflow prevention devices are required any time chemicals are injected into irrigation water. These devices can be quite expensive if using municipal water supplies.

## Irrigation Systems for Water Application

Two fundamental types of irrigation systems are used by strawberry growers—overhead and trickle. Overhead irrigation systems apply water to the entire area over the plants, wetting leaves, plants, and soil, and eventually roots (photos 4-8 and 6-1). Overhead systems may be portable, mobile (travelers), or solid-set (static pipe). Many different types of irrigation sprinklers are available, from those that cover a relatively small area to "cannons," which can irrigate as much as an acre at a time. Generally, the larger the area a sprinkler is designed to cover, the less uniformly it will cover the area.

Trickle (drip) irrigation offers the advantage of applying water directly to the soil surface of the planting. In doing so, plants stay dry and less water is lost to evaporation, so irrigation water is used more efficiently. In row crops such as strawberries, the water is most often delivered via a tube that runs along the length of the row. The advantages and disadvantages of trickle and overhead irrigation are outlined in table 6-2 on page 41.

The fact that the plants stay dry with trickle irrigation is a benefit, particularly during fruiting, because free water on the foliage and fruit encourages the development of fungal and bacterial diseases. However, because wetting the flowers is essential for frost control, most strawberry growers use overhead irrigation rather than trickle irrigation. Overhead irrigation systems are also frequently used to cool plants in the summer to avoid stress from excessive heat.

When choosing a system, an important factor to consider is irrigation system efficiency, especially when the water supply is limited or expensive to access. With sprin-

### *Did you know?*

In an extensive study of strawberry farms in Ontario, Canada, researchers concluded that:

- much variability exists between fields on the same farm in their need for irrigation
- rainfall can be variable across fields within a farm
- most growers do not irrigate soon enough after the last rain event to avoid stressing the plants
- most growers do not apply enough water when they irrigate
- irrigating strawberries after renovation is critical for yield and stand longevity

*Source:* Huffman, Harrow Experiment Station, Ontario.

**Table 6-1.** Comparison of various chemical injection methods

| Injector | Advantages | Disadvantages |
|---|---|---|
| **Centrifugal Pumps** | | |
| Centrifugal Pump Injector | Low cost. Can be adjusted while running. | Calibration depends on system pressure. Cannot accurately control low injection rates. |
| **Positive Displacement Pumps** | | |
| Reciprocating Pumps | | |
| *Piston pumps* | High precision. Linear calibration. Very high pressure. Calibration independent of pressure. | High cost. May need to stop to adjust calibration. Chemical flow not continuous. |
| *Diaphragm pumps* | Adjust calibration while injecting. High chemical resistance. | Nonlinear calibration. Calibration depends on system pressure. Medium to high cost. Chemical flow not continuous. |
| *Piston/diaphragm* | High precision. Linear calibration. High chemical resistance. Very high pressure. Calibration independent of pressure. | High cost. May need to stop to adjust calibration. |
| Rotary Pumps | | |
| *Gear/lobe pumps* | Injection rate can be adjusted when running. | Fluid pumped cannot be abrasive. Injection rate is dependent on system pressure. Continuity of chemical flow depends on number of lobes in a lobe pump. |
| Miscellaneous Pumps | | |
| *Peristaltic pumps* | Very low cost. Injection rate can be adjusted while running. | Short tubing life expectancy. Injection rate dependent on system pressure. Low to medium injection pressure. |
| **Pressure Differential Methods** | | |
| Suction Line Injection | Very low cost. Injection rate can be adjusted while running. | Permitted only for surface water source and injection of fertilizer. Injection rate depends on main pump operation. |
| Discharge Line Injection | | |
| *Pressurized mixing tanks* | Low to medium cost. Easy operation. Total chemical volume controlled. | Variable chemical concentration. Cannot be calibrated accurately for constant injection rate. |
| *Proportional mixers* | Low to medium cost. Calibrate while operating. Injection rates accurately controlled. | Pressure differential required. Volume to be injected is limited by the size of the injector. Frequent refills required. |
| **Venturi Injectors** | | |
| Venturi Injector | Low cost. Water powered. Simple to use. Calibrate while operating. No moving parts. | Significant pump pressure required to operate the system. Does not provide a constant parts per million concentration in the irrigation water. |
| **Combination Methods** | | |
| Proportional Mixers/ Venturi | Greater precision than proportional mixer or venturi alone. | Higher cost than proportional mixer or venturi alone. |

*Source:* Haman, et al., *Chemical Injection Methods for Irrigation,* Florida Cooperative Extension Service, 1990.

**TABLE 6-2.** Trickle irrigation versus overhead irrigation: benefits and liabilities

| Irrigation Factor | Trickle as Compared to Overhead |
|---|---|
| Water storage capacity | Trickle irrigation requires about half the water needed by overhead systems. Water is used more efficiently since it is applied to the root zone. |
| Water quality | Trickle requires extremely clean, particle-free water. Pond and creek water need extensive filtration. |
| Pump and pipe network | Trickle requires lower flow rates and operating pressures, so less energy is required for pumping. Smaller pumps and pipes are required. |
| Water use efficiency | Plants are supplied with the water they need, not an excessive amount. |
| Disease/weed management | Diseases that develop when free water is on leaf and fruit surfaces do not develop with trickle irrigation, since water is applied directly to the root zone. Weeds are less problematic between rows or in non-irrigated areas. However, weeds can occur at the emitters. |
| Labor/automation | Trickle irrigation generally requires less labor (particularly when compared to portable overhead pipe, which needs to be moved periodically) and can be extensively automated. |
| Wind | Water can be applied efficiently under windy conditions. |
| Fertilizer | Trickle requires less fertilizer, since fertilizer is distributed only near plant roots. |
| Moisture distribution | Trickle limits distribution. This can be a problem only for certain crops, such as tree fruits, where only a small portion of the soil is wet. |
| Frost protection | Typical trickle irrigation systems are not effective for frost protection. Newly developed minisprinklers show promise for this purpose, but they have not been extensively tested. |
| Rodents/insect/people damage | Trickle systems may be eaten/damaged by rodents and insects. Also, because components are more fragile, they can be damaged by routine field operations. They are relatively easy to repair. |
| Cost | Some trickle systems require a higher initial investment than overhead, particularly when automated. |

klers, not all of the water sprayed into the air reaches the ground. About 25% is lost directly to evaporation (the actual amount varies with droplet size, temperature, humidity, and wind speed). Additional water is lost through leaks in the system. Engineers often plan for a 40% water loss when determining water storage capacity needs for an overhead sprinkler system. Thus, if 1 inch of water is needed to replenish soil moisture for the crop and the sprinklers are rated and spaced to apply 1 inch per hour, more than one hour would be needed to apply 1 inch of water to the soil. Trickle systems are more efficient because they are minimally affected by evaporation. For most on-farm uses, trickle systems are rated at 80 to 90% efficiency and sprinkler systems around 60 to 75%. Nonuniform water application and water losses in the trickle distribution line may reduce efficiency. With the cost of trickle systems decreasing, many growers are using both systems simultaneously to ensure good plant establishment.

## Planning an Irrigation System

Many growers consult professional irrigation designers (either from private companies or Cooperative Extension) before planting strawberries rather than plan every aspect of the irrigation system themselves. Be prepared for such a consultation with the following information:

1. An aerial photograph of the entire farm (optional). The Natural Resources Conservation Service can often provide a copy of an aerial photograph, with a normal scale of 1 inch being equal to 660 feet.

2. A topographic map showing changes in elevation. The topographic lines should show either 10- or 20-foot variations. This will be unnecessary for flat farms (those with less than a 20-foot elevation change). Area libraries may have a map that you can copy, or you can obtain a map by writing to your local Natural Resources Conservation Service. If neither of these sources can help you, request ordering information from the Branch of Distribution, U.S. Geographical Survey, Federal Center, Denver, Colorado 80225.

3. A detailed sketch of the fields and management data. These are the most important items an irrigation designer will need. Specific information includes:
   a. Preferred type of irrigation system (if known).
   b. Diagram showing fields with their dimensions and location relative to other fields. Water location and power sources should also be detailed.
   c. Approximate elevation variation in the field(s).
   d. Type of soil and soil texture.
   e. Plant type and details that relate to timing and amount of water required for that type of plant.
   f. Length of rows.
   g. Row direction.
   h. Number of rows per field (trickle).
   i. Distance between rows (trickle).
   j. Spacing of plants in the row (trickle).

4. Water supply information.
   a. If the water supply is a pond, the approximate size and depth of the pond, the source of pond water (springs or streams), and the history of the pond's water-holding ability through the summer. You should also be able to approximate how long it takes for the pond to refill if water is used from it. Finally, a description of the pond's cleanliness (weed growth, algae on the surface, silt buildup) should be provided.
   b. If the water supply is a well, the capacity (gallons/minute at zero pressure), size (diameter) of the well casing and the water pipe inside, depth, standing water level, and well identification number. Have the water tested for iron and pH and note whether there is sand or silt in the pumped water.
   c. If the water supply is a stream, the availability of water through dry months, the approximate flow rate in gallons per minute, and a description of the water cleanliness during the summer season. To test for cleanliness, take a water sample and allow it to settle.

5. Existing equipment information, including pump specifications.

6. Electrical power availability. If possible, note the voltage and phase available, the distance of the electricity from the pump site, and the power company's address and phone number.

7. Any consideration of your future irrigation needs.

To summarize, the system designer will need to first determine the plant water requirements and how the water can be delivered. Then the designer will compare the water supply capacity to the crop demand and look at other design factors.

## Water Supply Considerations

An adequate and dependable supply of good-quality water must be available at a reasonable cost throughout the growing season if irrigation is to be successful and cost-effective. The water source should be as close as possible to the area to be irrigated to minimize the pumping and supply line cost. Large ponds, lakes, streams, springs, groundwater, municipal water, and wastewater are all potential water sources.

The legal right to withdraw large quantities of water for irrigation must be verified. Water rights in the eastern United States are called *riparian,* or landowner's, rights, because anyone is entitled to use any water associated with land ownership. However, a riparian owner's rights are not absolute and are subject to reasonable use interpretations. In some western states, water is available only through appropriative rights. In some areas, permits are required before surface water or groundwater can be withdrawn for irrigation. Contact your state or provincial agriculture department for information on water use regulations.

Water sources must be able to provide water as often as it is needed. Stream flow and shallow groundwater sources are strongly influenced by climate, so they may not provide enough water during the dry part of the year when irrigation is needed most. Sometimes municipal water systems allow connections for irrigation purposes. However, this option may be expensive if water-use prices are high or if large areas need to be irrigated. Furthermore, if the municipality enforces water rationing, it may not permit irrigation during droughts. Although wastewater sources are generally poor quality and may not supply enough water to fulfill crop needs, they are being used more frequently for irrigation.

The irrigation water supply must be large enough to replenish the moisture taken from the rooting volume. Since irrigation is not 100% efficient, the water supply rate must be higher than the crop water use rate. Crop water requirements depend on climate, plant type, and soil moisture availability. Water supply systems are generally evaluated using two criteria, seasonal water demand and daily water demand. The water supply must be sufficient to satisfy the requirements of the irrigation system and must supply enough water to meet crop needs.

Pumping and pressurizing water can be expensive (see table 6-3 below). The energy required is often overlooked by growers. Pumping 1 acre-foot of water from a well 100 feet deep with a pump running at 70% efficiency costs about $100 (at $0.10 per kilowatt hour). The energy cost to pressurize surface water to 43 pounds per square inch is the same as lifting the same volume of water 100 feet.

## Seasonal Water Demand

Seasonal water demand is the average amount of water a crop will need for the entire growing season. Growers find this amount useful for sizing water supply systems where water is stored for irrigation, such as in ponds. In the eastern and midwestern United States, typical summer-fruiting strawberries grown in matted rows require about 1 to 2 inches of water per week, or about 25 to 30 inches per season. Demand tends to be higher in the warmer coastal areas. For a thirty-day drought period, or a growing season with 15 inches of rainfall, an additional 10 to 15 inches of water would be required to meet the seasonal demand. Growers should store from 3 to 13 acre-inches of water for each acre irrigated during the season. An acre-inch is a unit of volume equal to 1 inch of water depth over an entire acre and is equivalent to 27,154 gallons of water.

**Table 6-3.** Cost to pump 1 acre-foot (325,850 gallons) of water 1 foot in elevation, assuming $0.10 per kilowatt-hour

| Pump Efficiency | Energy Requirement (kilowatt hours) | Cost |
|---|---|---|
| 100 | 1.02 | $0.102 |
| 75 | 1.37 | $0.137 |
| 60 | 1.71 | $0.171 |
| 50 | 2.05 | $0.205 |
| 40 | 2.56 | $0.256 |

(Pumps generally run at 60 to 80% efficiency, depending on friction losses through the motor, strainer, suction pipe, and column.)

Because sprinkler irrigation systems are not 100% efficient (they are usually around 60 to 75% efficient), the rule of thumb is to store 40,000 gallons of water for every 1 acre-inch application. For example, a 5-inch seasonal demand would require 200,000 gallons per acre (5 inches x 40,000 gallons per acre-inch) if irrigated with an overhead sprinkler system. To irrigate a 20-acre parcel, a total of 4 million gallons (200,000 gallons per acre x 20 acres) should be available in storage. To store this water, a grower would have to have a 200-foot-by-200-foot pond that can store water to a depth of 13.4 feet (1 cubic foot = 7.48 gallons), or have a smaller pond with a rapid recharge rate.

## Peak Evapotranspiration Rate (Daily Peak Use Rate)

At some time during the growing season, environmental conditions and crop characteristics will demand peak water-use, or peak evapotranspiration, rates. The peak evapotranspiration (ET) rate is another useful value for sizing water supply systems such as continually flowing springs, streams, wells, or municipal systems. Both the water supply and the irrigation system must be capable of supplying water at the peak rate. Irrigation schedules based on the daily peak use ensure that enough water is applied when needed.

Peak ET rates are the highest in July and August (see table 6-4 on the following page). Since these rates represent long-term and monthly averages, demand during any single day could be another 25% higher, especially under hot, windy conditions. To use the information in table 6-4, look up the location closest to the site to be irrigated, select the peak ET rate value, and convert it to the appropriate units of interest. For example, at Harrisburg, Pennsylvania, the potential peak ET rate averages 0.22 inch per day. To irrigate 1 acre to a depth of 0.22 inch during a twenty-four-hour period will require about 5,970 gallons (27,154 gallons per acre-inch x 0.22 acre-inch). This will require an irrigation system that can sup-

**Table 6-4.** Monthly average potential evapotranspiration or peak-use rate of water demand for July and August at various locations in the United States

| State | Location | Average Peak Use Rate (inches/day) | State | Location | Average Peak Use Rate (inches/day) |
|---|---|---|---|---|---|
| **Arkansas** | Fort Smith | 0.24 | **Massachusetts** | Boston | 0.24 |
| | Little Rock | 0.23 | | Blue Hill Observatory | 0.23 |
| | Texarkana | 0.22 | | Nantucket | 0.20 |
| **California** | Bishop | 0.45 | | Pittsfield | 0.22 |
| | Eureka | 0.16 | | Worcester | 0.22 |
| | Fresno | 0.39 | **Michigan** | Alpena | 0.20 |
| | Mount Shasta | 0.39 | | Detroit | 0.25 |
| | Oakland | 0.22 | | Escanaba | 0.20 |
| | Red Bluff | 0.43 | | Flint | 0.21 |
| | Sacramento | 0.36 | | Grand Rapids | 0.24 |
| | San Francisco | 0.26 | | Lansing | 0.24 |
| | Stockton | 0.38 | | Marquette | 0.19 |
| **Connecticut** | Bridgeport | 0.22 | | Muskegon | 0.22 |
| | Hartford | 0.21 | **Minnesota** | Duluth | 0.21 |
| | New Haven | 0.20 | | International Falls | 0.20 |
| **Delaware** | Wilmington | 0.22 | | Minnesota–St. Paul | 0.22 |
| **Idaho** | Boise | 0.38 | | Rochester | 0.22 |
| | Lewiston | 0.35 | | Saint Cloud | 0.21 |
| | Pocatello | 0.36 | **Missouri** | Columbia | 0.23 |
| **Illinois** | Cairo | 0.21 | | Kansas City | 0.25 |
| | Chicago | 0.24 | | St. Joseph | 0.22 |
| | Moline | 0.22 | | St. Louis | 0.23 |
| | Peoria | 0.22 | | Springfield | 0.23 |
| | Springfield | 0.23 | **New Hampshire** | Concord | 0.20 |
| **Indiana** | Evansville | 0.22 | | Mt. Wash. Observ. | 0.15 |
| | Fort Wayne | 0.22 | **New Jersey** | Atlantic City | 0.22 |
| | Indianapolis | 0.23 | | Newark | 0.23 |
| | South Bend | 0.23 | | Trenton | 0.23 |
| **Iowa** | Burlington | 0.22 | **New York** | Albany | 0.20 |
| | Des Moines | 0.22 | | Binghamton | 0.17 |
| | Dubuque | 0.21 | | Buffalo | 0.22 |
| | Waterloo | 0.19 | | New York | 0.23 |
| **Kentucky** | Lexington | 0.23 | | Rochester | 0.21 |
| | Louisville | 0.23 | | Syracuse | 0.21 |
| **Maine** | Caribou | 0.17 | **North Carolina** | Asheville | 0.18 |
| | Portland | 0.20 | | Cape Hatteras | 0.20 |
| **Maryland** | Baltimore | 0.25 | | Charlotte | 0.20 |
| | | | | Greensboro | 0.20 |
| | | | | Raleigh | 0.20 |
| | | | | Wilmington | 0.21 |

**Table 6-4.** Monthly average potential evapotranspiration or peak-use rate of water demand for July and August at various locations in the United States — *continued*

| State | Location | Average Peak Use Rate (inches/day) | State | Location | Average Peak Use Rate (inches/day) |
|---|---|---|---|---|---|
| **Ohio** | Akron | 0.22 | **Tennessee** | Bristol | 0.19 |
| | Cincinnati | 0.23 | | Chattanooga | 0.21 |
| | Cleveland | 0.24 | | Knoxville | 0.22 |
| | Columbus | 0.22 | | Memphis | 0.22 |
| | Dayton | 0.24 | | Nashville | 0.23 |
| | Sandusky | 0.24 | **Vermont** | Burlington | 0.21 |
| | Toledo | 0.25 | **Virginia** | Lynchburg | 0.21 |
| | Youngstown | 0.21 | | Norfolk | 0.20 |
| **Oklahoma** | Oklahoma City | 0.28 | | Richmond | 0.21 |
| | Tulsa | 0.25 | | Roanoke | 0.22 |
| **Oregon** | Astoria | 0.15 | **Washington** | Olympia | 0.20 |
| | Eugene | 0.24 | | Seattle | 0.21 |
| | Medford | 0.33 | | Yakima | 0.33 |
| | Pendleton | 0.38 | **West Virginia** | Charleston | 0.20 |
| | Portland | 0.22 | | Elkins | 0.15 |
| | Salem | 0.25 | | Parkersburg | 0.20 |
| **Pennsylvania** | Allentown | 0.21 | **Wisconsin** | Green Bay | 0.20 |
| | Erie | 0.21 | | LaCrosse | 0.21 |
| | Harrisburg | 0.22 | | Madison | 0.22 |
| | Philadelphia | 0.22 | | Milwaukee | 0.22 |
| | Pittsburgh | 0.19 | | | |
| | Williamsport | 0.21 | | | |
| **Rhode Island** | Block Island | 0.19 | | | |
| | Providence | 0.21 | | | |

*Source:* Goehring, 1992.

ply about 4 gallons per minute (gpm) to each acre irrigated (5,970 gallons ÷ 1,440 minutes per day).

If these values are increased 25% to account for higher single daily peak uses in the months of July and August, then the average peak use rate becomes 0.28 inch per day with a requirement of 5.3 gallons per minute per day per acre [(27,154 gallons per acre-inch x 0.28 acre-inch) ÷ 1,440 minutes per day]. Thus, a spring, stream, well, or municipal water source would have to supply 4 to 5 gallons per minute continuously for each acre irrigated to meet the peak demand in the summer months.

Round-the-clock irrigation is not always possible or desirable, so growers must make the numerical adjustments for the number of hours they plan to irrigate. For example, if a grower wants to irrigate for only ten hours a day with a sprinkler system operating at 75% efficiency, then the water supply must be capable of delivering approximately 16 gallons per minute per acre to meet the daily demand discussed in the previous paragraph.

## *Water Quality*

In most strawberry production areas, water quality is generally good enough for irrigation. However, quality should always be a concern when a water source is assessed. Water quality includes its physical, chemical, and biological constituents.

Physical constituents refer to sand, silt, or other suspended materials in water. While the physical constituents are usually not damaging to fruit crops, they can damage or clog the irrigation system. A high sand content, for example, damages pumps and sprinklers, and suspended materials can clog trickle systems. Surface water sources, such as ponds and rivers, usually contain more particles and should be evaluated carefully, especially if trickle irrigation is being considered. Filtering or frequent backflushing of screens is required when using pond water for trickle irrigation. Screen and disc filters clog if the water contains algae or organic materials. A media (sand) filter works best for surface water, because it has more depth for trapping particles and the media is lifted during backwash to flush the debris out.

Chemical constituents of water refer to pH, dissolved material, proportions of dissolved ions, and any organic compounds such as oil. Although generally not a problem, organic solvents or lubricants in the water can damage plants. If water pH is high (7.0 or above), lower it with sulfuric acid to prevent nutritional problems in the field. Certain pesticides can be deactivated by high-pH water, so it is important to be aware of the water pH.

Biological constituents such as bacteria and algae are often present in surface water. They are usually not harmful to fruit crops and can be controlled under most circumstances, but they can affect irrigation system performance, particularly if trickle is used. Water contaminated with sewage should not be used to irrigate strawberries.

## Scheduling Irrigation

Once an irrigation system is in place, the major decisions are when to irrigate, how much water to apply, and how to use and maintain the equipment. Always irrigate when drying will be rapid—never irrigate at night unless the purpose is to protect plants from frost. This will avoid excessive wetting on the leaves and fruit, which can encourage fungal development. Also try to avoid windy conditions, since wind increases water loss due to evaporation and drift.

Crop rooting depth, canopy development, fruiting habits, and nutrition and water requirements in a given climate largely determine the irrigation schedule. Soil infiltration and water-holding characteristics (see tables 6-5, 6-6, and 6-7) help determine the rate and duration of water application and affect the soil's ability to make water available to plants. Actual water use will vary daily throughout the season, so develop a method to make sure the crop has an appropriate amount of water available. Never apply water faster than the soil can absorb it, unless irrigating for frost protection.

Several methods are used to determine whether or not to irrigate, some being more reliable than others. When

**Table 6-5.** Infiltration rates of overhead irrigation for various soil types

| Soil Texture | Infiltration Rate (inches/hour) |
|---|---|
| Coarse sand | 0.75–1.00 |
| Fine sand | 0.50–0.75 |
| Fine sandy loam | 0.35–0.50 |
| Loam or silt loam | 0.25–0.40 |
| Clay loam | 0.10–0.30 |

*Note:* Do not apply water faster than the soil can absorb it, unless irrigating for frost protection.

**Table 6-6.** Maximum irrigation period (hours) with trickle irrigation for various soil textures, assuming 50% moisture capacity at the beginning of the cycle

| Flow Rate (gal/hr/100 ft) | Soil Texture | | | | |
|---|---|---|---|---|---|
| | loamy sand | sandy sand | clay loam | silt loam | loam |
| 12 | 5.0 | 8.0 | 11.5 | 15.5 | 17.5 |
| 18 | 3.5 | 5.0 | 7.5 | 10.5 | 11.5 |
| 24 | 2.5 | 4.0 | 5.5 | 8.0 | 8.5 |
| 30 | 2.0 | 3.0 | 4.5 | 6.5 | 7.0 |
| 36 | 1.5 | 2.5 | 4.0 | 5.0 | 6.0 |
| 42 | 1.5 | 2.0 | 3.0 | 4.5 | 5.0 |
| 48 | 1.5 | 2.0 | 3.0 | 4.0 | 4.5 |

**Table 6-7.** Water-holding capacity of various soil types

| Soil Type | Inches Water/ Inch Soil |
|---|---|
| Sand | 0.02–0.06 |
| Fine sand | 0.04–0.09 |
| Loamy sand | 0.06–0.12 |
| Sandy loam | 0.11–0.15 |
| Loam | 0.17–0.23 |
| Silty clay loam | 0.14–0.21 |
| Clay | 0.13–0.18 |

plants show visible signs of water deficit, such as wilting, plant growth has already been severely affected. Irrigation at this point may save the crop, but production will still suffer.

## Feel Method

With this method, the soil's appearance after being squeezed by hand is used to estimate water content. With a lot of experience, this method can be quite reliable, and charts are available to describe how different soils should look and feel at different moisture contents. However, a common mistake is to feel the surface soil layers rather than soil around the root tips, where most moisture is taken up. Avoid this problem by using a probe to sample soil in the crop root zone.

## Water Budget Method

The water budget method is an accounting process of daily water use and rainfall inputs. Plant water use is estimated daily based on crop development and climate conditions, and is compared to the soil's water-holding capacity. Often, pan evaporation is used to keep track of water losses. An evaporation pan is literally a pan with a gauge in it to determine how much water has evaporated, and is correlated with plant evapotranspiration.

Assume that the rooting depth of strawberries is 8 inches on a sandy loam, high-organic-matter soil. After a soaking rain or after irrigation, the soil should hold about 1.2 inches of water (8 inches x 0.15 from table 6-7). Irrigation should begin when available water is depleted by 50%, or 0.6 inch in this example. If evapotranspiration removes about 0.22 inches of water per day from the soil, then after three days 50% of the available water is depleted and irrigation (or rain) is again required. With the water budget method, moisture loss is monitored and continuously calculated, and water is replaced based on the calculations. (Evapotranspiration rates for your location can be estimated from table 6-4 on page 44.)

With experience, this method can be quite reliable. Computer software programs using this budget method are available and can be adapted to particular site conditions. Computers can also be used to automate irrigation.

## Guttation Method

Strawberry plants exhibit a phenomenon called guttation, which is the exudation of water droplets from small pores at the tips of the younger leaves (photo 6-2). The water is visible only very early in the morning (predawn) in plants that have an ample supply of soil moisture. It is not frequently used as an irrigation scheduling tool for strawberries, but it certainly offers potential.

Growers can look for guttation in the early morning in the driest area of a given field, being careful to examine the tips of the youngest leaves coming out from the crown. Placing a bucket over the area to be examined the evening before will eliminate any evaporative loss of guttated water from wind. If water droplets are not being exuded, it is time to irrigate. This system has lots of appeal, because it allows the plant to tell the grower when its water supply in the soil is dwindling.

## Other Tools for Measuring Soil Water

Many instruments have been developed to help growers schedule irrigation. Evaporation pans, atmometers, infrared thermometers, pressure bombs, and porometers monitor evaporative demand, plant stress, or leaf moisture status. Tensiometers, gypsum or ceramic electrical resistance blocks, conductivity probes, matric potential (heat-dissipating) sensors, neutron probes, and time domain reflectometry (TDR) probes are used to monitor soil moisture. Some of these tools, such as evaporation pans, atmometers, tensiometers, and gypsum blocks, are relatively inexpensive and easy to use. Others are more expensive and are used mainly for research. All of them require constant monitoring, maintenance, and calibration to be reliable for scheduling irrigation.

A tensiometer is a simple, inexpensive tool for measuring soil moisture status (figure 6-2). The ceramic tip of the tensiometer should be placed in the rooting zone of the strawberry plant, approximately 6 inches deep. When the reading reaches a critical level, irrigation is required. This critical level depends on soil type. Soil moisture

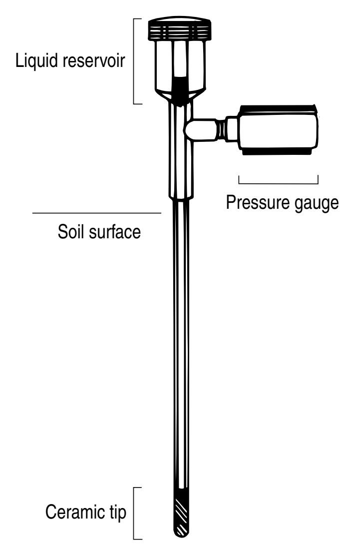


**Figure 6-2.** Tensiometer

should not be depleted below 50% of the soil's capacity. Irrigation should be started when the tensiometer reading reaches this level, about 20 to 40 centibars (cbars) in sandy soils, 40 to 60 cbars in loamy soils, and 50 to 80 cbars in clay soils. Tensiometers work well in sandier soils but may require more service. When the soil dries out too much, there is so much pressure in the tensiometer that the water column pulls apart, and air enters where a vacuum once was. Servicing involves refilling the tensiometer with water and pumping back out all of the air so the column is again completely filled with water.

Gypsum blocks are also inexpensive, simple to use, and can reflect moisture more accurately in drier soils than tensiometers. Practically speaking, however, they do not offer much advantage, since, as mentioned previously, plants should be watered before soil moisture falls below 50% of capacity. The gypsum block contains two electrodes cast in a small block of gypsum. The gypsum protects the electrodes from corrosion and confines the electrical path to within the block. A hand-held battery-operated resistance meter is connected to the wires to indicate the electrical resistance. The more water there is in the soil (and in the gypsum block), the more the current will flow within the gypsum block between positive and negative charges.

Some instruments have been developed for automated monitoring of water requirements and, when integrated with the appropriate irrigation system, can automate the entire irrigation process. More information regarding these tools or scheduling methods mentioned above is available in publications listed at the end of this chapter.

## Irrigation System Components

Sprinkler and trickle systems have some common components, such as the pumping unit, control head, mainline and submain pipes, and laterals. The water-distribution hardware for both systems is similar (figure 6-3). Differences between systems are the physical characteristics of these components and the equipment that ultimately applies the water, either sprinklers or emitters.

### *Pumping Unit*

The pumping unit, which consists of a pump coupled to a power source, draws water from the supply source and pressurizes it for delivery through the irrigation system. A centrifugal pump or a submersible or deep well turbine pump may be used. Normally, a centrifugal pump cannot be placed more than 20 feet above the water line. Pumps are available in a wide range of flow capacities and delivery pressures. Selecting the correct style of pump and the proper size will depend on site characteristics and the final irrigation system layout.

Pump size depends on the discharge or amount of water to be delivered at a given time (that is, the number of sprinklers being operated simultaneously multiplied by the discharge rate of sprinklers), and the head pressure required to lift the water and operate the sprinklers or trickle emitters. Since sprinklers usually have higher discharge and pressure requirements, pumps for sprinkler systems are generally larger than those for trickle systems. This is one reason why trickle systems are more energy-efficient than sprinkler systems.

Although the pumping units must meet certain hydraulic requirements, several options are usually available to meet site requirements and preferences. When growers can tie into municipal or household systems, where water is already pressurized, a pumping unit is unnecessary. The primary concern is that the supply (volume and flow rate) is large enough.

### *Control Head*

The control head is the combination of items that control, measure, or treat the water. Control heads can range from simple, manually operated heads with a single valve to quite sophisticated heads with automatic controllers and sensors, water meters, pressure regulators, filters, and nutrient or chemical injection equipment. Control heads for trickle systems are often more complex because of the necessary water filtration equipment.

Automated equipment can be adapted to some systems to measure soil moisture, start the irrigation system, and send water to the appropriate areas. The more complex and automated the control head and irrigation system, the greater the initial capital investment.

### *Mainline and Submain Pipes*

Mainline and submain pipes deliver water from the pump and control head to the laterals or other water distribution equipment. These pipes are usually classified as permanent, rigid and portable, or flexible and portable. Submain pipes are not always necessary.

Permanent piping is usually made of galvanized steel or plastic (either rigid PVC or polyethylene). This piping is installed below ground, with the exception of steel

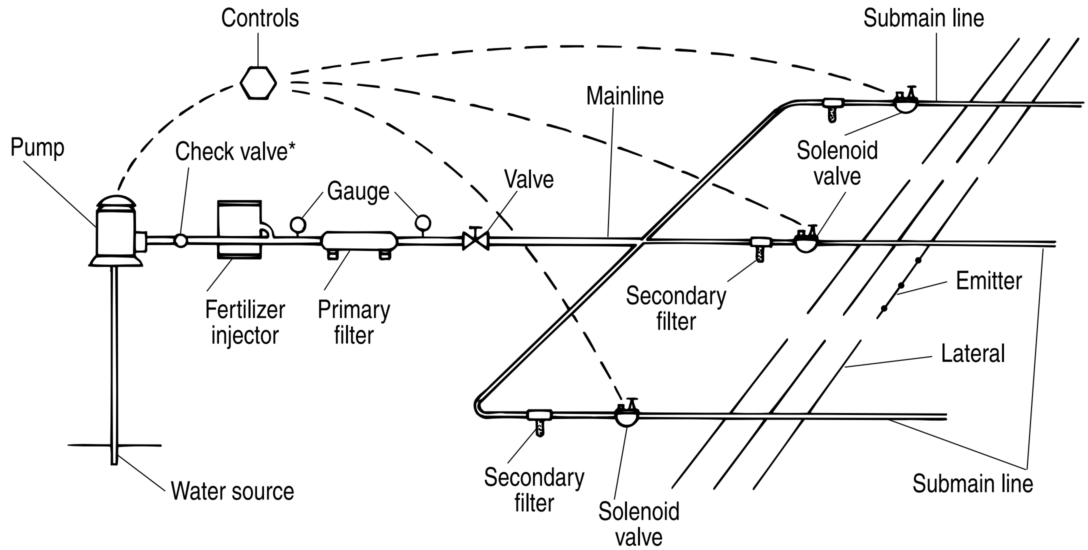


**FIGURE 6-3.** Irrigation system components *A backflow preventer or vacuum breaker is required in some areas.

pipe, which can be installed above ground. For perennial crops such as blueberries, permanent buried mainlines with hydrants spaced throughout the field offer several advantages, but they require high initial investment.

Rigid and portable (solid-set) piping is usually made of lightweight aluminum equipped with quick coupler fittings. Although moving pipe is labor-intensive, portable piping systems offer flexibility and provide irrigation at a lower initial cost.

Flexible and portable pipe refers to conduits made with lightweight, durable rubber or synthetic compounds. These pipes are generally used with self-propelled sprinklers.

Although friction losses decrease per unit length from steel to aluminum to plastic pipe, proper pipe diameter is a more important factor for flow velocity. Pipe size is determined according to the discharge requirement, the allowable flow velocity within the pipe, and the trade-off between the tolerable friction loss and the total time of system operation in which that loss must be overcome. Since the total discharge requirements for sprinkler systems are higher than those for trickle systems, pipe sizes are often larger with sprinkler systems.

Pipe type (its material and whether it is permanent or portable) is generally not a major factor in achieving desired flow characteristics. Therefore, equipment selection depends mainly on the grower's preference and a trade-off between equipment and labor costs.

### *Lateral Pipes*

Lateral pipes deliver water from the mainline or submain lines to the sprinklers or trickle emitters. They are of the same three general types as the mainline pipes but are usually smaller. Lateral pipe sizes are designed to minimize pressure losses so that sprinkler or emitter discharge at the far end of the lateral stays within 10% of the sprinkler or emitter discharge near the mainline to provide uniform water application. Pressure is usually lower in trickle laterals than in overhead laterals. Some trickle system laterals combine the functions of a lateral and an emitter; these include porous pipe, perforated pipe, and multichamber tubes.

### *Components Specific to Trickle Irrigation Systems*

Compared to sprinkler nozzle sizes, trickle system emitters have very small openings, usually pinhole size. Different emitters have different internal flow characteristics that determine how sensitive they are to pressure changes and particles in the water. A 150- to 200-mesh screen is normally required for water filtration.

Some emitters have larger orifices, are self-cleaning, or can be taken apart and cleaned. Periodic chlorine injections can keep systems free of algae, bacterial slime, and iron precipitates. Chlorine treatment (resulting in 1 to 2 ppm residual chlorine at the emitter) should occur upstream from the filter in order to remove precipitated iron and microorganisms. This may require 5 to 10 ppm chlorine at the injector, especially if there are high levels of iron or microorganisms in the water. Swimming pool test kits can be used to calibrate the chlorine levels. If water pH is above 7.5, chlorine will not be effective. Separate acid injections, along with periodic flushing of the system, also help remove mineral buildup.

Emitters normally operate at pressures of 5 to 40 pounds per square inch, with flow rates of 0.5 to 1.5 gallons per hour. Emitter spacing depends on the discharge rate and soil type because most of the water distribution is through the soil. The low pressure requirements of emitters result in more sensitivity to pressure losses along a lateral line or an elevation gradient. Pressure-compensating emitters may be necessary to achieve uniform water application on rolling terrain. Since the pressure and discharge requirements of emitters are usually smaller, the annual operating costs of trickle systems tend to be lower than those for sprinkler systems. Trickle irrigation systems should be sized for the mature planting.

### *Components Specific to Sprinkler Systems*

The basic types of sprinklers include rotating sprinklers, stationary spray-type nozzles, and perforated pipe. Rotating sprinklers, such as the slowly rotating impact-driven sprinkler, are most common (photo 4-8). Fixed spray nozzles are becoming more popular, although they are most widely used in landscaping. Perforated pipe is the simplest sprinkler, consisting of a pipe with numerous holes through which the water sprays.

Rotating impact sprinklers come in many sizes and variations to meet various design conditions. Some microsprinklers operate at pressures as low as 10 pounds per square inch (psi), while the large gun types require pressures exceeding 80 psi. Sprinkler discharge ranges from a few gallons of water per minute (gpm) to 1,000 gpm for a big gun. Wetted diameters can range from only a few feet to several hundred feet. When irrigating new plantings, avoid big guns with high pressures.

When selecting an irrigation system solely to provide water to the plants, use a high discharge rate with large droplets to minimize evaporative loss and the time that foliage is wetted. But do not use such a high rate as to cause puddling in the field.

Pressure, discharge rate, and wetting diameter are the most significant characteristics of a sprinkler; but nozzle size, jet angle, wind speed and direction, sprinkler overlap, and sprinkler rotation speed are also important. These characteristics determine water application rates, sprinkler spacings, and water droplet sizes. For uniform water application, sprinklers are generally spaced so that 50 to 60% of their wetted areas overlap. Annual operating costs of irrigation increase with increasing pressure and discharge requirements. The large gun-type sprinkler will require up to twice as much fuel or electrical energy as smaller sprinklers to apply equal amounts of water.

## Equipment Use and Maintenance

The appropriate use and maintenance of irrigation equipment, both in season and during storage, will increase its life and reduce operating and maintenance costs. An irrigation equipment dealer should provide an owner's manual and guidelines for operating and caring for the equipment.

The pumping unit and control head will require the most maintenance in terms of lubrication, cleaning, and protection from dirt, moisture, freezing, and animals. Leaking pump seals and pipe gaskets should be replaced as necessary. Sprinkler nozzles that are worn more than $1/16$ inch larger than specified or emitters that are clogged should be replaced. Mains and laterals, particularly in trickle systems, should be flushed periodically to remove buildup of precipitates and sediment. Equipment used in freezing weather must be properly lubricated and should be self-draining. The careful use and continued maintenance of irrigation equipment should ensure many years of trouble-free performance and the satisfaction of producing a bountiful strawberry harvest year after year.

## Further Reading

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CHAPTER 7

# Soil and Nutrient Management

Nutrition and fertilization are important but poorly understood components of the overall management of a strawberry planting. It is difficult to get accurate nutritional recommendations for a particular farm, because many factors influence nutrient uptake and availability. For example, pH, moisture, organic matter content, clay content, and mineral composition of the soil all strongly influence nutrient availability. Management practices such as tillage, irrigation, herbicide use, and fertilization history also affect the plant's ability to take up nutrients. Finally, weather plays a role: conditions that reduce transpiration may cause temporary nutrient deficiencies. Since all of these factors interact to affect nutrient uptake and since these factors differ from farm to farm, it is difficult to provide precise recommendations. An understanding of certain principles, however, will allow a grower to better manage nutrients according to the specific characteristics of his or her particular farm.

## Soil Components

Soil is the substrate in which the roots grow and anchor the plant. Furthermore, it is the medium that provides nutrients and water to the plant. The four major components of soil are minerals, organic matter, water, and air (figure 7-1). A balance among these four components is necessary for optimal plant growth. For example, excessive water can reduce the oxygen content of the soil and cause roots to die. Insufficient water causes plants to wilt and inhibits nutrient uptake.

The composition and size of the mineral fraction of soil has a large influence on nutrient availability. Some minerals are very insoluble in water, so the associated nutrients may be relatively unavailable even if they are present in large quantities. Nutrient availability is increased if soil particles are small. The composition of the mineral fraction affects the release rate of nutrients; for example, certain clays have a lattice structure that traps ions between layers, rendering the ions unavailable. A soil high in phosphates or high in pH can also reduce the availability of certain nutrients, such as iron and zinc. Because the chemistry governing the availability of nutrients in the soil is complex, predictions about crop response to soil type or fertilizer addition are imprecise.

Organic matter is another major component of soil and consists of decomposing plant material, animal wastes, and microorganisms. Organic matter is a source of nitrogen, phosphorus, and sulfur and helps to increase the availability of positively charged ions, such as calcium, magnesium, and potassium. Organic matter constituents tend to have a negative charge that holds onto positive

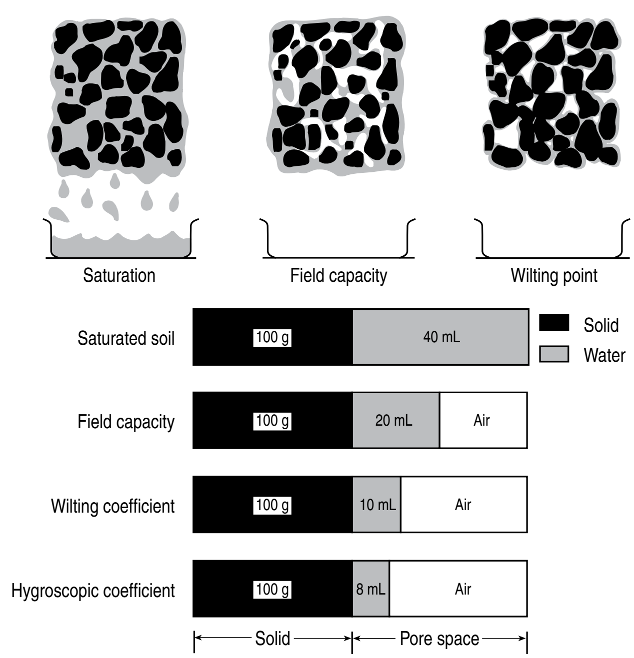


**FIGURE 7-1.** Components of soil

ions, affecting their availability to plants. Soils that are high in organic matter content also have a large buffering capacity, are resistant to changes in pH, and tend to have a high water-holding capacity.

## Some Basics

Often soil contains sufficient nutrients, but they are in a form that is unavailable to the plant. For example, a soil may contain 25,000 parts per million (ppm) potassium, but the amount available to the plant may be just 500 ppm. Many of the factors listed above influence the conversion of mineral elements from unavailable forms to available forms. Soil tests attempt to estimate the amount of plant-available nutrient, not the total amount in the soil.

Nutrients are available to the plant as individual ions that have a positive or negative charge, or as acids (table 7-1). The behavior of nutrients in the soil is influenced significantly by this charge. For example, ammonium ($NH_4^+$) tends to be retained by adsorption to negatively charged clays and organic matter, whereas nitrate ($NO_3^-$) is more readily leached. When ammonium is taken into a root, a proton ($H^+$) is excreted to maintain a neutral charge balance. The additional hydrogen ions that result from ammonium fertilization decrease the soil pH and affect the availability of other nutrients.

**Table 7-1.** Ionic forms of plant-available nutrients supplied by the soil

| Element | Cations | Anions | Neutral |
|---|---|---|---|
| Nitrogen | $NH_4^+$ | $NO_3^-$ | |
| Calcium | $Ca^{2+}$ | | |
| Magnesium | $Mg^{2+}$ | | |
| Potassium | $K^+$ | | |
| Phosphorus | | $HPO_4^{2-}$<br>$H_2PO_4^-$ | |
| Sulfur | | $SO_4^{2-}$ | |
| Copper | $Cu^{2+}$ | | |
| Iron | $Fe^{2+}$, $Fe^{3+}$ | | |
| Manganese | $Mn^{2+}$ | | |
| Zinc | $Zn^{2+}$ | | |
| Boron | | | $H_3BO_3$ |
| Molybdenum | | $MoO_4^{2-}$ | |
| Chlorine | | $Cl^-$ | |

Soil pH is the most important factor affecting the availability and uptake of plant nutrients. Some nutrients become more available at a low pH, others at a high pH, and others between pH extremes (figure 7-2). At a soil pH of 6.0 to 6.5, all essential nutrients are potentially available to the plant, so this is the recommended target for pH adjustment in most locations. However, in cases where certain micronutrients are present at high or low levels, the optimal soil pH may be higher or lower than 6.0 to 6.5.

Another important concept to understand is how plants respond to increasing levels of a nutrient. If a particular nutrient is very low, a plant will respond rapidly to increasing levels of that nutrient (figure 7-3). However, as levels continue to increase, the response becomes smaller and smaller until no further response can be measured. At very high levels, toxicity can occur, resulting in a yield decrease. Therefore, it is not the case that provid-

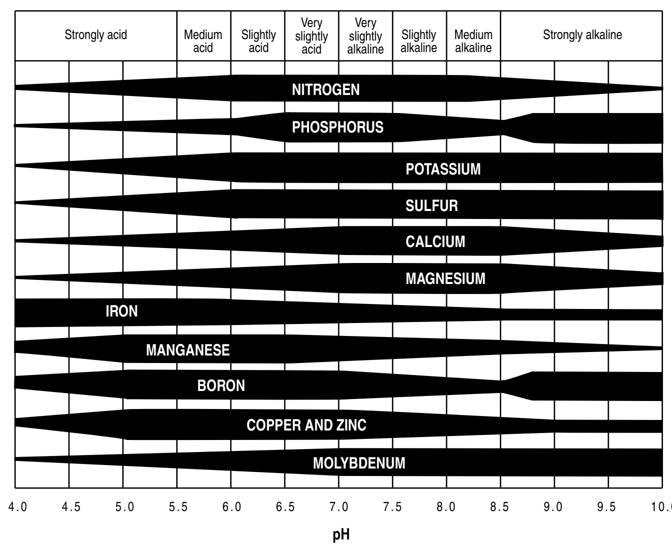


**Figure 7-2.** Nutrient availability as affected by soil pH

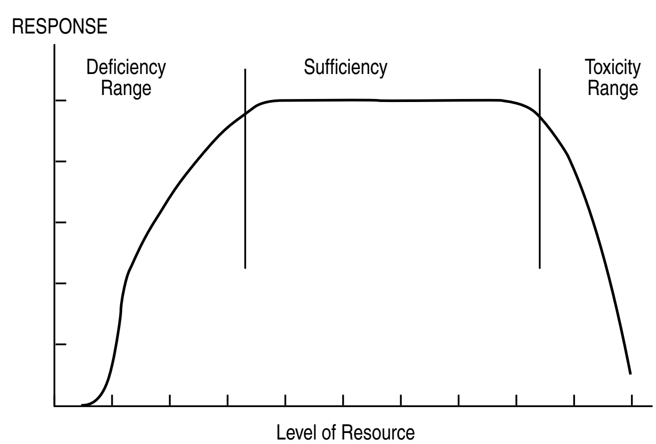


**Figure 7-3.** Response of a plant to increasing levels of a resource

ing additional nutrients will always benefit the plant. In fact, high levels of some nutrients reduce the availability of others.

If the level of a particular nutrient is low, adding a small amount often results in a growth flush. This tends to dilute the concentration of the nutrients in plant tissues, although the total amount in the plant is greater. For this reason, it is not unusual to see foliar nutrient levels fall following fertilization.

Finally, it is important to realize that at least thirteen nutrients are essential to plant growth. Although nitrogen (N), potassium (K), phosphorus (P), calcium (Ca), magnesium (Mg), and sulfur (S) are the soil nutrients required in the greatest amounts, molybdenum (Mo), for example, is equally important, even though it is required at levels about 100,000 times less.

## Diagnosing Nutrient Problems

### *Visual Diagnosis*

An obvious method for determining whether plants are receiving adequate nutrients is to look for symptoms such as pale foliage, poor growth, misshapen fruit, and discolored plant tissue. Often particular combinations of symptoms are associated with specific nutrients. The disadvantage of relying on visual diagnoses is that by the time symptoms appear, performance has already been compromised. Also, it is rare that only a single nutrient is deficient. For example, if the soil pH is too high, then iron (Fe), manganese (Mn), and zinc (Zn) become unavailable almost simultaneously. Multiple deficiencies make visual diagnoses difficult. Finally, symptoms of toxicity can sometimes resemble symptoms of deficiency. Basing fertilizer recommendations on visual symptoms alone is risky.

### *Soil Tests*

Soil tests have been used for many years to estimate the amounts of nutrients available to plants. Once these numbers are known, a recommendation is made with the assumption that plant performance is related to nutrient availability. Using a soil test to assess nutritional status is much better than relying on a visual diagnosis of plant symptoms, but the test must be done correctly to ensure valid results.

Take soil samples for testing from the top 8 inches of soil. This is where most of the strawberry roots will grow. Collect samples from ten to twelve locations throughout the field (refer to figure 2-1 on page 8), and mix them together in a bucket. Remove about 1 pint of the bulked soil for analysis. More than one test is required when the soil changes within the field. No more than 10 acres should be included in any one sample.

Soil tests are most appropriate for the year prior to planting. With the exception of N, sufficient fertilizer and lime can be applied and incorporated prior to planting to meet nutritional needs over the life of the planting.

Soil testing laboratories use different methods to extract plant-available nutrients. For this reason, results are not directly comparable from one laboratory to another. In addition, extractants used for estimating available P, K, Ca, and Mg are not appropriate for estimating levels of micronutrients. Therefore, soil test results for most micronutrients have little meaning.

Soil test recommendations for strawberries are really just ballpark estimates of fertilizer needs, because crop response data for each nutrient on different soil types have not been generated. Most growers assume a higher level of precision in soil tests than actually exists. A soil test approximates nutrient needs, but it cannot really be used to fine-tune a fertilizer program.

### *Terms Used in Interpreting Soil Tests*

pH — The relative acidity or alkalinity of a soil. A pH of 7 is neutral, a pH less than 7 is acidic, and a pH greater than 7 is alkaline.

Cation Exchange Capacity (CEC) — A measure of the ability of a soil to adsorb calcium, potassium, and magnesium ions (among others) and of its resistance to change pH in response to liming or sulfur additions. Clays and soils high in organic matter tend to have a high CEC, whereas sands have a low CEC.

Cation — A positively charged ion. The most common in soils are calcium (Ca), potassium (K), magnesium (Mg), and aluminum (Al).

Base Saturation — The percentage of the exchange sites that contain a calcium, potassium, magnesium, or other cation. The higher the percent base saturation, the higher the pH.

### *Foliar Analysis*

Plant tissue analysis is used to measure directly the amount of nutrients in various plant parts. Recommendations are based on the levels of these nutrients at specific times of the year. In most cases, sufficiency ranges are known for strawberries or are estimated from other crops (table 7-2). Unlike visual diagnoses, foliar nutrient analyses can alert the grower when nutrient levels are approaching deficiency so corrective action can be taken. Unlike soil tests, foliar analyses provide accurate results for all essential mineral nutrients.

Currently, recommendations are based on newly expanded leaves collected after renovation in late July or early August. Other sampling times or plant parts may prove to be more appropriate for certain nutrients; but until more detailed studies are done, foliar samples collected in midsummer are the standard.

Collect at least fifty leaves, remove their petioles, and wash them in distilled water. Dry them, place them in a paper bag, and send them to the laboratory for analysis. Samples should be representative of the entire field. If a particular area of the field looks poor or has been fertilized differently from the rest, sample it separately.

### *The Best Approach*

A combination of soil testing, tissue analysis, and observation of crop response is the best approach to assessing nutrient status. Prior to planting, conduct a soil test and amend the soil according to recommendations. After planting, conduct a foliar tissue analysis at least every other year. The soil pH should be monitored regularly and a complete soil test performed every three years. Always be alert for any unusual-looking leaves and unexplained reductions in growth or yield.

**Table 7-2.** Sufficiency ranges for foliar nutrient levels in strawberry leaves in midsummer (perennial systems)

| Nutrient | Deficient Below | Sufficient | Excess |
|---|---|---|---|
| N (%) | 1.9 | 2.0 – 2.8 | 4.0 |
| P (%) | 0.20 | 0.25 – 0.40 | 0.50 |
| K (%) | 1.3 | 1.5 – 2.5 | 3.5 |
| Ca (%) | 0.5 | 0.7 – 1.7 | 2.0 |
| Mg (%) | 0.25 | 0.3 – 0.5 | 0.8 |
| S (%) | 0.35 | 0.4 – 0.6 | 0.8 |
| B (ppm) | 23 | 30 – 70 | 90 |
| Fe (ppm) | 40 | 60 – 250 | 350 |
| Mn (ppm) | 35 | 50 – 200 | 350 |
| Cu (ppm) | 3 | 6 – 20 | 30 |
| Zn (ppm) | 10 | 20 – 50 | 80 |

## Soil Amendments

Many materials are useful as soil amendments: fertilizers, lime, manure, composts, green manures, and others. Each has unique properties that are beneficial under certain circumstances.

### *Lime*

Liming affects soil pH, which strongly influences nutrient uptake and plant growth. Proper liming can increase soil productivity and increase the efficiency of other fertilizers. Lime also provides Ca and possibly Mg, depending on the source. Lime is used to balance the acidification that occurs when certain fertilizers, manures, or composts are used (table 7-3 on page 56). Other materials may contain Ca and Mg (for example, gypsum), but they do not influence soil pH significantly.

The proper amount of lime to apply depends on the soil test recommendation (see chapter 2). Not all limestone is the same—some is less pure than others. The purity is indicated by the calcium carbonate equivalent (CCE). If a particular limestone has a CCE of 80%, then 5 tons per acre would be applied if the soil test recommended 4 tons (4 tons ÷ 0.80 = 5 tons). Limestone also differs with respect to the speed at which it reacts with the soil. The more finely ground the limestone, the faster it reacts, so particles should be smaller than a 20-mesh size—preferably of 100-mesh size. In addition, if the soil test recommends Mg, a high-Mg lime (dolomitic lime) should be used, even though it may be more expensive. Finally, lime is sold by weight; so if the limestone is not completely dry, adjust application rates accordingly (that is, increase rates by the percentage of moisture in the lime).

### *Manure*

Manure is a source of both nutrients and organic matter and can significantly improve soil structure. If it is readily available, manure can replace some synthetic fertilizers and save the grower money.

The urea in manure is unstable and will volatilize quickly unless incorporated into the soil. The solid organic fraction decomposes more slowly and provides N over a long period of time—even into subsequent years. However, in most situations, insufficient N is released from ma-nure

**Table 7-3.** Equivalent acidity and alkalinity of nitrogenous fertilizer materials

| Material | % Nitrogen | Pounds of Pure Lime for Neutralization: Per Pound of Nitrogen | Pounds of Pure Lime for Neutralization: Per 100 Pounds of Material |
|---|---|---|---|
| Inorganic sources of nitrogen | | | |
| Sulfate of ammonia | 20.5 | 5.35 | 110 |
| Ammo-phos A | 11.0 | 5.00 | 55 |
| Anhydrous ammonia | 82.2 | 1.80 | 148 |
| Calcium nitrate | 15.0 | 1.35 | 20 |
| Nitrate of soda | 16.0 | 1.80 | 29 |
| Potassium nitrate | 13.0 | 2.00 | 26 |
| Manufactured organic nitrogen | | | |
| Cyanamid | 22.0 | 2.85 | 63 |
| Urea | 46.6 | 1.80 | 84 |
| Natural sources of organic nitrogen | | | |
| Cocoa shell meal | 2.7 | 0.60 | 2 |
| Castor pomace | 4.8 | 0.90 | 4 |
| Cottonseed meal | 6.7 | 1.40 | 9 |
| Dried blood | 13.0 | 1.75 | 23 |
| Fish scrap | 9.2 | 0.90 | 8 |
| Guano, Peruvian | 13.8 | 0.95 | 13 |
| Guano, white | 9.7 | 0.45 | 4 |
| Milorganite sludge | 7.0 | 1.70 | 12 |

to meet the total requirements of the strawberry plant during critical periods of crop growth (table 7-4); manure supplemented with N fertilizer has provided better results than manure used alone. Manure spread in autumn should be applied over a cover crop, which helps retain much of the N from manure that otherwise might be lost to leaching and runoff.

Manure is also a source of organic P and K, but these nutrients are released slowly as the organic matter decomposes. However, in a field that has received manure applications over a long period of time, available P should be high. Growers who use manure for fertilizer should monitor Mg levels closely, because manure is not a good source of Mg.

## Compost

Compost is partially broken down organic matter that provides a source of nutrients and organic matter to plants. Because of the loss of water and carbon dioxide that occurs during the composting process, the quantity of the final product is much less than that of the raw materials; but compost materials will contain a higher concentration of N, P, and K. However, N is less available in compost compared to manure, because less is in

### *Pathogen Contamination*

Growers using manure should take practical steps to minimize the risk of pathogen spread onto the berries. To minimize the risk of pathogen contamination:

- Store slurry for sixty days in summer or ninety days in winter prior to field application
- Compost fresh manure to kill most pathogens
- In fall, apply fresh manure onto a cover crop, not to bare ground
- Incorporate manures at least sixty days prior to harvesting
- Never sidedress with slurry of fresh manure prior to harvest

**Table 7-4.** Percentage of manure nitrogen available to crops in the current year

| Time of Application | Poultry | Cow |
|---|---|---|
| Incorporation the same day | 0.75 | 0.50 |
| Within 1 day | 0.50 | 0.40 |
| Within 2–4 days | 0.45 | 0.35 |
| Within 5–6 days | 0.30 | 0.30 |
| After 7 days | 0.15 | 0.20 |
| Applied previous fall | | |
| Without a cover crop | 0.15 | 0.20 |
| With a cover crop | 0.50 | 0.40 |

the ammonium form and more is in the residual organic form. For example, whereas 35% of manure N might be available in the year the manure is spread, only 10% of the N in compost is available.

Compost has properties that make it potentially beneficial for strawberry growers beyond the nutrient contribution. Compost improves soil structure and water-holding capacity, and some composts suppress diseases because of the high level of microbiological activity they contain. Composted manure does not present a health hazard and is odor-free.

### *Green Manure*

Green manure is a term used to describe a cover crop that is grown for the purpose of incorporation into the soil. An incorporated cover crop provides organic matter, which improves soil structure and water-holding capacity. Cover crops can also sequester residual N that is released from or applied to the soil. Green manures with a high N content (such as legumes) decompose quickly. Those with a low N content (such as cereal grains) decompose more slowly, tying up N for a period of time. Strawberries should not be planted immediately after incorporation of a green manure, or they could experience "nitrogen drag."

## Individual Nutrients

### *Nitrogen (N)*

The strawberry plant has an increasing demand for N throughout the establishment year; therefore, a constant supply of N is required for optimal growth. In the fruiting year, N applications in the spring can be detrimental. Studies have found that an early spring N application can result in an increase in gray mold and mites and a reduction in fruit quality. The best time to apply N is immediately after fruiting, with supplementation in late summer to maintain N availability through autumn.

Nitrogen sources include ammonium-based fertilizers, nitrate fertilizers, organic sources, and organic matter (table 7-5 on page 58). The amount of N released from organic matter can be significant. Plants tend to grow better in soils high in organic matter (greater than 6%) than those low in organic matter (less than 2%), even with supplemental N fertilization. Most commercial growers apply synthetic fertilizers, even when organic matter is high. This ensures adequate amounts of N during critical growth periods. Nitrogen is released slowly from soil organic matter and manures, so a sufficient amount may not be available at a critical time if one relies solely on organic sources. When added organic matter is high in carbon, N can become temporarily unavailable. This may occur when straw or other plant residues are incorporated into soil.

Fertilizer N is available in two forms: nitrate and ammonium. The strawberry prefers nitrate N over the ammonium form. Nitrate N is very soluble in water, has a low salt index, and is readily available to the plant. However, nitrate fertilizers are subject to leaching and are generally more expensive than ammonium fertilizers. Therefore, many fertilizers contain the ammonium form of N because it is less expensive to manufacture and soil organisms eventually convert the ammonium form into the nitrate form. (Some ammonium-based fertilizers are coated with S or synthetic resin to further slow the release of N to the plants and extend its availability, but these fertilizers are expensive.) Because the ammonium ion has a positive charge, it tends to be adsorbed to soil colloids and is less easily leached. So ammonium-based fertilizers are commonly used in strawberry production even though they tend to acidify the soil (table 7-3).

In newly planted fields, use calcium nitrate for fertilization, especially if the site was fumigated prior to planting. Calcium nitrate has a readily available form of N, has a low salt index, and is not subject to volatilization. On well-established plantings, other sources of N are suitable. Many growers prefer ammonium nitrate because it provides for both a rapid response (in the form of nitrate) and a slow release (in the form of ammonium). Urea is usually the least expensive N source, but it is subject to volatilization under certain conditions. If volatilization occurs, N may be lost to the air. Volatilized ammonia can blacken strawberry leaves since they are close to the soil. Incorporating urea will prevent this loss.

**TABLE 7-5.** Typical composition of some common chemical sources of fertilizer nitrogen and potassium

| Source | %N | %$P_2O_5$ | %$K_2O$ | %MgO | %S |
|---|---|---|---|---|---|
| Ammonium sulfate | 21.0 | — | — | — | 24.0 |
| Anhydrous ammonia | 82.0 | — | — | — | — |
| Ammonium chloride | 25.0–26.0 | — | — | — | — |
| Ammonium nitrate | 33.0–34.0 | — | — | — | — |
| Ammonium nitrate-sulfate | 30.0 | — | — | — | 5.0–6.0 |
| Ammoniated ordinary superphosphate | 4.0 | 16.0 | — | 0.5 | 10.0 |
| Monoammonium phosphate | 11.0 | 48.0–55.0 | — | 0.5 | 1.0–3.0 |
| Diammonium phosphate | 18.0–21.0 | 46.0–54.0 | — | — | — |
| Ammonium phosphate-sulfate | 13.0–16.0 | 20.0–39.0 | — | — | 3.0–14.0 |
| Calcium nitrate | 15.0 | — | — | — | — |
| Potassium nitrate | 13.0 | — | 44.0 | 0.5 | 0.2 |
| Sodium nitrate | 16.0 | — | — | — | — |
| Urea | 45.0–46.0 | — | — | — | — |
| Potassium chloride | — | — | 60–62 | — | — |
| Potassium sulfate | — | — | 50–52 | — | 17 |
| Potassium magnesium sulfate | — | — | 22 | 11 | 22 |
| Potassium nitrate | 13 | — | 44 | — | — |
| Potassium and sodium nitrate | 15 | — | 14 | — | — |
| Manure salts | — | — | 22–27 | — | — |
| Potassium hydroxide | — | — | 83 | — | — |
| Potassium carbonate | — | — | <68 | — | — |

Foliar applications of urea are of limited value in strawberries. Although a significant amount of N can be absorbed through the leaves, only a small amount can be applied at any one time, usually less than 2 pounds per acre actual N.

Soil tests are of limited value in estimating N availability, as large fluctuations occur from week to week. Some progress is being made to assess N status from plant sap using specific ion detectors, but the practical use of these tools is still years away. Growers must continue to rely on scheduled fertilizer applications and leaf analysis until more sophisticated methods are developed. A typical N fertilization regime might be as follows:

Year 1: 30 pounds per acre four weeks after planting
40 pounds per acre in early September

Year 2: 70 pounds per acre immediately after fruiting
30 pounds per acre in early September

This amount would be typical for a sandy loam soil with 3% organic matter content. Plants growing on sandier soils might require more, and plants in heavier soils with high organic matter content will require less. Adjust application rates up or down depending on the results of a leaf analysis. In general, growers in the Northeast provide adequate N to strawberry plants. Only about 1% of leaf samples show inadequate N. If the foliar leaf level in late July or early August is below 2%, then increase your current N application by 10% for each 0.1% that the sample is below 2%. This additional N can be applied in early September. If the foliar level is above 2.8%, then decrease your current N application by 10% for each 0.1% that the sample is above 2%. Too much N can induce a K deficiency. If the N/K ratio in your leaf sample is greater than 1.5, then you may have to reduce N even though the level is within an acceptable range.

Nitrogen deficiency results in smaller plants on which older leaves develop a reddish color (photos 7-1 and 7-2). Symptoms are most apparent in late summer.

## Phosphorus (P)

The total amount of P in the soil averages about 900 pounds per acre across all soil types, but only a fraction is available for plant growth. Much of the P is tied up in soil minerals, insoluble precipitates, and organic matter. Little P is dissolved in the soil solution, so most uptake occurs through diffusion. Good root growth is required for the plant to obtain an adequate surface area to facilitate P uptake. Strawberries tend to have a low demand for P relative to other crops. Only a small percentage of commercial fields are deficient in P; in most cases, excess P is more of a concern.

Phosphorus tends to react with cations in the soil solution, forming insoluble precipitates with Fe, aluminum (Al), Ca, and Zn. Excess P fertilization can result in micronutrient deficiencies.

Phosphorus availability is affected by soil pH, soil moisture, soil type, organic matter content, the amount of Ca and Al in the soil, and soil temperature. Extremes in pH, temperature, and moisture can limit availability, as can excessive Ca and Al. Soils with a large quantity of clay will fix more P than lighter soils. Certain microorganisms can increase P availability, including phosphobacteria and some mycorrhizal fungi. Humic acids from organic matter decomposition increase the solubility of P. Available P is increased after incorporating a green manure, even though no additional P will have been added.

Because inorganic P has a low solubility in water, it is not subject to leaching. However, it must be incorporated to be effective. Phosphorus fertilizers (table 7-6 on page 60) applied to the soil surface will not move into the root zone within a useful time period. Preplant incorporation is necessary. Large granules of fertilizers are slow to break down; so for maximum effectiveness, uniformly distribute small granules throughout the root zone. Keep soil pH near 6.5 to ensure that P is available.

Phosphorus can be applied though a drip irrigation system in the form of phosphoric acid. Materials containing P are incompatible with many other fertilizers. Use caution when applying through a drip irrigation system.

Plants deficient in P develop a purplish cast in older leaves. Younger leaves may turn dark green (photo 7-3). Foliar P levels tend to decline after fruiting. If P levels are low in July, then apply 100 pounds per acre in a form that is readily available to the plant (table 7-6 on page 60).

## Potassium (K)

Strawberries have a relatively high demand for K, as it is a major component of fruit. Much more K is present in the soil than is available to the plant. For example, soils may average 25,000 ppm, but the concentration in the soil solution may be only 10 ppm. Soil tests estimate the amount of K on exchange sites, which is also available for plant uptake. This amount is variable but can be up to 600 ppm. Since little K is dissolved in solution, diffusion is the most important mechanism of uptake. Therefore, good root development is essential to increase the surface area through which the K can diffuse.

The availability of K is very dependent on soil chemistry. The amount of organic matter, the soil texture, the type of clay, and the mineral base also influence availability. In most cases, increasing the organic matter will increase exchange capacity, allowing more K to be adsorbed to the exchange sites. Negatively charged clays also provide exchange sites for K; however, certain clays can trap K ions between layers when they dehydrate. High levels of other nutrients, such as Ca and Mg, can replace K on the exchange sites. A balance among these three cations is necessary for proper nutrition.

Preplant incorporation of K (table 7-5) is most effective, while fertigation can be used to supply K in established plantings. Surface applications of K fertilizers are of limited value for short-term crops such as strawberries. Foliar uptake is possible, although the total amount that can be supplied through this method in a single application is small. Sequential applications are effective but expensive.

Potassium is required for many physiological processes in the plant, including enzyme activation, transport of sugars, stomatal functioning, charge balance, protein synthesis, and photosynthesis. Deficiencies occur on older leaves first and result in marginal necrosis. Leaflet petioles may become necrotic also, and leaflets may

**Table 7-6.** Composition of phosphatic fertilizer materials

| Material | Total N (%) | Total K (%) | Total S (%) | Total Ca (%) | Total Mg (%) | P Total (%) | P Available* (% of total) |
|---|---|---|---|---|---|---|---|
| Ordinary super-phosphate | — | — | 11–12 | 18–21 | — | 7–9.5 | 97–100 |
| Conc. (triple) super-phosphate | — | — | 0–1 | 12–14 | — | 19–23 | 96–99 |
| Enriched super-phosphate | — | — | 7–9 | 16–18 | — | 11–13 | 96–99 |
| Dicalcium phosphate | — | — | — | 29 | — | 23 | 98 |
| Superphosphoric acid | — | — | — | — | — | 34 | 100 |
| Phosphoric acid | — | — | 0–2 | — | — | 23 | 100 |
| Potassium phosphate | — | 29–45 | — | — | — | 18–22 | 100 |
| Ammonium phosphate nitrate | 30 | — | — | — | — | 4 | 100 |
| Ammonium poly-phosphate | 15 | — | — | — | — | 25 | — |
| Magnesium ammonium phosphate | 8 | — | — | — | 14 | 17 | — |
| Raw rock phosphate | — | — | — | 33–36 | — | 18–32 | 2 – 3 |

* By neutral 1.0N ammonium citrate procedure.

darken (photo 7-4). Potassium levels in leaves tend to fluctuate during the season and decrease as crop load increases. If foliar levels are low, then supplemental K can be added with the amount dependent on soil type. A reasonable supplement in a sandy soil would be 100 pounds per acre; in a heavier soil, half that amount can meet K needs. Fall application is desirable. Excess K can induce a Mg deficiency, so if the K/Mg ratio exceeds 4, then additional Mg should be applied if K is also applied.

## *Sulfur (S)*

Sulfur occurs in elemental form, as well as in sulfides, sulfates, and organic combinations with carbon and N. The majority of S comes from decomposing organic matter, although a significant amount is dissolved in rain, up to 100 pounds per acre annually. Most is absorbed by mass flow. Because S availability is associated with carbon and N cycling, large annual variations occur, giving soil tests limited value under most conditions.

Sulfur is an essential component of proteins; when S is deficient, overall plant vigor is decreased and leaves turn a reddish color (photo 7-5). In the Northeast, S has not been considered problematic, especially since the region gets more than its share of acid rain.

The major use of S for strawberry growers is for pH reduction. If soils are too alkaline, the addition of S will lower the pH. Sulfur is oxidized by bacteria into sulfuric acid, which helps to neutralize basic ions such as Ca and Mg. The size of S granules is the major factor influencing the rate of soil pH change. After ninety days, only about 1% of the S will react if the granules are unable to pass through a 10-meshes-per-inch screen (0.2 inch in diameter), whereas nearly half will react if the size is less than 100 meshes per inch.

## Calcium (Ca)

Calcium is a major component of pectin, the strengthening agent of cell walls. Without sufficient Ca, fruit are soft, and the leaf tips turn brown and do not completely expand. In severe cases, runner plants turn brown and new leaves develop interveinal necrosis (photos 7-6, 7-7, and 7-8).

Symptoms of Ca deficiency are common, but this is rarely due to insufficient Ca in the soil. Ca mobility is limited, both in the soil and in the plant, and the factors affecting mobility indirectly influence Ca uptake. Calcium can enter the plant only through unsuberized root tips—not along the entire length of root. Therefore, factors that limit mass flow, such as low soil moisture and cool, cloudy, humid weather, can reduce the amount of Ca entering the plant to below critical levels. Since Ca movement within the plant is also limited, deficiencies occur in new growth at points farthest from the root system.

Adequate Ca is usually present if the soil pH is within an acceptable range. With drip irrigation, Ca can be leached out of the wetted zone over time. In most cases, though, maintaining good soil moisture is the best way to prevent tip burn associated with Ca deficiency.

Apply adequate limestone prior to planting to adjust the soil pH to 6.0 to 6.5. In lighter soils, more Ca may be required than is needed for pH adjustment. If Ca is required but the pH is already high, gypsum can be used as a Ca source. Over a five-year period, as much as 2,000 pounds of Ca can be leached out of the root zone. Accommodation for this drop in Ca, and concomitant drop in pH, should be anticipated prior to planting.

Many growers have reported firmer, shinier fruit in response to foliarly applied Ca (for example, calcium chloride) during fruit development, but this has not been documented in controlled studies.

## Magnesium (Mg)

Magnesium supply is quite variable from soil to soil. Deficiencies are common, especially on sandy, acidic soils. Magnesium is an essential element in chlorophyll, so without it the plant turns yellow, starting with interveinal areas on older leaves (photo 7-9). Cold, wet, cloudy weather induces Mg deficiency in marginal situations, since uptake is mainly by mass flow.

Magnesium availability increases with soil pH up to 8.5 (see figure 7-2 on page 53). Magnesium can be relatively unavailable at a low pH. Also, high levels of Al can reduce Mg availability, and excessive K can induce Mg deficiency. A K/Mg ratio of less than 5 is desirable. If this ratio is high, additional Mg could be beneficial even if Mg is within the desired range. Since Mg is fairly soluble, it can be effectively applied to leaves (depending on the formulation, at 5 pounds actual Mg per acre) or to the soil surface (at 40 pounds per acre). It can also be preplant incorporated (as dolomitic lime). The least expensive source of Mg is dolomitic lime, but it must be incorporated prior to planting. A soluble form is magnesium sulfate (Epsom salts) at 20% Mg.

## Iron (Fe)

Iron is the fourth most abundant element in the Earth's crust, but concentrations in soils vary widely. Much of the Fe in soil is in the insoluble ferric form ($Fe^{3+}$), which is unavailable to plants. Available Fe in the ferrous form ($Fe^{2+}$) is obtained from clays, minerals, and hydroxides. Root exudates, microbial byproducts, and organic matter are natural chelates that can increase Fe availability up to threefold.

Iron becomes more available with decreasing soil pH. Excessive liming can induce an Fe deficiency, which results in yellowing of younger leaves, because Fe is involved with chlorophyll synthesis (photo 7-10). Excess P can form insoluble precipitates with Fe. Nitrogen sources also affect Fe availability—fertilization with ammonium sources of N tends to decrease soil pH around the root zone, thereby increasing Fe availability.

Rarely is an Fe-containing, soil-applied fertilizer required to relieve a deficiency. Acidification of soil is the most cost-effective way to increase Fe availability. Foliar applications are useful during the time when soil pH is being lowered; formulations vary, so follow the label directions.

## Manganese (Mn)

Manganese is widely distributed in northeastern soils. With the exception of the mid-Atlantic coastal plain, few soils are inherently low in this nutrient. However, across the United States, Mn is the most commonly deficient micronutrient. Manganese availability is strongly associated with soil pH, and deficiencies most often occur on alkaline soils or on soils that have been heavily limed. In some soils, toxicity can occur if the pH is too low. Strawberries are very tolerant to extremes in Mn levels, so this nutrient is of little concern to most growers.

If Mn is deficient, soil pH should be lowered to below 6.5. Foliar sprays may temporarily relieve a deficiency, which is characterized by generally poor growth without distinguishing symptoms.

## *Boron (B)*

Boron is the only nonmetal among the micronutrients and usually does not occur as a charged ion. This, coupled with its small size, makes it especially prone to leaching. In coarse-textured soils that are low in organic matter, up to 85% of the available B can be leached with only 5 inches of water. The level of B in soil varies widely, so B is one of the most commonly deficient micronutrients in strawberry plantings. Furthermore, soils naturally low in B occur throughout the United States and Canada.

Boron is essential for root growth (photo 7-11). If root growth is poor (photo 7-12), deficiencies of other nutrients can develop and plants become stunted. Plants deficient in B show asymmetrical leaf growth (photo 7-13), and berries can be deformed despite adequate pollination (photo 7-14). Foliar levels tend to decline during the season. If a foliar analysis indicates 30 ppm B or less early in the season, levels may be inadequate to sustain the plants through fruiting. To supplement soil B, apply no more than 1 pound of actual B per year. Uptake occurs through leaves and roots, so the best time to apply B is after leaves are mowed at renovation. Blending granular B with other fertilizers makes application easier. A foliar application might consist of 1.5 pounds per acre solubor (20% B) in 100 gallons of water.

Mass flow is the most important mode of uptake for B, so conditions not favoring water uptake may induce a deficiency. Levels of other nutrients, especially Ca, K, N, and P, have been reported to affect B uptake.

A narrow range exists between deficient and toxic B levels. Toxic levels sometimes accumulate with irrigation in arid climates or where overapplication has occurred. Hard, yellowish berries and uneven ripening can result if levels exceed 100 ppm.

## *Zinc (Zn)*

Zinc deficiency is widespread in North America. Total soil Zn is not a good predictor of availability to plants, as Zn has a strong tendency to combine with anions in the soil to form insoluble precipitates. Zinc is also complexed by organic matter, which can reduce availability in certain circumstances. Zinc availability increases as soil pH decreases.

Zinc functions in enzyme activation and synthesis of growth regulators. Plants with Zn deficiency are stunted, have narrow leaves, and tend to accumulate high levels of P. Plants perform poorly if the P/Zn ratio is greater than 140.

Zinc is relatively immobile in the soil; so preplant applications such as zinc sulfate, although effective, can be expensive. Soil surface applications are not effective. Sequential foliar applications can be the least expensive means of supplying Zn. Fertigation also may be an effective way to increase plant Zn levels.

## *Copper (Cu)*

Copper is one of the least mobile nutrients in soil or plants. For this reason, when Cu is deficient, corrections are difficult. Although a significant amount of soil Cu is insoluble, a significant pool may be complexed with natural organic chelates. This pool is available for plant uptake.

Only small areas of North America contain soils that are inherently low in Cu. However, high soil pH and excessive P, Zn, and Al restrict Cu absorption and translocation. Furthermore, Cu adsorption to Fe, Al, and Mn oxides can be significant. The dynamics of Cu in the soil are very complex.

Visual symptoms of Cu deficiency are not distinctive, although Cu is an essential component of many enzyme systems. Foliar levels above 7 ppm are considered adequate, but no response to applications have been reported when levels are above 3 ppm.

Copper is toxic to both roots and leaves, so remedial action can cause more harm than good. Foliar Cu applications can burn leaves, so small amounts of chelated forms are recommended. However, because of low mobility, foliar levels may not increase in response to foliar applications.

## *Molybdenum (Mo)*

Molybdenum is an important component of enzymes involved with N metabolism, but levels in the soil are very low. The plant needs only small amounts of Mo (less than 1 ppm); so deficiencies are common only in acidic, sandy, leached soils. Foliar applications are effective for providing the small amounts required.

## Fertilizer Sources

Many types of fertilizer can be used in strawberry plantings provided that they meet the nutrient requirements of the plant. Organic sources of nutrients may be obtained easily (table 7-3 on page 56) and often improve soil organic matter. However, the release rate of nutrients from organic fertilizers is often slow, and large amounts of fertilizer are required to meet requirements for optimum growth. Concentrated synthetic fertilizers usually are easier to apply; are more consistent in composition (tables 7-5 on page 58, 7-6 on page 60, and 7-7); and release nutrients quickly. The disadvantages of synthetic fertilizers are that they often have a high salt index (they can burn the plant); they are subject to leaching; and they may contain chlorides, which are toxic at high levels. Fertilizers should be used sparingly in young

**Table 7-7.** Inorganic compounds commonly used as micronutrient sources

| Micronutrient Source | Solubility in $H_2O$ | Percent Element |
|---|---|---|
| **Boron (B)** | | |
| $Na_2B_4O_7$ (anhydrous borax) | Soluble | 20 |
| $Na_2B_4O_7 \cdot 5H_2O$ (fertilizer borate) | Soluble | 14 |
| $Na_2B_4O_7 \cdot 10H_2O$ (borax) | Soluble | 11 |
| $H_3BO_3$ | Soluble | 17 |
| **Copper (Cu)** | | |
| $CuSO_4 \cdot H_2O$ | Soluble | 35 |
| $CuSO_4 \cdot 5H_2O$ | Soluble | 25 |
| $CuSO_4 \cdot 3Cu(OH)_2 \cdot H_2O$ | Insoluble | 37 |
| $CuO$ | Insoluble | 75 |
| **Iron (Fe)** | | |
| $FeSO_4 \cdot H_2O$ | Soluble | 33 |
| $FeSO_4 \cdot 7H_2O$ | Soluble | 20 |
| $Fe_2(SO_4)_3 \cdot 9H_2O$ | Soluble | 20 |
| $FeSO_4 \cdot (NH_4)_2 SO_4$ | Soluble | 22 |
| **Manganese (Mn)** | | |
| $MnSO_4 \cdot 4H_2O$ | Soluble | 26–28 |
| $MnCl_2$ | Soluble | 17 |
| $MnCO_3$ | Insoluble | 31 |
| $MnO_2$ | Insoluble | 41–68 |
| **Molybdenum (Mo)** | | |
| $Na_2MoO_4$ (anhydrous) | Soluble | 47 |
| $Na_2MoO_4 \cdot 2H_2O$ | Soluble | 39 |
| $(NH_4)_2MoO_4$ | Soluble | 49 |
| $MoO_3$ | Slightly soluble | 66 |
| $CaMoO_4$ | Insoluble | 48 |
| **Zinc (Zn)** | | |
| $ZnSO_4 \cdot H_2O$ | Soluble | 36 |
| $ZnSO_4 \cdot 7H_2O$ | Soluble | 22 |
| $ZnCl_2$ | Soluble | 47 |
| $ZnSO_4 \cdot 4Zn(OH)_2$ | Slightly soluble | 55 |
| $ZnCO_3$ | Insoluble | 52 |
| $ZnO$ | Insoluble | 60–78 |

plantings because of sensitivity to salts. Calcium nitrate is recommended on first-year plantings as a N source because of its low salt index, especially if the field was fumigated before planting. If more than 100 pounds per acre of K is required, potassium sulfate is recommended over potassium chloride to avoid chloride toxicity.

Many fertilizers tend to acidify the soil; so if large amounts are applied, additional lime may be necessary to buffer against pH changes (table 7-3 on page 56). Fertilizers are available that contain micronutrients (table 7-7 on page 63); but in many cases, micronutrients become fixed in soil and are unavailable to the plant shortly after application. For this reason, chelates and fertigation are the preferred application methods for micronutrients.

## Chelated Nutrients

Chelate is derived from a Greek word meaning *claw* and is used to describe metallic cations complexed to large organic molecules. Complexed ions are protected from reaction with inorganic constituents that would make them unavailable for uptake by plants. Plant roots exude chemicals that act as chelates. Chelates can result from the breakdown of organic matter, or they can be synthesized. Zinc, Cu, Mn, and Fe are among the essential plant micronutrients that form chelates with organic molecules.

Chelates vary in their stability and suitability as sources of micronutrients. Under most conditions, Fe chelates are more stable than those of Zn and Cu, which in turn are more stable than Mn chelates. This is because Fe has a higher affinity for chelates. If Cu chelate is added to a soil high in Fe, the Fe may displace the Cu, rendering the Cu subject to soil reactions. Therefore, the ability of chelates to increase nutrient availability depends on the level of other available cations. With foliar applications, the organic chelates are less reactive and cause less phytotoxicity. However, because of their large size, their movement into a leaf is more limited than with inorganic salts.

## Fertigation

Fertigation is often the most effective way of providing certain micronutrients to strawberries (table 7-8). Applications can be more uniform than with ground equipment and can be made during any weather. Less fertilizer is usually required as well. Disadvantages include the capital expense and time to set up and calibrate the system. The potential for leaching is greater with fertigation, and it is highly regulated by most states. Drip irrigation systems are susceptible to plugging if improper fertilizer materials are used. Although little is known about fertigation for perennial strawberries, an increasing number of growers are finding it worthwhile to install a fertigation system and experiment on their own.

### Nutrient Compatibility

Below are some rules regarding compatibility.

1. Do not mix Ca products with those containing phosphates or sulfates.
2. Do not mix Mg, Zn, Fe, or Cu products with products that contain phosphates. Water naturally high in Fe can be a problem, so the Fe must be removed prior to injection of P fertilizers.
3. Do not mix Fe chelates with other chelated products.

The amount of fertilizer to apply is dependent on many factors, but a starting point is 4 pounds per acre actual N per week between early May and mid-September of the planting year, and 10 pounds per acre actual N per week between mid-July and mid-September of the fruiting year. This amount should be adjusted accordingly if granular fertilizers are used. Other nutrients can be added if a leaf analysis indicates the need.

If fertigation is to be used, consider water quality and uniformity of water application by the system. Water low in salts, suspended particles, and bacteria is essential, as is a system designed to deliver equivalent amounts of water throughout a field. Consult *Trickle Irrigation in the Eastern United States* for information on designing trickle irrigation systems for proper application of water and injection of chemicals; see page 160 for a book description and page 158 for ordering information.

Irrigation lines should be filled with water before injecting fertilizers, then flushed after injection is complete. Fertigation should occur near the end of the irrigation cycle to prevent leaching. Flush lines thoroughly between different fertilizers to avoid incompatibility problems (see sidebar above). Chlorination may be required to control algae and bacterial slime that can plug emitters. Fertigation should not be used to correct major soil nutrient and pH problems; this should be done before planting.

Combinations of certain nutrients can form insoluble precipitates with each other, plugging the emitters and causing untold misery for the operator. To determine if chemicals are compatible, shake them together in a jar to determine if precipitation occurs.

**Table 7-8.** Materials for fertigation and their solubilities

| | Solubility (pounds/gallon water) |
|---|---|
| **A. NITROGEN** | |
| Ammonium nitrate (33.5-0-0) [$NH_4NO_3$] | 9.8 @ 32˚F |
| Ammonium sulfate (20-0-0) [$(NH_4)_2SO_4$] | 5.9 @ 32˚F |
| Calcium nitrate (15-0-0 + 22%Ca) [$Ca(NO_3)_2$] | 10.1 @ 64˚F |
| Magnesium nitrate (11-0-0 + 9.5%Mg) [$Mg(NO_3)_2$] | 3.5 @ 64˚F |
| Potassium nitrate (13-0-45) [$KNO_3$] | 1.1 @ 32˚F |
| Sodium nitrate (16-0-0) [$NaNO_3$] | 6.1 @ 32˚F |
| Urea (44-0-0) [$NH_2CONH_2$] | 6.5 @ 41˚F; 10 @ 77˚F |
| **B. POTASSIUM** | |
| Potassium chloride (muriate of potash) (0-0-60) [KCl] | 2.9 @ 68˚F |
| Potassium nitrate (13-0-45) [$KNO_3$] | 1.1 @ 32˚F |
| Potassium sulfate (0-0-48–54 + 16–18%S) [$K_2SO_4$] | 0.6 @ 32˚F; 1.0 @ 77˚F |
| **C. PHOSPHORUS** | |
| Phosphoric acid (0-55–77-0) [$H_3PO_4$] | 43.1 (liquid) |
| Mono-potassium phosphate (0-52-35) [$KH_2PO_4$] | 2.75 @ 77˚F |
| Diammonium phosphate (DAP) (21-54-0) [$(NH_4)_2HPO_4$] | 3.5 @ 32˚F |
| Mono-ammonium phosphate (MAP) (11-48-0) [$NH_4H_2PO_4$] | 1.9 @ 32˚F |
| Mono-calcium phosphate (0-53-0 + 16%Ca) [$Ca(H_2PO_4)_2$] | 0.15 @ 86˚F |
| **D. CALCIUM** | |
| Calcium nitrate [$Ca(NO_3)_2$] | 10.1 @ 64˚F |
| Hydrated lime [$Ca(OH)_2$] | 0.02 @ 68˚F |
| **E. MAGNESIUM** | |
| Epsom salts (10%Mg and 13%S) [$MgSO_4 \cdot 7H_2O$] | 5.9 @ 32˚F |
| Magnesium nitrate (9.5%Mg) [$Mg(NO_3)_2$] | 3.5 @ 64˚F |
| **F. BORON** | |
| Solubor (20.2%B) | 1.0 |
| Boric acid (17.5%B) [$H_3BO_3$] | 0.5 @ 86˚F; 2.3 @ 212˚F |
| Borax (11.3%B) [$Na_2B_4O_7 \cdot 10H_2O$] | 0.13oz @ 32˚F; 14lbs @212˚F |
| **G. MANGANESE** | |
| Manganese sulfate (24.6%Mn) [$MnSO_4 \cdot 4H_2O$] | 8.7 @ 32˚F |
| Manganese chelates (up to 12%Mn) | — |
| **H. IRON** | |
| Iron chelates (up to 10%Fe) | — |
| Ferrous sulfate (20%Fe + 11.5%S) [$FeSO_4 \cdot 7H_2O$] | 1.3 |
| **I. ZINC** | |
| Zinc sulfate (23%Zn + 11%S) [$ZnSO_4 \cdot 7H_2O$] | 8.0 |
| Zinc sulfate monohydrate (36%Zn + 18%S) [$ZnSO_4 \cdot H_2O$] | — |
| Chelated zinc products (up to 14%Zn) | — |
| **J. COPPER** | |
| Copper sulfate (25%Cu + 13%S) | 2.6 @ 32˚F |
| Chelated copper products (up to 13%Cu) | — |
| **K. All water-soluble complete fertilizers (NPK) and commercial mixtures** | |

CHAPTER 8

# Insect, Mite, Mollusc, and Vertebrate Scouting and Management

Arthropods in the strawberry planting can be beneficial (like bees, spiders, and predatory mites); benign (like green metallic beetles); or harmful (like tarnished plant bugs). Harmful insects and mites attack the fruit, buds, leaves, and roots of the strawberry plant. They can also increase the susceptibility of damaged plants to other pests. The grower's objective should be to minimize damage from harmful insects while preserving beneficial insects.

This chapter is designed to familiarize growers with the biology of strawberry insects and mites, to help growers identify the damage pests cause, and to briefly outline ways growers can control pests. Emphasis is on cultural controls, since regulations and restrictions concerning pesticide use are continually changing and vary from state to state. Growers should consult their local extension personnel for recommendations concerning the most effective control procedures available in their area.

## Bees

Scientific names: *Aphis mellifera* and others

Wind and bees are responsible for pollinating the one hundred to five hundred ovules in a strawberry flower. Although a majority of ovules can be pollinated without bees, bees are essential for the berries to reach their full size potential and achieve a good shape. Partially pollinated berries are small and tend to have a rough, dimpled, seedy appearance, similar to boron deficiency (photo 7-14). A direct relationship exists between the number of fertilized ovules on a receptacle and final fruit size.

Many bees species are capable of pollinating strawberries, and most of these species occur in the wild. Of the managed bees, honey bees are the most commonly used for strawberries. One or two strong hives per acre are sufficient to provide for the pollination needs of strawberries. A brood nest that spans five or six frames is optimal.

Place hives off of the ground, east-facing, in an area that receives maximum sunlight. Windbreaks near the hive are helpful. Do not allow grass to grow up around the hives, and avoid spraying nearby fields with pesticides while the bees are present. Avoid using highly toxic pesticides within a week of introducing the bees (table 8-1). Before introducing the bees, mow the field to eliminate competing flowers and thus encourage the bees to visit the strawberries. Keep an ample supply of fresh water near the hive.

**TABLE 8-1.** Relative toxicity of pesticides to honey bees

| Chemical | Toxicity |
|---|---|
| Benlate (benomyl) | low |
| Brigade (bifenthrin) | high |
| Captan | low |
| Diazinon | high |
| Dibrom (naled) | high |
| Furadan (carbofuran) | high |
| Guthion (azinphosmethyl) | high |
| Kelthane (dicofol) | low |
| Lorsban (chlorpyrifos) | high |
| Malathion | high |
| Methoxychlor | low |
| Morestan (oxythioquinox) | low |
| Sevin (carbaryl) | high |
| Thiodan | medium |
| Thiram | low |

Some growers maintain areas near their fields exclusively for native and feral bees. The bees forage and nest in these sites and are available for the pollination needs of fruits and vegetables.

## Fruit Damage

### *Tarnished Plant Bug*

Scientific name: *Lygus lineolaris*

The tarnished plant bug (TPB) is a small ($^1/_4$ inch) bronze-colored insect with a triangular marking on its back (photo 8-1). The immature stage, or nymph, is smaller and bright green (photo 8-2). Superficially, TPB nymphs resemble aphids, but the nymphs have a more tapered body and longer legs and are much more active. TPB overwinters in the adult stage; nymphs are active in early spring and throughout the summer. Both adults and nymphs feed on the developing flowers and fruit, sucking out plant juices with straw-like mouth parts. Their feeding results in deformed fruit, typically referred to as "cat-faced" berries, "button" berries, or nubbins (photo 8-3). Cat-faced fruits are generally unmarketable.

Typically, two to three TPB generations occur per year, but the overwintering adults and the first spring generation of nymphs and adults are the most threatening to June-bearing strawberries. With dayneutral cultivars, the situation becomes more difficult, because the TPB population increases during the summer and continues to feed on flowers and developing berries as long as they are available.

Managing TPB is critical because crop losses from damage can reach as high as 90%. Controlling weeds in and around the plants may reduce populations of this insect. Weeds around the edges of the field should be mowed regularly to discourage the buildup of TPB. However, do not mow weeds while strawberries are in bloom, since this will encourage migration into the field.

Begin sampling for TPB nymphs before the bloom period starts. The nymphs cannot be detected with sticky traps, because they do not fly and therefore will not come into contact with the traps. Sample nymphs by shaking flower clusters over a white surface (for example, white cardboard or piece of plastic). This shaking causes the nymphs to fall out of the flower clusters and onto the white surface, where they can be seen and counted. At least thirty flower clusters should be sampled evenly across a field. If the average nymph count exceeds 0.25 nymphs per cluster before 10% bloom or if more than four out of thirty clusters are infested with nymphs, then applying an insecticide may be warranted.

Sample at least once a week following a V-shaped sampling pattern in the field (see figure 2-1 on page 8). If no nymphs are found in the field until mid to late bloom, then raise the threshold to 0.50 nymphs per flower cluster and make spray applications only after bloom is over; this protects bees and other pollinators. Early spray applications are preferable, because they prevent buildup of TPB populations during bloom and avoid the spray residue left on fruit by late-season spray applications.

### *Strawberry Bud Weevil*

Scientific name: *Anthonomus signatus* Say (clipper)

The strawberry bud weevil, or "clipper," is an important pest of strawberries. It occurs somewhat less frequently than tarnished plant bug but can cause economic injury. This insect is a very small beetle ($^1/_8$ to $^1/_4$ inch) with a copper-colored body and a black head with a long snout (photo 8-4).

This insect overwinters as an adult in the soil or plant debris, either in the strawberry field or in nearby woods. In the spring the female weevil emerges from the overwintering site and moves into fields. After locating a suitable host plant, she chews a small hole in unopened flower buds and lays an egg in the hole. She then girdles the stem just below the bud. The flower bud dries up and dangles from the stem, eventually falling to the ground (photo 8-5). The immature weevils, or grubs, develop in the girdled buds and pupate in the soil. There is only one generation of this insect per year, and opportunities to manage it are limited.

Clippers may cause only minimal damage some years. To scout for clippers, begin examining the plants as soon as flower trusses are visible in the crown. Examine the plants once a week, looking for clipped buds or the presence of the adult weevil in the unexpanded flower clusters. The insects find shelter among the clusters of buds, especially on cold days. A careful, very close inspection is usually necessary to ensure an accurate assessment of injury.

As with tarnished plant bug sampling, follow a V-shaped sampling pattern (see figure 2-1 on page 8) in the field, sampling at five to ten locations. Additional samples may be taken along wooded edges of the field since the weevil migrates into the field from woods and hedgerows.

Examine a 2-foot section of row at each location. A sampling frame (a 2-foot-square frame made of wood or other lightweight material) may be made for this purpose.

Traditionally, 0.6 clipped buds per foot of row was used as the economic threshold. However, recent research has shown that many varieties compensate for clipper damage by increasing the size of remaining berries and producing more flowers. Therefore, the threshold of 0.6 clipped buds per foot is too low—five clipped buds per foot of row is a better threshold for most varieties. In most cases, clippers cause negligible losses.

Clipper presence is usually limited to the edge of a field near woods, so a border application of insecticide (the first five to ten rows) may be sufficient for control. Attempts to use row covers to exclude clippers have not been effective, presumably because some individuals will overwinter in the strawberry field and then emerge under the row cover, possibly to wreak havoc.

## Strawberry Sap Beetle

Scientific name: *Stelidota geminata* Say

Sap beetles cause hollowed-out cavities on ripe fruit, an injury very similar to slug injury. They also disseminate organisms that cause fruit rot. Larvae are small (photo 8-6), and their damage is less obvious because larvae develop in decomposing fruit.

Adults are small, oval beetles about $\frac{1}{10}$ inch long and dark brown in color, with no prominent markings on their wing covers (photo 8-7). They are sometimes hard to see because they drop to the ground when disturbed. They are found primarily when there is ripe fruit in the field and can be seen in the cavities of chewed fruit.

The best management for this pest is sanitation; keep the field as free of ripe fruit as possible. Trapping sap beetles with bait baskets of overripe fruit or beer placed between the edges of the field and wooded areas may help prevent the beetles from infesting a field. Sprays can be directed at the infesting beetles but are not very compatible with integrated pest management (IPM) tactics, because the risk of residue on ripe fruit is high; the benefit of cleaning up the problem must be weighed against this residue risk. Preventing the problem by avoiding overripe fruit in the field is the best strategy. Early renovation of fields may reduce populations the following year. Current research is focusing on a parasite that reduces egg laying and eventually kills the host.

## Sap (Picnic) Beetle

Scientific name: *Glischrochilus quadrisignatus* Say

This beetle causes some damage to ripe strawberries but is much less of a pest than the strawberry sap beetle. Adults are about $\frac{1}{4}$ inch long and are black with four yellowish orange spots on their backs (photo 8-8). Overwintered beetles emerge from organic matter in sheltered sites, usually after temperatures exceed 60° to 65°F for several days. They feed, mate, and lay eggs in the organic matter. After larval and pupal development is completed, new adult beetles appear from July to September, and they start feeding on the ripening fruits. There are two generations per year.

The sap beetle, also called the "picnic beetle" because it can become a nuisance at any outdoor function where food is present, is attracted to fruit or any fermenting material. At any time from the start of fruit coloring through harvest, these small beetles may be found feeding on ripe or injured berries. They either feed near the surface or bore into the fruit, where they can be found next to the receptacle.

Because the beetles are attracted to injured and overripe fruit, control of other fruit-damaging pests and prompt harvesting of ripe berries can help reduce damage from this pest. Sprays should be applied, if necessary, as fruit begins to color or as soon as beetles become evident.

## Flower Thrips

Scientific name: *Franliniella tritici*

Flower thrips are very small. The adults are little more than a millimeter in length with yellowish, cigar-shaped bodies. They are weak fliers, with fringed wings that allow them to be carried by the wind. The immature stages are wingless, but they can move very quickly around a plant, hiding in protected places. While flower thrips are not thought to be able to survive the winters in the Northeast outside of greenhouses, they can ride air currents from southern areas and arrive suddenly in high populations if conditions are right. These insects feed by piercing plant tissues and sucking up the resulting sap. They seem to prefer to feed on flower parts but will move on to leaf and other tissues when thrips numbers are high. Thrips have a rapid generation cycle; once in a field, populations can build quickly.

Affected plants look generally healthy, but the fruit is very small and hard. Cracking may occur on fruit, and fruit may show a bronze discoloration (photo 8-9).

Thrips are a common sight on strawberry flowers, but significant injury from them is unusual. Check your plants for the presence of thrips when the first flowers begin to open. Blowing gently on the flowers will cause thrips to emerge, as they respond to the carbon dioxide in human breath.

Because thrips are very small, a 10x or 20x magnifying glass is helpful in locating them. Collect ten flower buds from a field, place the buds in a plastic bag, and seal the bag. Put the bag in a hot place—like the hood of a car—for a few minutes to kill the thrips, then count them. If there are more than one hundred thrips (or ten per flower bud), treatment should be considered. In general, sprays applied for tarnished plant bug just prior to bloom will probably get good control of thrips as well.

## *Slugs*

Scientific names: Various

Slugs are dark gray, black, yellow, or brown wormlike mollusks. They may be covered with spots and range in size from 1½ to 7 inches long. Slugs have become a common pest of vegetables, field crops, and ornamentals throughout the United States and Canada. Large numbers of slugs can be found in a wet year when the preceding winter was mild, especially in heavily mulched fields.

A slug is often described as a snail without a shell. The head of the slug has two sets of tentacles. The eyes are on the tips of the upper tentacles. The lower tentacles, which are shorter, are used for tasting and smelling. The mouth is located between and below the lower tentacles and is equipped with a radula, a tooth-covered rasp that the slug uses to grate plant tissue. The slug glides along a path of mucus that is secreted by the pedal gland located just below the mouth.

The slug mates throughout the warm months in most areas of the country. It is hermaphroditic, meaning that an individual slug has both male and female reproductive organs. An individual may start out as a male, then become both male and female, and finally become solely female, depending on the species. Certain species may even self-fertilize, which means they can produce viable offspring without mating. After mating, clusters of eight to sixty clear jellylike eggs are laid in sheltered areas on the ground. Newly hatched slugs resemble the adults but are much smaller. The average life span of the slug is from nine to thirteen months, and an adult can lay from three hundred to five hundred eggs during its lifetime. Because the eggs are very resistant to cold and drying, they are often the only life stage to overwinter. The adults can survive mild winters and winters where they are well sheltered in the ground.

Slugs injure plants by chewing holes of various sizes in the fruit (photo 8-10). Because slugs often feed at night, the only evidence of their presence may be glistening patches or streaks of dried slime seen on the plants and the ground nearby.

One way to sample slug populations in field crops is to dig holes 4 inches in diameter and 6 inches deep and cover them with asphalt shingles wrapped in aluminum foil. The reflective surface keeps the hole dark, cold, and moist—an ideal hiding place for slugs. The hole also can contain a shallow dish containing beer as an attractant. Slugs exhibit homing behavior and a tendency to aggregate. They will return to a secure hiding place night after night and will also seek out other slugs.

In some years, slug damage can be high even when large numbers of slugs are trapped from fields. Treating fields with poisonous slug baits in the fall and again in early spring provides some control. Unfortunately, the straw mulch which provides many benefits in terms of disease and weed suppression encourages high slug populations. Slug populations are often highest in fields that were in sod the previous year or that had crop debris on the ground. If strawberries are to be planted following sod, plow as early as possible in the fall.

## *Birds*

Scientific names: Various

Birds are often the first "customers" into a strawberry field when the fruit begin to ripen. Most growers do not have a problem with birds, but in a few cases, birds destroy significant amounts of early-ripening fruit. Cedar waxwings, robins, mockingbirds, and seagulls are the major problem species and are difficult to discourage. Cedar waxwings and robins descend on strawberry fields in flocks from roosting sites in trees and peck large holes in the fruit (photo 8-11). They are quite docile and will remain in the field despite the presence of humans. Maintaining a near constant presence in the field and eliminating roosting sites will reduce the damage caused by these birds. Audio and visual scare devices can be effective if their location in the field is frequently changed. Cannons and screamers are effective for short periods of time but are annoying to neighbors and customers. Computer-generated species-specific bird distress calls, coupled with moving hawk models, can be effective for more than a week at a time. Cedar waxwings and robins are songbirds protected by law and may not be killed.

# Leaf Damage

## *Strawberry Leaf Roller*

Scientific name: *Ancylis comptana fragariae*

The immature stage of this insect (the larvae) feeds on strawberry leaves. The larvae are small green or bronze caterpillars up to $^1/_2$ inch long at maturity (photo 8-12). They occur in the field prior to bloom and in mid to late July. Larvae are first found on the undersides of leaves in silken covers, then on upper sides of leaves that have been folded or rolled and tied with silken threads.

To control this pest, remove and destroy rolled leaves. If infestation is severe, a pre- or post-bloom spray application may be needed. Timing will depend on when larvae are present; often a pre-bloom insecticide spray is recommended.

## *Two-Spotted Spider Mites*

Scientific name: *Tetranychus urticae*

Two-spotted spider mites are very small ($^1/_{50}$ inch) insect-like creatures that feed on strawberry foliage (photo 8-13). Under heavy infestations, mite feeding destroys leaf chlorophyll and causes leaves to turn bronze (photo 8-14). Yield reductions may occur from heavy infestations.

Two-spotted spider mites (TSSM) are usually found on the undersides of leaves; are barely visible to the naked eye; and are especially active during hot, dry months. TSSM overwinters in the adult female stage. In the spring or early summer, females lay unfertilized eggs, which hatch into males, and fertilized eggs, which hatch into females, at a rate of two to six per day, depending on temperature. A female can live sixty to seventy days. Mites generally form colonies and may be most noticeable by the webbing that they produce in the vicinity of the colonies. These colonies are usually localized in "hot-spots" in the field rather than being evenly distributed throughout the field. Therefore, it is important to sample the field regularly and thoroughly, looking for leaf stippling or bronzing, which indicate "hot-spots," and examining individual leaves with a hand lens.

Symptoms of mite damage include yellow stippling, bronzing, and curling downward of leaves, especially older ones. Webbing is visible on undersides of leaves.

Sample mites weekly by using the V-pattern (see figure 2-1 on page 8) in the field with five to ten sample locations. Sample five leaves at each location. Examine the undersides of the leaves with a hand lens for the presence or absence of TSSM. Record the information on a field map so that "hot-spots" can be identified and treated. Several miticides are registered for use on TSSM in strawberries, and their use may be necessary with large populations. Some growers use miticides as the initial "knock down" agent, then release predators seven to ten days later for continued control. For chemical control, use a 25% infestation of a sixty-leaf sample as an action threshold. When spraying for mites, make sure to get good coverage on the undersides of leaves. Use 200 gallons per acre at 100 pounds per square inch, if possible.

There is a native predator in the Northeast that feeds on two-spotted spider mite. This predator, *Amblyseius fallacis* (also a mite), is equally small but has a big appetite. It can be distinguished from TSSM because it lacks the two spots on its back and is teardrop shaped, shiny, and pale yellow in color (photo 8-15). In addition, *A. fallacis* moves rapidly across a leaf as it reaches for prey. Two-spotted mites generally move slowly across the leaf. When sampling a field, note the presence of both predators and TSSM. Fields with lots of predatory mites should not be sprayed.

Several companies now commercially produce predatory mites that feed on spider mites, including *Amblyseius fallacis*. These predators can be released in strawberry plantings and provide some control of two-spotted mites. More research is needed to determine appropriate release rates and timing, although predators should be released at a lower threshold than one would apply a pesticide. It is also important to encourage natural enemies of spider mites by reducing the use of pesticides that harm natural enemies (table 8-2). High nitrogen rates also encourage mites to build up in the planting.

## *Cyclamen Mite*

Scientific name: *Phytonemus pallidus*

The cyclamen mite is primarily a greenhouse pest but also causes serious losses in strawberry plantings. This tiny mite ($^1/_4$ millimeter long) is scarcely visible to the unaided eye (photo 8-16); even the adults are visible only with a good hand lens or microscope. Mature cyclamen

**Table 8-2.** Relative toxicity of pesticides to beneficial mites

| Chemical | Toxicity |
|---|---|
| Benlate (benomyl) | medium |
| Brigade (bifenthrin) | high |
| Captan | low |
| Guthion (azinphosmethyl) | low |
| Kelthane (dicofol) | medium |
| Lorsban (chlorpyrifos) | medium |
| Morestan (oxythioquinox) | low |
| Ronilan (metalaxyl) | low |
| Sevin (carbaryl) | high |
| Vendex (hexakis) | low |

mites are soft-bodied, pinkish orange in color, and shiny. The hind legs are threadlike or whiplike in the female and grasping or pincerlike in the male. Eggs are translucent, comparatively large, and often so abundant that they appear as a white mass along the midveins of the folded leaves. The immature stages, an active larva and immobile nymph, are translucent white.

Adult females survive the winter in protected areas around the crowns of strawberry plants. In early spring, when the plants begin to grow, the mites start reproducing. Most females move to the young, folded leaves to lay their eggs; as each leaf begins to open, the females move down to the next developing leaf bud. The eggs and immature stages are thus protected within the folded leaves. The folded strawberry leaves also provide the high humidity that cyclamen mites require.

Under favorable conditions, each female lays about ninety eggs, about 80% of which develop into females. The mites can grow from eggs to adulthood within two weeks. In warm climates, they keep multiplying throughout the spring, summer, and fall. Because they mature so quickly and have such a long egg-laying period, all stages of development are present throughout the period of reproduction, and populations can increase very rapidly under favorable conditions. Cool weather greatly reduces reproduction, and by early fall most of the females are hibernating around the crown of the plant. Two peaks of reproduction occur: the larger peak occurs in early June during harvest and is followed by a sharp decline in July and August; the smaller peak occurs near the end of September.

The cyclamen mite feeds on young, unfolding leaves in the crown of the plant. These leaves appear stunted, crinkled, purplish, and malformed when they emerge (photo 8-17). The first obvious symptoms of cyclamen mite feeding are a slight retardation of growth and somewhat roughened, off-color leaves. The leaves soon become crinkled and the stems do not elongate, so the plants take on a characteristic flat appearance and buds fail to open.

When infestations become very high, the new leaves are severely stunted and crinkled and form a more or less compact mass in the center of the plant. At this time, the leaves are usually brownish green. When leaf infestations become too heavy, the mites move out to feed on the flowers, causing them to wither and die. Fruits on infested plants are small, dry, and distorted, and the seeds stand out on the flesh of the berry in a characteristic manner. Just a few mites per leaf may reduce plant productivity significantly.

The cyclamen mite has been extremely difficult to control with pesticides because of its high rate of reproduction and its inaccessibility on the strawberry plant. Some success has been achieved with hot water dips prior to planting, with fumigation, and with systemic miticides. Miticide can reach the crown leaves more easily when it is applied during bed renovation (when rows are narrowed and leaves mown off) than when it is applied while the leaf canopy is still present. Spray volume (200 gallons per acre) and pressure (100 pounds per square inch) must be high for the spray to contact the mites.

Establishing new plantings with mite-free nursery stock and isolating new plantings from old ones are of primary importance in controlling cyclamen mites. The mites can be easily carried from one point to another on implements, clothing, or older plants.

Strawberry plants maintained in a vigorous state are less susceptible to the cyclamen mite, and cultivars vary in their susceptibility. Some predatory mites, if managed properly, may effectively reduce cyclamen mite populations. The predatory mites are usually present in older fields (three or more years old), provided that pesticides that destroy predators are not used (see table 8-2).

## Aphids

Scientific names: *Chaetosiphon—C. fragaefolii, C. thomasi,* and *C. minor*

Strawberry aphids are soft-bodied insects. The adults are less than $^{1}/_{16}$ inch long. Winged and wingless adult females may be present at the same time. The wingless form is pale green or yellowish. The winged form is light green with black markings (photo 8-18). Species of *Chaetosiphon* are distinguishable by the number and arrangement of knobbed dorsal abdominal setae.

Several generations occur in a season, but strawberry aphids are most numerous in the spring and fall. Aphid reproduction is not favored by hot, dry, summer weather but by cool, damp conditions. The development of winged aphids peaks in spring (March through June) and in fall (September to November).

At least one aphid species occurs in every strawberry growing area. In Ohio, *C. minor* and *C. thomasi* are most important, whereas in most other areas from California to New England, *C. fragaefolii* and *C. thomasi* are most common.

Aphids usually occur on new shoots and buds in the crown of the plant and also along the veins on the undersides of leaves. They generally remain motionless when a plant is being examined. *Chaetosiphon* species feed exclusively on leaves and petioles, sucking out plant juices. When present in large numbers, they weaken the plant. In the process of feeding, they excrete large quantities of honeydew on which sooty mold grows. Although not very harmful to the plant, sooty mold can make picking difficult and render the fruit unmarketable.

The purpose of aphid control, generally, is to manage the spread of aphid-vectored virus diseases. Aphids can be controlled with several insecticides. However, the decision to use an insecticide and the selection of a particular insecticide depends on several factors: the time of application (planting time, before harvest, after harvest, or in the remainder of the season); aphid resistance to insecticides; the problem to be controlled (aphid injury or virus transmission); and the presence of other pests and predators. Many pesticides effective against aphids are also toxic to predators (photo 8-19); such pesticides should be used only when aphid infestation is severe.

## Potato Leafhopper

Scientific name: *Empoasca fabae*

The potato leafhopper occurs throughout eastern North America and may reduce plant growth and runner production in commercial plantings of susceptible strawberry cultivars. Adults and nymphs feed along the veins on the undersides of leaves by sucking up plant juices. In the feeding process, they apparently inject with their saliva a toxic substance that causes plugs to form in the vascular system of the plant. The margins of affected leaves develop a light yellow color, and new growth can be stunted (photo 8-20).

The adult leafhopper is bright green and about $^1/_8$ inch long (photo 8-21). It takes flight quickly when disturbed, so sweep-nets are used to catch and identify them. Young nymphs are smaller and light green and are easily identified by their habit of moving sideways when disturbed. Females deposit eggs within leaves and stems of plants, and nymphs develop on the undersides of leaves. Nymph activity is greatest from late spring to midsummer. Adult leafhoppers are highly mobile, migrating from the southern to northern states each year. The wide host range of this insect, nearly 140 plant species, facilitates the annual migration. The leafhopper is adequately controlled by several broad-spectrum pesticides.

## Spittlebug

Scientific name: *Philaenus spumarius*

The spittlebug is a serious pest of strawberries throughout North America and Europe. It is present in most of the United States east of the Mississippi River and along the Pacific Coast; but it is most problematic in areas of high relative humidity, such as the northeastern United States and Oregon. Spittlebugs feed on more than four hundred species of agricultural plants. They get their name from the frothy spittle they produce as nymphs to protect themselves (photo 8-22).

Adult spittlebugs resemble leafhoppers; they are about $^1/_4$ inch long. Newly emerged adults are bright green but later turn dull brown or mottled gray (photo 8-23). Adults are present on vegetation from late May or June until freezing occurs in the fall. There is only one generation per year. Eggs, which are yellowish and about $^1/_{30}$ inch long, are laid as early as July; but the peak egg-laying period is during September and October. Spittlebugs overwinter as eggs inside the lower parts of the strawberry plant in masses of two to thirty. The masses are held together in rows by a cement-like substance. Newly hatched nymphs appear from April to May and are whitish to bright yellow or orange; they later turn green. At 10% bloom of strawberries, they are quite small—about the size of a pinhead—and later may reach a length of $^1/_4$ inch. They produce a protective frothy spittle about $^2/_5$ to $^4/_5$ inch or more in diameter. Nymphs remain inside the spittle until they transform into adults, five to eight weeks after the eggs hatch.

The nymphs pierce the plant stems and suck plant juices. Initially, they feed at the bases of plants, but later they move up into the developing tender foliage. This feeding can cause distorted leaves and stunted berry growth. The crinkled and dark green appearance of the leaves can resemble leaves affected by crinkle virus, but spittlebug injury is not viral; plants recover after the spittlebug departs.

Spittlebugs have always been considered a problem in pick-your-own operations, because their spittle annoys the strawberry pickers. However, spittlebugs rarely become a large enough problem to cause significant yield loss.

Begin to estimate spittle mass density at 10% bloom. Randomly inspect five to ten 1-square-foot areas per acre of strawberries at two-week intervals. On hot, dry days, the nymphs and their spittle may be at the base of the plant, so it will be necessary to spread the plants and inspect the crowns and soil surface. On warm and humid or rainy days, the spittle masses can usually be seen on the surfaces of leaves and stems. Young nymphs will be small and orange; nymphs at later stages will be as long as $^1/_4$ inch and orange to green in color. Populations are usually largest in weedy fields. A threshold of two bugs per square foot may warrant treatment.

### *Cutworms*

Scientific names: Various

The immature stage (larvae) of these insects cause feeding injury to plants. Larvae may reach 2 inches long at maturity (photo 8-24). The color and arrangement of stripes and spots varies from one kind of cutworm to another. Cutworms may be observed on plants at night during spring and summer. Larvae consume leaves, buds, and developing fruits. Options for control vary considerably from state to state.

## Root Damage

### *Strawberry Rootworm*

Scientific name: *Paria fragaria*

The adult form of this insect is a small ($^1/_8$ inch) beetle that is round and copper-colored with dark markings on its back (photo 8-25). The immature root-feeding grubs are also small ($^1/_8$ inch) and creamy white in color with three pairs of legs. They actively feed on roots in the late spring to early summer. The new generation of adults appears after renovation (late July or early August).

This insect can be observed most easily in the field as adult beetles feeding on leaves. Feeding occurs at two times in the growing season (May and July through August) and results in shot holes in the leaves. The second feeding period is usually more evident because a greater number of beetles are feeding. The earlier feeding is done by the overwintering population.

As with all 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 of the insect. The presence of adults can be detected by observation of the feeding injury or direct sightings of the adult beetles in the field. Sticky traps may aid in sighting strawberry rootworm adults since they feed primarily at night.

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.

No threshold is established for this insect. Feeding injury, as with all the root-feeding insects, is most damaging if root diseases (such as black root rot) infect the plants as a result of wounding. Therefore, it is advisable to keep the root-feeding population low.

### *Root Weevils*

Scientific name: *Otiorhynchus* spp.

There are more than twenty species of root weevils that attack strawberries in the United States. In the Northeast, the three major species are the black vine weevil, *Otiorhynchus sulcatus* (Fabricius); the strawberry root weevil, *O. ovatus* L.; and the rough strawberry weevil, *O. rugostriatus* Goeze.

The root weevil adult is a brown to black beetle, with rows of pits or punctures along its back (photo 8-26). Like other weevils, its mouth parts are extended into a snout. The three species discussed here look similar but differ in size. The strawberry root weevil is the smallest in size, about $^1/_5$ inch and black to light brown; the rough strawberry weevil is generally an even chocolate brown and $^1/_4$ inch long; and the black vine weevil sometimes has small flecks of yellow on its black body and can reach $^2/_5$ inch in length.

Adults of *Otiorhynchus* generally emerge in late May through June from pupae in the soil. They feed at night on foliage and hide during the day. The adults are unable to fly, so they must travel through the field on foot. After a period of approximately thirty to sixty days (for the black vine weevil) or ten to fourteen days (for other species), they begin to lay eggs. Some larvae of these species do not pupate in the spring and will remain in the soil throughout the summer. They then pupate in the fall and overwinter as adults, to emerge the following spring.

Depending on the species, peak egg laying occurs from late July through August. Eggs are laid in the soil around the plants; they are pearly white when laid but soon change to an amber color. Eggs of the strawberry root weevil are $1/_{50}$ inch long; those of the black vine weevil are $3/_{100}$-inch spheres.

Larvae, or "grubs," are creamy white or dirty white to brown, have no legs, and lie in a characteristic "C" position in the soil (photo 8-27). Grubs of the strawberry root weevil are about $1/_{4}$ inch long when fully grown; those of the black vine weevil are $1/_{2}$ inch long. By October, most of the eggs have hatched into larvae; hatching occurs about ten days after the eggs are laid. Young larvae feed on fine roots and bark in midsummer, overwinter in the soil, and cause their heaviest damage in the spring. Black vine weevil pupae are soft and white. Adults emerge after a short pupation period in April, May, or June, depending on the species and site. Only one generation occurs per year.

Adult root weevils eat notches in the leaves, but this damage is seldom important. The larvae cause serious damage by tunneling in the roots and crowns as they feed. Most of the damage is caused by the later instars of larvae during March and April that eat the fine roots and burrow into crowns. Evidence of feeding is a reddish brown sawdust-like frass surrounding the crown (photo 8-28). Plants wilt, become stunted, and may eventually collapse under the stress of fruiting or hot weather.

Heavily damaged areas in the field can be large—sometimes up to $1/_{2}$ acre—and circular, because of the beetles' behavior of gathering in groups. Without control, damage can be so severe by the second fruiting year that early termination of the planting is necessary. Newly transplanted strawberry plants can be particularly susceptible to black vine weevils.

To prevent the spread of insects to other beds, plow under old beds as soon as possible. Rotate fields to an unsuitable host (for example, corn or pumpkins) for at least two years. Fall plow infested beds; this will destroy a large number of adult weevils, since these pests do not fly. Keep new beds far from infested sites and clean farm equipment before moving from infested fields to new fields to prevent the pests from spreading.

Parasitic nematodes have been used effectively on black vine weevil larvae in cranberries but have not yet been used successfully in strawberries. Larvae are also attacked by some general predatory insects including carabid and staphylimid beetles. Some plant resistance has been noted in various strawberry clones, but this has not yet been incorporated into commercially acceptable varieties.

No economic thresholds have been established for root weevils, but two to eight black vine weevils per plant are known to cause economic damage. Soil fumigation provides effective preplant control of larvae. Chemical applications to the soil following bed renovation can reduce populations. Postharvest foliar sprays to control the adult beetles during the summer are a common treatment. Present research is directed at optimum timing of this treatment; treatment should be delayed until as many adults as possible have emerged but applied before egg laying begins.

### White Grubs
*(Japanese Beetle, Rose Chafer, Asiatic Garden Beetle, June Beetle)*

Scientific names: *Popilla japonica, Macrodactylus subspinous, Autoserica castanea, and Cotinia nitida*

White grubs cause root damage that weakens the plant and also provides an entry site for root diseases. Adult stages may also cause leaf damage.

The Japanese beetle is metallic brown/green in color (photo 8-29) and approximately $1/_{2}$ inch long. It is often found feeding in small groups on leaves. The beetle overwinters as a white grub in the soil and emerges in July. The adult rose chafer (photo 8-30) is longer with a reddish brown head. The body is covered with yellow hairs, giving it a muted yellow appearance. This beetle is nearly 1 inch long and $1/_{2}$ inch across with flattened margins. Asiatic garden beetles are small ($3/_{8}$ inch) and a velvety cinnamon-brown color. June beetles are a robust $1\,1/_{2}$ inches long and shiny brown in color (photo 8-31). All of these beetles have wide host ranges, although some feed more heavily in strawberries than others.

The larvae (or grubs) of these insects look quite similar to one another; are generally referred to as white grubs (they are C-shaped, have three sets of legs, and are up to $\frac{1}{2}$ inch long); and are very difficult to manage after a strawberry bed has been planted. They are distinguishable from the larvae of root weevils, which are smaller (about $\frac{1}{4}$ inch long) and have no legs.

As adults, the beetles feed on the leaves. Damage results in a skeletonized leaf. Leaf feeding typically occurs in late July through mid-August. It is unknown how much damage is tolerable. But if leaf area is greatly reduced, the following year's flower bud formation, which is initiated in the fall, could be affected.

Management of grubs in the soil is very difficult. Adults are an easier target. Chemical controls for adult beetles are available and considered to be effective. Traps that use pheromone and feed lures (specifically for Japanese beetle) are commercially available and quite effective at catching beetles. There is controversy, however, about whether traps attract more beetles to the area or are helpful at drawing them out of the field. Either way, placement should be at least 20 yards away from the strawberry field.

Milky spore disease is a commercially available bacterium that is incorporated into the ground and attacks the grubs for many consecutive years. Several formulations are on the market. The difficulty is in getting the bacteria established in northern soils, and results have been inconsistent. Therefore, milky spore cannot be considered a reliable control measure until this problem is overcome.

Pre-establishment practices should be followed to decrease the risk of white grub problems. Do not plant on newly turned sod land; rather, plow the field and let it lie fallow or in a rotational cover crop such as sudan grass, buckwheat, pumpkins, or squash for at least one season prior to planting strawberries. Also, avoid siting a strawberry field next to a large, grassy field, which could be a source of these beetles and their larvae.

## Further Reading

Cooley, D. R. and S. G. Schloemann. *Integrated Pest Management for Strawberries in the Northeastern United States*. University of Massachusetts Cooperative Extension Bulletin C211.

Maas, J. L. *Compendium of Strawberry Diseases*. St. Paul, Minnesota: American Phytopathological Society, 1984.

Williams, R. N. and W. R. W. Rings. *Insect Pests of Strawberries in Ohio*. OARDC Research Bulletin 1122. Ohio Agricultural Research and Development Center, Ohio State University, 1980.

CHAPTER 9

# *Disease Management and Physiological Disorders*

Fungi are ubiquitous in the strawberry planting. Most are beneficial because they help with decomposition of dead plant material and make nutrients available. Some compete with harmful fungi and keep their populations low. However, a small number of microorganisms are extremely harmful to strawberries, and these are discussed below.

## Fruit Damage

### *Sunscald*

Sunscald is not caused by a pathogen, although the symptoms are often mistaken for a disease. Sunscald is a result of the outer fruit cells dying due to direct exposure to intense ultraviolet sunlight on hot days. Affected fruit exhibit light gray to brownish watery patches on the exposed side (photo 9-1). These patches will dry to form tan sunken lesions, and fungal organisms may invade the damaged tissue, causing it to turn black. Varieties that tend to have a lot of exposed fruit—that is, fruit not shaded by leaves—tend to experience more sunscald injury. Earliglow seems to be more susceptible to this problem than many other varieties.

Evaporative cooling of plants with overhead irrigation has been suggested as a technique to prevent sunscald, but its effectiveness has not been demonstrated.

### *Gray Mold*

Scientific name: *Botrytis cinerea*

Gray mold is consistently the most important disease of strawberry fruit. Symptoms occasionally appear on green fruit, usually as firm brown lesions expanding from the cap end. However, symptoms are much more common and noticeable on ripe fruit just before and after harvest, when infected berries become covered with the powdery mass of gray fungus spores (photo 9-2) that gives the disease its name.

The *Botrytis* fungus overwinters primarily in dead strawberry leaves or as inconspicuous infections of attached green leaves. During periods of wet or foggy weather in the spring, the fungus produces thousands to millions of spores on each dead or aging leaf. These spores are spread throughout the planting by wind and moving air currents, then infect open strawberry flowers during periods of rain and fog. Temperatures of 59° to 77°F are ideal for infection, although infections are also common at lower temperatures when weather is persistently wet.

Most gray mold infections occur during bloom. Although they may become visible on green berries, notably at the stem end (photo 9-3), more often they remain dormant until the fruit begins to ripen. The fungus then resumes activity, rapidly colonizes the berry, and produces its characteristic mass of gray spores. This process is accelerated by prolonged periods of favorable temperatures and high humidity within the fruiting canopy or in storage. Additional disease spread can occur when healthy fruit comes in direct contact with infected fruit or if fungal spores germinate on improperly stored fruit that is allowed to become wet. Remember, though, that the vast majority of berries that rot before harvest and in storage were actually infected during bloom.

Because the *Botrytis* fungus requires prolonged periods of high humidity and wetness to produce its spores, infect blossoms, and develop in the berries, the key to gray mold control is cultural practices that promote good air circulation and rapid drying within the fruiting canopy. Selecting a proper site, practicing good weed control, and avoiding excessively wide plant rows are all important for minimizing losses from this disease. Avoid practices that promote lush plant growth (for example, applying excessive nitrogen or irrigation water), since these also promote gray mold development. Research in New York has consistently demonstrated that supplying extra nitrogen in the spring (that is, in addition to the nitrogen normally applied at renovation) increases the number of infected berries by approximately 300 to 500%. This risk should be considered with respect to any perceived benefits of such practices.

Strawberry varieties differ in their susceptibility to gray mold, although none are completely resistant. Among popular varieties, Earliglow seldom suffers serious losses in the field. This may be partly due to the "escape" from the disease provided by the variety's exposed fruit and the tendency of its caps to fold away from the berries as they ripen; if so, other varieties with similar traits may also be less prone to gray mold. In contrast, Allstar fruits appear to be particularly susceptible.

Fungicide treatments should focus on the bloom period. The amount of protection needed depends on how wet the weather is. One to three applications of a fungicide during bloom generally provide excellent control, although some growers obtain acceptable results with good cultural practices alone, particularly in dry years. Additional fungicide sprays after bloom seldom provide additional control of gray mold, although they may help control other diseases under wet conditions. A promising form of biological control in which a beneficial fungus is delivered to strawberry blossoms by bees is currently under development and may be available in the future.

### Leather Rot

Scientific name: *Phytophthora cactorum*

Leather rot occurs sporadically in northern growing areas, but it can cause serious economic losses when it occurs. It is more common in southern and midwestern states than in the Northeast. Berries may become infected any time during their development. Infected portions of green berries turn brown but remain firm (photo 9-4), and the infection quickly expands until the entire fruit (inside and out) becomes dark and leathery in texture. Affected berries do not become covered with the powdery gray spores characteristic of *Botrytis*. They may be covered with white fungal growth following periods of wet weather, or if they are incubated for one or two days at room temperature in a plastic bag with a wet paper towel. Infected mature berries are often inconspicuous but are usually somewhat softer than healthy fruit and have a dull pink to lavender or purplish color. Such fruit generally have a sharp, pungent smell that is easiest to detect when they are broken open. They also have a strongly bitter, offensive taste that is easily imparted to jams or other products made from them.

The leather rot fungus is common in many soils. It produces its infective spores when the soil becomes puddled due to excessive rainfall or irrigation, and the spores swim up to the soil surface. Fruit lying on the ground can become infected upon contact with the fungus, and fruit in the plant canopy can become infected when contaminated soil or puddled water is splashed onto them. Once initial infections occur, the leather rot fungus produces a new type of spore on the diseased berries during periods of rain, fog, and dew. These spores are spread to healthy fruit by wind and splashing rain; they can cause a new cycle of infections if the berries they land on remain wet for just a few hours at temperatures in the optimal range of approximately 60° to 80°F. Once leather rot gets started in the field, disease incidence can explode in just a few days if weather conditions remain favorable to the pest.

Although leather rot can spread rapidly through the air once it becomes established, the weak link in the disease cycle is the need for the fungus to first move from the soil to the fruit. Therefore, cultural practices that inhibit this process are the first and most important line of defense. Establishing a thick layer of mulch between the soil and the fruit significantly reduces leather rot development. Choosing planting sites with good soil drainage and minimizing soil compaction and rutting from equipment operation will reduce puddle formation and thus the production of infective spores. (This also helps protect against infection by the red stele fungus, which is related). Practices that promote good air circulation and rapid drying within the canopy will also help limit disease spread. Some fungicides can provide an additional measure of protection, but they are most effective when used in combination with appropriate cultural practices. Many fungicides used for control of gray mold and other strawberry diseases are ineffective against leather rot; check for current recommendations.

### Anthracnose

Scientific name: *Colletotrichum acutatum*

Anthracnose favors wet, warm conditions, so it is most common with dayneutral strawberry varieties. Junebearers can sustain significant losses, however, if weather conditions are favorable. Outbreaks of anthracnose are sporadic in the North but have become much more frequent since the mid-1980s.

Both green and ripe fruit can become infected. The primary symptom is one or more slightly sunken brown to black circular spots (lesions) about $^1/_8$ to $^1/_2$ inch in diameter. Lesions can develop anywhere on the fruit surface (photo 9-5). In wet or humid weather, a thin, glistening layer of creamy pink to salmon-colored spores can form in the centers of these lesions. If conditions are dry or if secondary organisms do not invade and cause soft rot, the fruit may become mummified and black. The anthracnose fungi may also attack stolons, petioles, and strawberry crowns, although fruit infections are a much more common cause of economic loss.

The anthracnose fungi persist primarily in infected fruit mummies or vegetative plant parts. Their slimy, pink spores are produced during periods of high humidity and warm temperatures and are spread to fruit by splashing and wind-driven rain. Once infection occurs, additional spore masses are produced within the sunken lesions. Spores can be spread to healthy fruit by additional rains, causing new infections and an epidemic or "snowballing" effect if favorable weather conditions persist.

Strawberry anthracnose is a difficult disease to control, especially under extended periods of warm, wet weather. Natural spread of the fungi is limited—generally within individual or adjacent plantings. The fungi do not appear to be present in all fields, so it is good to plant crowns that are free of infection to begin with; however, there is no current procedure for certifying anthracnose-free nursery material or detecting the pathogen through routine inspection prior to planting. The anthracnose fungi persist in the soil (within infected plant residues) only for a limited time. Thus, fumigation or rotation out of strawberries for two to three years should be practiced if replanting into a site with a previous anthracnose problem.

Cultural practices that promote good air circulation and rapid drying of the fruit should be used. Because the fungus spores are moved primarily by splashing water, straw mulch between rows will help reduce disease spread; conversely, plastic mulches promote disease spread, since they serve as "trampolines" for raindrops. Similarly, overhead irrigation can distribute spores and lead to new infections once an epidemic has started. Some available fungicides will provide an additional but limited measure of disease control.

Strawberry cultivars vary in their susceptibility to anthracnose, but all varieties can become infected. Field rankings suggest that highly susceptible varieties include Earliglow, Honeoye, Allstar, Raritan, Cavendish, Glooscap, Kent, Lateglow, and Tristar. Redchief, Redcoat, and Jewel are more tolerant. However, field rankings are not always consistent from one location to another.

### *Green Petal*

Green petal disease, also known as clover phyllody, occurs sporadically. The incidence of infected plants is generally low but can be as high as 20%. This disease is usually more of a curiosity than a serious problem.

A characteristic symptom of this disease is that infected plants develop flowers with green petals that later turn red. Such flowers either fail to form fruit, or they form fruit composed mostly of large green seeds (photo 9-6). Fruit from infected plants may also have a "button berry" look. In a few varieties, small leaflike structures replace individual seeds and grow out of parts of the berry. (This is also a common symptom of the aster yellows disease.) The young leaves of plants infected with green petal may be extremely stunted and have yellow edges.

Green petal is caused by a microorganism similar to a bacterium in a group known as mycoplasma-like organisms (MLOs), or phytoplasmas. This organism also infects different clover species and persists in the gut of leafhoppers that feed on infected plants. The leafhoppers can then spread the disease to healthy plants as they continue feeding.

Strawberry varieties vary considerably in their resistance or tolerance to this disease. When infected plants are noticed, they and any daughter plants should be removed from the field to prevent additional spread of this MLO.

## Leaf Damage

### *Bacterial Angular Leaf Spot*

Scientific name: *Xanthomonas fragariae*

Angular leaf spot is a bacterial disease that is becoming a serious problem in parts of the upper Midwest and eastern Canada. It is a sporadic but potentially important disease in the Northeast. Early symptoms are small, water-soaked spots (lesions) on the lower leaf surface that are angular in shape because their expansion is limited by the network of fine leaf veins (photo 9-7). When infected leaves are picked and held up against bright light, these lesions are characteristically translucent (photo 9-8), although they appear dark green against a normal or dark background. As the disease progresses, numerous lesions can join together to cover large portions of the leaf. These become visible on the upper leaf surface as reddish brown regions that eventually die, giving the leaf a ragged appearance. A symptom that helps distinguish angular leaf spot from other diseases is the presence of a thick fluid that forms on the underside of infected leaves during wet weather, then turns into a brownish varnish-like film as it dries. Economic losses from the disease are most common when the bacterium infects the berry caps, causing them to become darkened and less attractive (photo 9-9).

The angular leaf spot bacterium is introduced into strawberry fields on infected planting material but can persist in the soil in infected leaf debris. It is spread by splashing water (rain, overhead irrigation), and infection appears to be favored when wetting events are associated with moderate daytime temperatures and low night temperatures (near freezing). Additional bacteria that develop within leaf lesions can ooze to the surface during periods of rain, fog, and dew, then cause new infections if they are disseminated by splashing water.

Once established, angular leaf spot is a difficult disease to control. Treatments with copper compounds and experimental antibiotic applications have been largely ineffective. Removal of infected leaf debris, to whatever degree possible, should be helpful. Avoid overhead irrigation while leaves are wet. Rotation out of severely infected fields for at least one year should eliminate sources of inoculum within a field, since the bacterium has no other common host. Tests are being developed to help identify infected plant material in the nursery.

### *Leaf Spot*

Scientific name: *Mycosphaerella fragariae*

Symptoms of leaf spot first appear as circular, deep purple spots. The spots enlarge and the centers turn grayish to white on older leaves and brown on young leaves (photo 9-10). A distinct reddish purple to rusty brown border surrounds the spots (lesions).

The leaf spot fungus overwinters in lesions on living leaves. Spores are produced from these spots in the spring and summer and are spread by splashing rain. Infection then occurs if leaves remain wet long enough. Infection can occur at temperatures of approximately 50° to 80°F, although 68° to 77°F is considered ideal. Lesions can also develop on fruit (causing the descriptively named "black seed disease"), stems, petioles, runners, and caps in very wet years. Leaf spot on the caps of fruit can make berries less attractive and unmarketable.

Although many varieties have good to moderate levels of resistance to this disease, some (such as Raritan, Honeoye, Kent, and Tribute) are very susceptible. In general, protective fungicide sprays are needed only on highly susceptible varieties during very wet fruiting periods. Under such conditions, sprays may be especially beneficial if wet weather the previous autumn provided high levels of overwintering spore inoculum. Few growers treat specifically for leaf spot, although some broad-spectrum fungicides and mixes aimed at fruit rots control leaf spot as well. Mowing of old leaves at renovation may provide a limited measure of cultural control.

### *Leaf Scorch*

Scientific name: *Diplocarpon earliana*

Symptoms of this disease are numerous small, irregularly shaped, purplish spots that develop on the leaves (photo 9-11). The spots differ from those of leaf spot in that they are purple throughout (no light center) and have no well-defined border. When numerous, blotches may grow together, causing the entire leaflet to appear purplish or reddish brown.

Spores of the leaf scorch fungus are produced in the spring on dead leaves that became infected the previous year. They are spread by wind and splashing rain and infect during periods of leaf wetness, particularly when the weather is warm (68° to 86°F is ideal). The disease is most likely to reach significant levels on older plantings of susceptible varieties, since this allows inoculum to build up over time. Disease control strategies are similar to those for leaf spot.

### *Leaf Blight*

Scientific name: *Phomopsis obscurans*

Leaf blight occurs sporadically — symptoms begin as one to several circular reddish-purple spots on a leaflet. Spots enlarge between major veins to form V-shaped lesions with a light brown inner zone and dark brown outer zone (photo 9-12). The entire leaflet may turn brown if multiple infections occur or if the petiole becomes girdled. Leaves are most susceptible to infection when they are less than two weeks old and become more resistant with age.

The details of the leaf blight disease cycle are not well characterized. The fungus overwinters on infected leaves that remain attached to the plant. It produces spores in the spring that are spread short distances by splashing rain to cause new infections. Unlike leaf spot and leaf scorch, there are no varieties with good resistance to this disease. If control is needed (such as when the disease was serious the previous year and when spring weather is wet), broad spectrum fungicides or mixes should be effective.

### *Powdery Mildew*

Scientific name: *Sphaerotheca macularis*

Powdery mildew causes significant disease symptoms on only a few varieties (such as Earliglow, Guardian, and Raritan). Disease severity is most pronounced in regions with high humidity and moderate temperatures such as near the Great Lakes and ocean coasts. The most conspicuous symptom is the rolling of infected leaves in the late summer and fall; purplish or reddish blotches (and sometimes a powdery growth) are revealed on the undersides of leaves (photo 9-13). Numerous pepper-like, black specks often appear in the fall. Flowers and fruit may become infected and covered with a fine white fungal growth, but this occurs only rarely. Rain is not necessary for disease spread.

There is no effective fungicide control registered for use. Cultural controls other than avoiding highly susceptible varieties have not been identified. The effect of late-season leaf infection on the following year's yield is unknown.

### *Aster Yellows*

Aster yellows is caused by a microorganism similar to the one that causes green petal and is also spread by leafhopper feeding. Fruit symptoms of the two diseases are very similar and may be almost indistinguishable; however, plants infected with aster yellows do not form button berries, nor do the green flower petals turn red. The leaves of infected plants are generally cupped, smaller than normal, and chlorotic to reddish in color. The plants eventually wilt and die. The symptoms on fruits and flowers distinguish aster yellows from other causes of plant collapse.

Aster yellows often kills infected strawberry plants within two months of the first appearance of symptoms, which limits its ability to spread within strawberry plantings. However, the organism has a very wide host range, so reinfection from outside the planting may occur. This is not considered a serious disease of strawberries in the East, and no specific control measures are recommended.

## Root Damage

### *Red Stele*

Scientific name: *Phytophthora fragariae*

Red stele is a major disease of strawberries in growing areas like the Northeast and upper Midwest, where cool, wet soil conditions occur. Symptoms often appear just before harvest. Diseased plants are typically stunted and wilted and often have off-color leaves with blue-green or reddish tinges. They often occur in groups, usually in the wettest sections of the planting. Because of pronounced differences in resistance among varieties, the severity of injury can change dramatically when the variety changes (photo 9-14).

Because other factors (for example, root weevil grubs) can cause somewhat similar symptoms, red stele is best diagnosed by digging up moderately diseased (not dead) plants in May or June and examining their roots. Typically, the fine lateral roots will be missing and some of the main fleshy roots will be rotted from the tip back. Cut one or more of these roots lengthwise just behind the rotten zone and look for the diagnostic reddish core (or "stele" in botanical terminology) (photo 9-15).

The red stele fungus is not present in all soils but can persist as dormant spores for many years once it has been introduced. In the fall and spring, some of these spores germinate to start the infection cycle. A different, infective spore type is then produced when the soil is so wet that it puddles, and these spores swim through the water-filled soil pores until they reach and enter strawberry root tips. The fungus grows up through the roots, causing them to rot. Additional infective spores are produced from infected roots during subsequent periods of soil saturation, and they swim to healthy roots to cause new infections. This process can repeat itself many times whenever the soil is saturated and temperatures are favorable (45˚ to 60˚F is optimum). Dormant spores produced inside the infected roots are released into the soil as the roots decay; this allows the fungus to persist during unfavorable weather or rotational cropping sequences.

Many varieties are available with resistance to multiple races of the red stele fungus, including: Earliglow, Lateglow, Northeaster, Mohawk, Primestar, Latestar, Allstar, Tribute, Tristar, Annapolis, Cavendish, Delmarvel, Lester, and Redchief. These are very useful for disease control and are strongly recommended in sites with a previous history of the disease. However, no variety is resistant to all races of the pathogen, and planting these varieties does not guarantee that disease will not occur.

Cultural practices that reduce the number and duration of soil saturation events (puddling) near the plant root zone are also very important for red stele control. These practices include selecting planting sites for good surface and internal drainage, avoiding soil compaction and rutting, and using raised bed planting systems. Specific fungicides are available for red stele control and can provide significant protection, particularly when used in combination with the preceding horticultural practices. Crop rotation and fumigation are of limited value, since these techniques never eliminate all dormant spores and the fungus reproduces rapidly from those that survive.

## *Black Root Rot*

Scientific name: Disease complex of *Rhizoctonia* spp., *Pythium* spp., other fungi, *Pratylenchus penetrans*

Black root rot is a disease complex with several different causes. It has been described for many years but is still poorly understood and difficult to control; as a result, it has become perhaps the major root disease problem in the Northeast (photo 9-16). Black root rot is typified by stunted or declining plants whose roots are covered to varying degrees with black lesions. The decline in vigor is most apparent during the last couple of weeks before harvest, particularly in dry years, and may seriously affect fruit size and yield. The disease often occurs during the first fruiting year and usually becomes much more severe in the year following the first appearance of symptoms. When affected plants are dug up about the time that fruit begins to color, many of the fine lateral roots will be missing or dead and irregular black patches may be visible over many of the fleshy white roots. In severely diseased plants, these black patches grow together so that no fleshy white roots are visible. The interior of blackened fleshy roots remains white (photo 9-17), whereas the interior of affected woody roots turns black.

Several fungi (particularly *Rhizoctonia* spp., but also *Pythium* spp. and assorted others) and the lesion nematode (*Pratylenchus penetrans*) have been implicated as causes of this disease. Plant stresses, such as those caused by cold damage, drought, excessive moisture, soil compaction, and herbicide injury (particularly from terbacil), often lead to problems with black root rot, perhaps by increasing the plants' susceptibility to infection and/or decreasing their ability to "grow out" of the problem. All of these factors have been associated with black root rot development. However, the best predictor of black root rot is the number of years the site has been planted with strawberries, since the disease typically occurs in sites with a long history of strawberry production and limited rotation.

Management of black root rot is difficult because the disease has different causes that may vary from site to site. To help prevent the disease, choose planting sites that have a minimal recent history of strawberry production (preferably at least a three-year rotation). Many growers fumigate land prior to planting in order to control black root rot. Although this practice appears to be effective in California and Florida, results elsewhere have been mixed; in fact, fumigation has increased black root rot damage in some locations, perhaps because the fumigant eliminated natural enemies of the causal organisms. Using raised bed planting systems appears to help reduce black root rot damage, as does minimizing soil compaction and exercising caution with herbicide rates and applications. Some strawberry varieties appear tolerant of individual causes of black root rot, but no variety shows resistance or tolerance to all causes. Honeoye seems to be particularly susceptible to this disease.

## Verticillium *Wilt*

Scientific name: *Verticillium dahliae*

*Verticillium* wilt occurs sporadically in the Northeast. It is always a threat when new plantings are established immediately after certain crops or weeds have been growing in the same soil. Crops that can build up dangerous levels of the *Verticillium* fungus in the soil include tomatoes, potatoes, eggplant, and pepper. Lambsquarters, pigweed, and horse nettle are common weeds that allow the fungus to build to damaging levels. Infected plants often appear to be scattered throughout the field, but their distribution is usually related to that of the infected crop or weed plants during the year(s) before strawberries were set.

Symptoms of *Verticillium* usually appear during the first year of planting. The outer leaves of infected plants turn brown around the edges and between the veins during warm summer weather. As the disease progresses, these leaves wilt, turn entirely brown, and die, while the inner leaves remain unwilted and green for some time (photo

9-18). Eventually, the entire plant dies. The roots of infected plants look dead but have no distinctive symptoms. The best clues for diagnosing the disease are the presence of green inner leaves on wilting plants after the outer leaves have died, and the crop and weed history of the field.

The *Verticillium* fungus lives in the vascular tissue of infected plants and blocks the flow of water, so the plants wilt and die. Dormant resting structures of the fungus are produced within infected plants and are released into the soil as the plant tissue decays. These structures germinate in the spring when they come in contact with new plant roots to cause the new season's round of infection. There is no plant-to-plant spread during the season or significant movement of the fungus through the soil, but *Verticillium* populations increase progressively over the years wherever host plants are available. This localized buildup of the pathogen accounts for the apparently random distribution of infected strawberry plants when they are set into an infested field.

Disease severity is directly dependent on the *Verticillium* population that is present at the time of planting. Thus, control can be obtained by planting into soils where highly susceptible crops and weeds have not been growing for the last three years. Preplant fumigation also provides very effective control. Some strawberry varieties (including Earliglow, Allstar, Scott, Tribute, and Tristar) have good resistance to *Verticillium* wilt.

### *Nematodes*

Scientific names: *Pratylenchus penetrans*, others

Several species of nematodes (microscopic roundworms) can damage strawberry roots. These nematodes feed on the roots, weakening plants. Some can transmit certain viruses. All tend to be more common in lighter soils. The most common and important nematode on strawberries is the root lesion nematode, *Pratylenchus penetrans* (photo 9-19). In addition to direct feeding damage (photo 9-20), this nematode can also increase the severity of black root rot when it is present in combination with certain fungi.

Nematodes travel only a matter of inches; thus, they must be present in soil at certain levels before planting in order to cause significant damage. The presence and population levels of nematodes in particular sites can be determined by some laboratories from soil samples collected before planting, and the results from these tests can be used to guide control decisions. Procedures for sampling and interpretation of the obtained results are normally supplied by the labs.

Treatments for nematodes must be made before planting. These include fumigation, rotation, and the use of particular cover crops. Some cover crops, such as marigolds, sudan grass, and varieties of rape, appear to suppress nematodes nearly as well as fumigation.

Some varieties show resistance to nematodes (Micmac, Annapolis, and Chandler), whereas others show tolerance (Guardian, Bounty, Glooscap, Governor Simcoe, and Veestar). Some show neither tolerance nor resistance and are susceptible to nematode feeding (Sparkle and Kent). Most varieties have not been assessed for their ability to resist or tolerate nematode feeding.

## Winter Injury

Symptoms of winter injury appear in the spring, when plants resume growing. Plants damaged over the winter either do not grow or grow poorly. Damage often occurs in fields or areas of the field where plants were not covered with mulch or snow during the coldest part of the winter. When cut in half, crowns with winter damage are brown or reddish brown. Part or all of the crown may be damaged, including the flower trusses (photos 5-1 and 5-2). An undamaged crown should be creamy white throughout. Some diseases that occur infrequently can cause browning or reddening of the crowns, but winter damage is a much more common cause of this symptom.

Winter injury occurs in various forms. Cold, dry winds can draw moisture from the crowns and injure tissue. Rapid freezing in autumn can cause ice to form within the crown and injure the vascular system. Freezing-and-thawing cycles in the spring can sever roots. Strawberry plants that are stressed but not killed may be more susceptible to infection by the microorganisms that cause black root rot.

Adequate and timely mulching is the best protection against winter injury (chapter 5). Plants on raised beds are more susceptible to winter injury, but the benefits of a raised bed often outweigh this increased risk.

## Further Reading

Converse, R. H. *Virus Diseases of Small Fruits*. United States Department of Agriculture–Agricultural Research Service Handbook 631.

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Funt, R. C., M. A. Ellis, and C. Welty. *Midwest Small Fruit Pest Management Handbook*. Columbus, Ohio: Ohio State University Press, 1997.

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CHAPTER 10

# Weed Management

Weed control is a fundamental requirement for strawberry production and demands a significant amount of resources from the grower. Without weed control, attempts at nutrient management and integrated pest management are obstructed, harvesting is difficult, and yields are depressed. Strawberry production systems promote weeds by disturbing the soil and stimulating weed seed germination, especially in the planting year.

## Integrated Weed Control

The most effective tools for managing weeds are herbicides, cultivation, and mulching. Continuous deep cultivation has limitations, because it promotes further weed seed germination, degrades soil quality, and disturbs runners. Cultivation is limited by weather and the location of the weeds in the beds. However, it has a low environmental impact, can improve aeration, and is a relatively simple procedure. Herbicides are used by most growers because they are economical, often reduce energy inputs into the system, and can minimize soil erosion. However, strawberry growers have few herbicides available to them, so they cannot rely exclusively on herbicides for weed control as can growers of many other crops. Only a small number of herbicides are labeled for use in the United States and Canada (see local pest management recommendations for labeled materials), and these have short residual periods in the soil. The labeled strawberry herbicides are not effective against all weeds, and the application timing is restricted to narrow periods. Therefore, rotations, hand weeding, mulching (chapter 5), hoeing, and cultivation are necessary supplements to chemical weed control. Higher planting densities will allow strawberry plants to rapidly cover the soil surface and make it more difficult for weeds to become established.

When using herbicides in combination with rotation and cultivation, be aware of potential carry-over effects of herbicides on subsequent crops. Within a strawberry field, cultivation can dilute any herbicide that was applied previously and can bring new weed seeds to the soil surface where they can germinate. Cultivation should be performed before applying an herbicide, unless the herbicide is meant to be preplant incorporated.

In general, shallow cultivation is preferred over deep cultivation in established plantings. Finger weeders, flextine cultivators, and rolling cultivators work well in new strawberry plantings (photos 10-1 and 10-2). When used every ten to fourteen days in new plantings, they can eliminate most weeds without disturbing the soil significantly. Cultivation before harvest can result in dirty fruit, so it is usually done during the renovation process and in early October on fruiting beds. Each cultivation will bring weed seeds to the surface of the soil where they can germinate; therefore, if possible, cultivation should be followed with mulching or a preemergent herbicide.

Mulching is used to provide insulation for the planting during winter (chapter 5), but it is also used to suppress weeds in the alleyways during the growing season of the second year and beyond. The importance of straw free of weed seeds cannot be overemphasized. Many weeds are introduced into strawberry fields through contaminated straw. Growers should either grow their own straw or work with the grain grower to ensure that proper measures are taken to keep the grain field weed-free. Ideally, straw should be cut before it sets seed to prevent volunteer grain in the strawberry field.

## Reducing Weeds Prior to Planting

Rotation is a primary means of reducing problem weeds prior to planting. In some cases, preplant cover crops can be grown to compete with emerging weeds, provided they do not produce seeds themselves (chapter 2). In other cases, crops other than strawberries can be grown to enable growers to use herbicides labeled for the primary weed species present in the field. This allows the grower to control problem weeds on a site prior to planting strawberries. In these situations, however, there is the possibility of herbicide carryover.

Fumigation can reduce the weed seed bank prior to planting, but this option is becoming limited. If fumigation is used (photo 2-3), soil should be in a condition that will promote weed seed germination (that is, finely cultivated and moist) and should not contain plant residue. Although not as effective as fumigation, crop rotations provide benefits that fumigation does not. Increasing soil organic matter content is perhaps the greatest advantage. Sweet corn, in particular, is a good rotational crop with berries, especially if the stover is worked into the soil to retain organic matter. Early sweet corn can be followed with oats to provide significant weed suppression in a single year. Sudan grass and marigolds have a suppressive effect on nematodes, and many rotations can reduce disease inoculum. Cover crops that are unrelated to berries (such as grasses and grains) usually make the best rotational companions (chapter 2).

A broad-spectrum, postemergent systemic herbicide (such as glyphosate) used prior to planting can reduce the number of perennial weeds in a field, especially if it is applied in midsummer of the year before planting. Earlier applications will control only those weeds that have emerged early. Later emerging perennial weeds, such as bindweed and nutsedge, will not be affected and can become serious problems later.

## Herbicides

*NOTE: Herbicide names used in the following discussion are to serve as examples only. They are not necessarily labeled for use in your state or province. Labels change annually, and companies may decide to discontinue a product. Read product labels prior to use.*

Weeds are the major pest of strawberry growers, so most producers use all the tools at their disposal, including herbicides. Herbicides need to be applied correctly to maximize performance. Herbicide performance can be optimized by:

- using the right herbicide for the soil type, problem weed, and time of year
- using the appropriate rate
- timing the application properly
- properly placing the herbicide
- providing conditions most appropriate for activation

Preemergent herbicides interfere with seedling establishment, so conditions must be favorable for weed growth (warm, moist soils) for these herbicides to work. Herbicides must be moved into the top few inches of soil where the weed seeds exist, usually through rainfall or irrigation in the case of strawberries. Herbicides on the soil surface or in a zone below the weed seeds will not be effective. In most soils, about 1 inch of water is required to move the herbicide into the soil. In sandy soils, the water requirement is less. For some herbicides, such as terbacil, 1 inch of water may be excessive on a sandy soil because the herbicide is very soluble in water and does not bind readily to the soil particles (see table 10-1 on page 86). DCPA (Dacthal) has a low solubility and is bound to the soil particles; these are desirable characteristics, except where the potential for surface runoff exists.

Preemergent herbicides should be applied just prior to the seed germination period of most problem weeds. The primary period of weed seed germination is in the spring. Napropamide applied in the fall will move into the seed germination zone during winter and be available to inhibit seedling establishment in the spring. Terbacil applied in the fall may wash out of the seed germination zone during winter since it is very soluble. Terbacil is best applied after harvest; it can burn new growth (photo 10-3) if applied in early spring (unless it is washed off of the leaves immediately after application) or at a high rate. Unfortunately, weed seeds germinate over an extended period of time, but it is not practical to have high levels of herbicide residue present in the soil at all times. Some weeds germinate during warm weather (such as foxtails), and others germinate in autumn (such as chickweed); but the primary period of weed seed germination is in the spring, so control efforts should be concentrated then. Weed competition during late summer and early fall has little effect on subsequent production, but spring weed growth is detrimental.

Most growers apply an herbicide and mulch in late autumn to suppress spring weeds. After harvest, they cultivate and apply an herbicide for warm-season species and

**Table 10-1.** Selectivity of preemergent strawberry herbicides labeled in the United States

| Herbicide | Degradation Half life | Rate | Weeds Controlled |
|---|---|---|---|
| Devrinol (napropamide) | 60 days (less in sunlight) 24-hour incorporation | 8 lbs/A | annual grasses, chickweed, knotweed, groundsel, lambsquarters, pigweed, purslane, pineapple weed |
| | | 4 lbs/A | annual bluegrass, large crabgrass, barnyardgrass |
| Dacthal (DCPA) | 30 days 72-hour incorporation | 8 lbs/A | chickweed, crabgrass, foxtail, lambsquarters, field pansy, purslane |
| | | 12 lbs/A | bluegrass, barnyardgrass, johnsongrass, knotweed, nightshade, panicum, pigweed, spurge |
| | | | No activity: galinsoga, mustards, nutsedge, ragweed, smartweed, velvetleaf |
| Sinbar (terbacil) | 90 days 2-week incorporation | 6 oz/A | chickweed, lambsquarters, mustards, crabgrass, foxtail, prickly lettuce, shepherdspurse |
| | | | Little activity: dandelion, milkweed, thistles, vetches, cinquefoil, sedges, quackgrass, red sorrel, groundsel, nutsedge |
| | | | *NOTE:* Sinbar can cause crop injury if used on sensitive varieties or on soils low in organic matter. |

apply another herbicide (and perhaps cultivate) later in the season for winter annuals. Napropamide is the best choice for a late-fall herbicide; terbacil is a better choice at renovation, because strawberry leaves are often mowed off, thus preventing foliar uptake; and DCPA is a good choice for September, since it has activity on late-germinating annuals (such as chickweed and purslane).

Selective grass herbicides (such as sethoxydim) are used to control specific problem weeds such as quackgrass. These must be applied when grasses are small and actively growing; they are most effective on perennial grasses when applied in late spring. Applying selective herbicides during a drought or when grasses are more than 8 inches tall results in incomplete control. They provide no residual activity.

Glyphosate, a nonselective translocated herbicide, can be used to wipe out weeds in established plantings and can be applied at least thirty days prior to planting in fallow fields. It slowly kills most plants that it contacts. Paraquat can be used to narrow rows in lieu of cultivation; it is a nonselective contact herbicide and is not translocated. Both herbicides can damage strawberry plants (photo 10-4), so direct contact should be avoided.

2,4-D is used for broadleaf weed control after harvest but prior to renovation. It is selective, so it can be applied directly over the strawberry plants. Weeds must be actively growing to take up the 2,4-D, so the planting should not be under drought stress during application. Many growers have found that 2,4-D is effective when applied in early November if the weather is warm. However, it should not be applied in early autumn when strawberry plants are initiating flowers.

Regardless of how one attempts to optimize performance, there will be times when herbicides are insufficient to control weeds, since not all herbicides are effective on all weed species. In strawberries, many weed species are not controlled by the labeled herbicides (table 10-2 on page 87). No amount of optimization will effectively eliminate these problem weeds from strawberry plantings.

## Weed Control without Herbicides: Use of an Alternative Planting System

The matted row strawberry system is very dependent on herbicide use. Dormant plants are set up to 2 feet apart in the row; then during the summer, the area between plants becomes filled with runners. This area must remain relatively weed-free in order for the runners to establish. The only way to accomplish this is through herbicides, hoeing, and hand-pulling. None of the available

### *Weed Control Options — Planting Year*

| | | |
|---|---|---|
| April–May | DCPA | Dacthal |
| | napropamide | Devrinol (½ rate) |
| | fluasifop | Fusilade |
| | sethoxydim | Poast |
| June–October | DCPA | Dacthal |
| | napropamide | Devrinol |
| | sethoxydim | Poast |
| November (dormant) | napropamide | Devrinol |
| | terbacil | Sinbar |
| | 2,4-D | |

### *Weed Control Options — Fruiting Year*

| | | |
|---|---|---|
| April | DCPA | Dacthal |
| | napropamide | Devrinol |
| | terbacil | Sinbar |
| May | sethoxydim | Poast |
| July | 2,4-D | |
| | paraquat | Gramoxone |
| | sethoxydim | Poast |
| | terbacil | Sinbar |
| September | napropamide | Devrinol |
| | DCPA | Dacthal |
| | paraquat | Gramoxone |
| November (dormant) | napropamide | Devrinol |
| | terbacil | Sinbar |
| | 2,4-D | |

*NOTE:* Restrictions exist on the total amount applied and number of applications in any one year. Not all of these herbicides can be applied during each period that they are listed.

herbicides have a sufficiently long residual activity to provide a weed-free area for the entire growing season.

One possible alternative for controlling weeds without herbicides is to plant strawberries similar to no-till corn into a killed sod. A sod residue suppresses weeds while the strawberry row becomes established, and minimal soil disturbance results in reduced weed seed germination (photo 10-5).

Seed grain rye in autumn, and mow it in spring when the plants start to flower. Cultivate a narrow strip into the rye residue and plant strawberries at a 6-inch spacing

**Table 10-2.** Specific problem weeds in strawberry plantings

| Weed | Control |
|---|---|
| **Bindweed** | Root system can grow as deep as 20 feet in the soil. Regular cultivation and systemic treatments are required for two years. |
| **Butter-and-eggs** | Reproduces by both seeds and rhizomes. Plants produce large numbers of seeds from June through October. Spot spray with a systemic herbicide. |
| **Canada thistle** | Extremely vigorous rhizomes. Deep plowing every two weeks for two years is required for control without chemicals. Otherwise, spot spray with a systemic herbicide in autumn, then cultivate after two weeks. |
| **Chickweed** | Control is difficult because seed germination occurs over a very long period of time, both in autumn and in early spring. An early September application of a preemergent herbicide is needed for control. |
| **Clovers** | Reproduces by seeds and rhizomes. Not susceptible to selective postemergent or preemergent strawberry herbicides. Rotate into a crop where clovers can be controlled before replanting to berries. |
| **Horsetail** | Resistant to almost all herbicides because it is not a grass or broadleaf weed. Drainage and regular cultivation will aid in control. |
| **Nutsedge** | Not a grass or broadleaf weed, so most herbicides have little effect. Nutlets form in the soil in midsummer while strawberries are fruiting; so once established, populations are difficult to suppress. Rotation and fumigation, coupled with soil drainage, will aid in control. Plowing but not tilling in late fall will expose some tubers to cold temperatures and kill them. |
| **Oxalis** | Seeds germinate over a long period of time and plants can overwinter, making control difficult. Cultivate and hand pull prior to seed formation. |
| **Purslane** | Cut plants can reroot after cultivation; seeds can mature on uprooted plants. Do not allow plants to grow larger than 3 inches prior to cultivation, and ensure that herbicides are applied prior to seed germination. |
| **Quackgrass** | Reproduces by extensive rhizomes and seeds that germinate over a long period of time. Somewhat resistant to postemergent graminicides. Combination of cultivation and a nonselective systemic herbicide is required prior to planting. |

### *Weed Management Cultural Practices*

- Do not allow weeds to go to seed in the strawberry field.
- Keep the area surrounding the strawberry field mowed to prevent weed seeds from blowing in.
- Ensure that straw used for mulch is weed-free.
- Rotate out of strawberries for a minimum of three years before replanting.
- Thoroughly compost manure before spreading it on a berry field.

(see the ribbon row method, chapter 4). Apply a light layer of straw mulch between the rows of plants. Allow plants to fruit after planting—this helps suppress runnering. With this system, bare soil suitable for weed growth is minimized, the proper plant density is established at planting, some yield is realized the first year, and yields in the subsequent year are high. Weeds are controlled for six to eight weeks after planting. This system works best on lighter soils. After eight weeks, cultivation may be necessary to control weeds.

## Using Cover Crops in Established Plantings

Another strategy of weed management is to seed a cover crop into an established planting of strawberries in an attempt to displace harmful weeds. This strategy involves filling open niches with a known species (either benign or with desirable traits) in order to displace weeds (with known undesirable traits) that would otherwise occupy the niche. Competitively displacing weeds with a more desirable species is better than allowing weeds to dominate or destroying soil structure through repeated mechanized cultivation. Cover crop species should be frost-sensitive so they die before producing seeds. Oats and sudan grass have been used successfully (photo 10-6). The use of certified seed can prevent accidental sowing of weeds along with the intercrop.

Cover crop manipulation in strawberry plantings can reduce weed pressure, providing some weed control without herbicides. This alternative to preemergent herbicides requires a higher level of management skill and an initial commitment to no herbicide use, since residues can affect cover crop seed germination. Growers who prefer not to use herbicides or who wish to reduce herbicide use may want to experiment with these systems.

## Geese for Weeding

Geese are used occasionally for weed control in new strawberry fields because they preferentially eat young grasses. They are especially useful in wet years when grasses are abundant, herbicides do not work, and the fields are too wet to cultivate. Six to eight geese can keep an entire acre free of grasses. However, the geese must be confined to the strawberry field with a fence, and they require supplemental food and water and a shelter. By placing the supplemental grain, the shelter, and the water at different corners of the field, the geese will be compelled to move throughout the field rather than stay in one place. Geese can be messy and may repel some pick-your-own customers.

Geese work best in a newly planted strawberry field. They should be introduced when the weeds are just starting to germinate—they will not readily eat established grasses. One-month-old birds are best as they have large appetites. With recent concerns over microbiological contamination of fruits and vegetables, geese should be restricted to nonfruiting fields.

## Summary

Use four strategies for controlling weeds in strawberry plantings. First, eliminate perennial weeds from the planting site one year prior to planting. Second, prevent weed seeds from migrating into the planting by keeping the area around the strawberry field mowed and using clean mulch. Third, prevent weed seeds from becoming established by using cultivation, mulching, and herbicides at the appropriate times and by planting at high densities. Fourth, eliminate weeds when they appear and before they produce seeds. A strawberry field with few weeds has fewer insect and disease problems and will be a pleasant place for customers to pick.

## Further Reading

Uva, R. H., J. C. Neal, and J. M. DiTomaso. *Weeds of the Northeast*. Ithaca, New York: Cornell University Press, 1997.

CHAPTER 11

# Spray Application Technology

Applying nutrients and crop protectants is an important part of strawberry production. During the last several years, there have been many changes in spray technology. New materials, management techniques, and application equipment have been developed. Some changes were the result of technical development; others were responses to new technology in pest control. Active research will introduce more changes in the future.

## Some Terminology

The basic purpose of a sprayer is to deliver a nutrient solution or a pesticide at the desired rate to targets such as crops, weeds, or soil. The sprayer must have a tank to carry the spray mix (the chemical plus the water in which it is carried). The sprayer must maintain a uniform spray mix using an agitator and control the flow of liquid with a pump and valves. The liquid is atomized into droplets by nozzles or a high-speed airstream. An airstream, either part of or separate from the atomization process, may aid in delivering the droplets to the target.

Coverage is the degree of spray treatment applied to all desired target surfaces (figure 11-1). For spraying strawberries, target surfaces may include soil, leaves, and/or fruit. Good foliar pest control requires uniform coverage, which is difficult because strawberry plants and rows may be of different sizes, densities, and shapes. Even if uniform plants could be developed, different parts of the plants are different distances and directions from the sprayer discharge. Often, a grower must overspray parts of the target to get adequate coverage (and control).

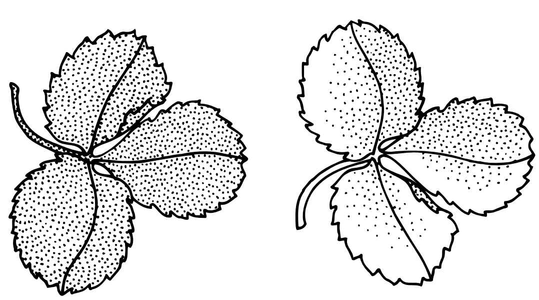



**FIGURE 11-1.** Even versus uneven spray coverage on a strawberry leaf

The application rate required for good coverage will depend on the pest control material and the pest problem. Herbicide applications may require as little as 20 gallons of spray solution per acre to provide the desired control. Some fungicide, insecticide, or miticide applications may require as much as 100 to 200 gallons of spray solution per acre to provide the desired control. Growers must be careful to properly choose and set up their spray equipment to avoid underapplication or overapplication of products and to minimize spray drift for both economical and environmental reasons.

## Power Spraying Equipment

A variety of sprayer types are available. A grower's best choice will depend on the planting system employed, including bed height and plant spacing; tractor size and power; and acreage to be sprayed. Equipment for treating strawberry plants is very similar to that being used to spray for weed control. This discussion will not include air-blast or orchard-type sprayers, since these are generally not recommended for making broadcast applications to low-lying row crops such as strawberries.

## Equipment Components

Strawberry sprayers used today are usually powered, broadcast, boom-type sprayers. These may or may not include some form of air-assisted atomization and/

or spray delivery. Very small commercial growers, homeowners, and hobbyists may choose smaller, hand-held manual sprayers.

Sprayers are either tractor-mounted or trailer units (figure 11-2). Tractor-mounted units are carried on the three-point hitch and are relatively compact and easy to maneuver. However, this arrangement transfers more weight from the front to the rear tractor tires. Ballast weights may be needed on the front end of the tractor to maintain stability and steering control, especially on hilly terrain. Mounted sprayers are powered from the tractor through the power take-off (PTO) shaft.

Trailer sprayers are heavier than tractor-mounted units. They have larger tanks and wider boom arms. Trailer sprayers are most often powered by the tractor PTO, but some may have a separate engine to power the pump and/or air system. Both tractor-mounted and trailer units may use air systems for atomization and/or spray delivery.

Most strawberry treatments are made using nozzles and booms configured for a broadcast or uniform application across the entire boom width. This is an appropriate application technique for materials that are applied across the entire field. However, not all applications need to target the soil as well as the strawberry plants. Directed spraying techniques put more spray where it will be most effective. Banding types of nozzles, such as the even flat fan nozzle, provide a uniform application of spray solution across most of the spray pattern. Banding nozzles are appropriate for applications of pesticides in a narrow strip between rows (for example, paraquat) or over rows (for example, fungicides or foliar fertilizers). Hose drops or directed spray application kits can be used to direct multiple nozzles at the sides and top of strawberry plants.

### *Sprayer Tanks*

Tank size may range from 50 to 500 gallons. A tank should be made of a material that will not react with the chemicals it contains. It must be corrosion resistant and easy to clean. Tanks are typically made of fiberglass, plastic, stainless steel, or steel with a durable protective coating.

A tank should have a large hatch opening for easy inspecting and filling. The hatch should have a cover to prevent spray mix from splashing out of the tank. However, the hatch must let air into the tank as the liquid is removed to prevent the tank from collapsing. A tank drain makes washing, rinsing, and draining much easier.

### *Sprayer Agitators*

Agitation is very important to keep the spray mix uniform and to keep wettable powders in uniform suspension. The sprayer tank should have an agitator — either a jet or mechanical type. A jet agitator uses part of the pump output to produce a jet stream in the bottom of the tank that provides a mixing action. Jet agitators are used on sprayers with centrifugal pumps, as their high flow rates support the jet. Mechanical agitators are used with piston or diaphragm pumps. Mechanical agitators are simply paddle wheels or propellers in the tank that mix the chemicals and water.

### *Sprayer Pumps*

Piston, diaphragm, and centrifugal pumps are all used on sprayers (figure 11-3). Piston and diaphragm pumps are positive displacement pumps; therefore, they are self-priming and can produce high pressures. Their flow rate is directly proportional to operating speed. Centrifugal pumps are non–positive displacement pumps; they are not self-priming and have a maximum working pressure of 200 pounds per square inch (psi) for multistage units.

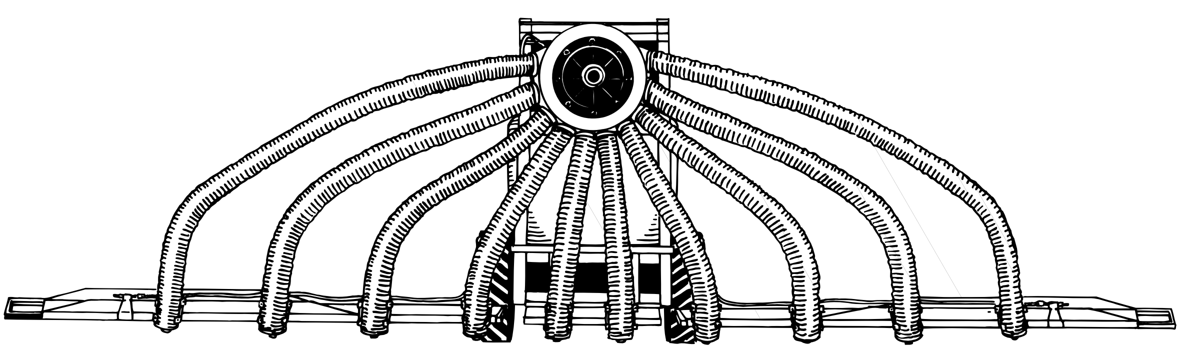


**Figure 11-2.** Rear view of a tractor-mounted sprayer type

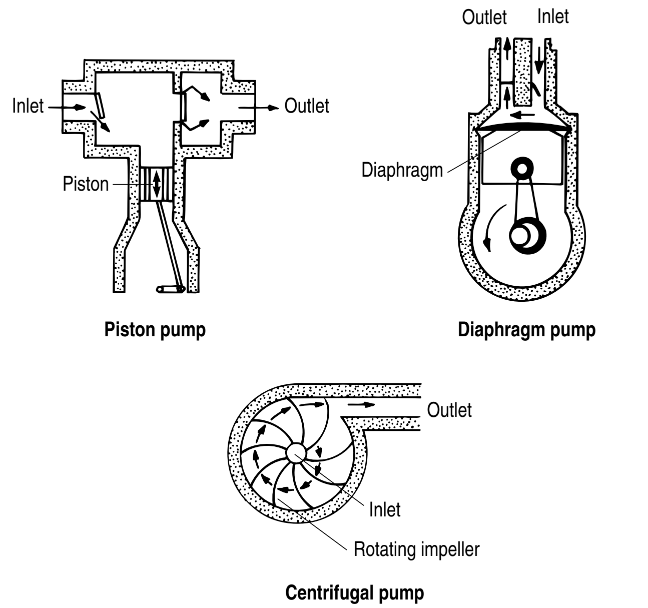



**FIGURE 11-3.** Pumps used on strawberry sprayers

Pumps should provide the required flow rate for the sprayer nozzles and (if necessary) jet agitator plus 20–25% extra capacity at the desired operating pressure. The extra capacity will provide a reserve to compensate for wear and other factors that may reduce flow over time. Power requirements of the pump are relatively low but still need to be considered (table 11-1).

## *Sprayer Nozzles*

Nozzles, a very important part of any sprayer, have three functions: flow control, atomization, and droplet distribution. Some nozzles do not have a built-in flow control, so another type of flow control is built into the system. The nozzles on strawberry sprayers are usually either hydraulic or air-shear types (figure 11-4).

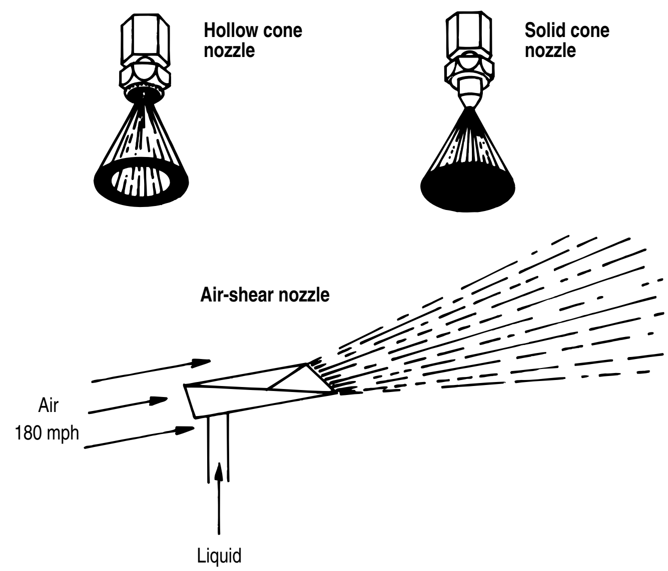



**FIGURE 11-4.** Sprayer nozzle types

Air-shear nozzles use a high-speed air stream to break the liquid into droplets, so these nozzles are limited to sprayers with a high-velocity air discharge. Depending on the nozzle configuration and injection angle, air speeds of 170–400 miles per hour are required. Discharging the spray directly into the air stream against the air flow produces the smallest droplets; at 90° to the air stream, intermediate droplets; and with the air stream, the largest droplets. Air-shear nozzles operate at low pressures, often in the 15–35 psi range, which results in slow wear rates for the nozzles and the pump. Also, air-shear nozzles have large openings that minimize plugging.

Hydraulic nozzles regulate spray flow by the size of the orifice (opening) and the pressure at the nozzle. Hydraulic nozzles atomize liquid spray mix by using pressure to force the liquid through the orifice. With enough speed and energy, the liquid breaks up into droplets when dis-

**TABLE 11-1.** Characteristics of different pump types

| | Pump Type | | |
|---|---|---|---|
| **Pump Characteristic** | **Centrifugal** | **Piston** | **Diaphragm** |
| Materials handled | Any spray solution | Any spray solution | Most spray solutions; some chemicals may damage diaphragm |
| Pressure ranges (psi) | 1–75 (single stage)<br>1–200 (multistage) | Up to 1,000 | Up to 700 |
| Flow rates (gpm) | 0–120 | 2–60 | 1–60 |
| Operating speeds (rpm) | 2,000–4,000 | 600–1,800 | 200–1,200 |

charged against the atmospheric pressure. High pressures and small orifices form small droplets (which are subject to drift), while low pressures and large orifices form large droplets (which provide poorer coverage).

Droplets are discharged from the nozzle tip in some specific pattern, depending on the design of the nozzle. With air-assist sprayers, the droplets are injected in front of or into an air stream and carried to the target. With a handgun or conventional boom sprayer, the speed built up at discharge must carry the spray droplets to the target.

Several types of hydraulic nozzles can be used for treating strawberry production areas. The type of nozzle used depends on the pest control situation, the target size, and drift concerns (table 11-2). Each nozzle type (except the even flat fan nozzle) requires overlap with adjacent nozzle spray patterns for uniform application.

### *Regular Flat Fan Nozzles*

The regular flat fan nozzle is a good general-purpose nozzle for broadcast spraying (figure 11-5). The spray stream from a regular flat fan nozzle has an ellipsoid shape—spray distribution forms an oval pattern on the ground under the nozzle. A single regular flat fan nozzle deposits more spray directly under the nozzle than on either side of the spray pattern. Regular flat fan nozzles are available with operating pressures of 30–75 psi.

Generally, flat fan nozzles produce a wide range of droplet sizes, including many small and large droplets. The percentage of small droplets decreases as the operating pressure decreases. Flat fan nozzles should be operated within their recommended operating pressure range to avoid distorting the spray pattern.

Unlike most flat fan nozzles, extended-range fan nozzles are designed to provide similar spray patterns over a wide or extended range of pressures (15–60 psi). The extended-range nozzle should be used in situations where nozzle pressure is adjusted significantly during normal sprayer operation; for example, when large pressure changes are made to change nozzle output.

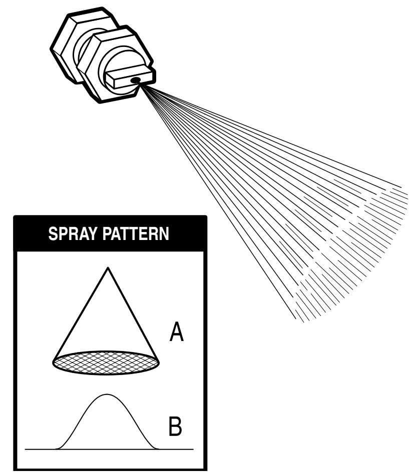



**FIGURE 11-5.** Regular flat fan nozzle spray pattern (A) and spray distribution (B)

Flat fan nozzles are generally used for herbicide or insecticide applications where deep foliage penetration is not required. Spray distribution is influenced by the nozzle spacing, nozzle height above the target area, and angle of the spray pattern (figure 11-6). Nozzles should be slightly slanted so that adjacent patterns do not interfere with each other.

Several fan nozzles are available to produce different spray angles. Wide-angle flat fan nozzles produce smaller droplets than regular flat fan nozzles at the same flow rates. However, they can be used closer to the ground than regular flat fan nozzles, which reduces the drift hazard.

**TABLE 11-2.** Different nozzles are used for different types of application

| | Nozzle Type | | | | | |
|---|---|---|---|---|---|---|
| Application | Flat Fan | Even Flat Fan | Hollow Cone | Flooding Fan | Flood Jet | Twin Fan |
| Preplant applications | X | | | X | X | |
| Broadcast pesticides (low penetration) | X | | | | X | |
| Banded applications | | X | | | | |
| Contact pesticides (high penetration) | | | X | | | X |

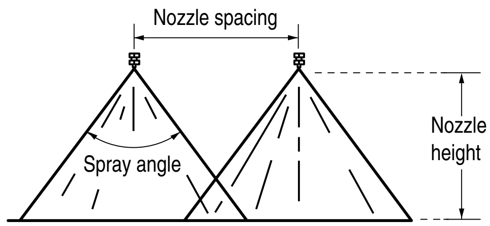



**Figure 11-6.** Setup of flat fan nozzles

Special flat fan nozzles produce a spray pattern with the spray deflected away from the center of the nozzles. The "off-center" nozzle may be used on the end of a boom to treat hard-to-reach areas adjacent to the spray swath.

Low-pressure flat fan nozzles are designed to provide the same spray distribution characteristics as other flat fan nozzles while operating at pressures under 20 psi. These nozzles produce a spray made up of fairly large droplets that are less susceptible to drift.

### *Even Flat Fan Nozzles*

Even flat fan nozzles are similar to regular flat fan nozzles but apply a more even volume of spray material across the spray pattern (figure 11-7). They are designed for applying spray solution in a band or narrow strip under the nozzle and do not need to be overlapped with other nozzles (figure 11-8).

Even flat fan nozzles generally produce a wide droplet spectrum that includes many small and large droplets. The width of the spray band can be changed by raising or lowering the nozzle height. Increasing the operating height of the even flat fan nozzle increases the effective spray width. Increasing the width of the spray band de-

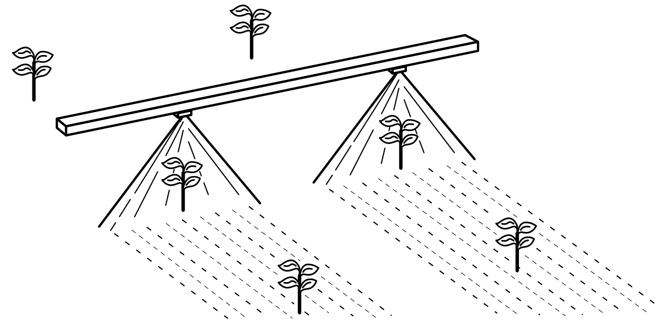


**Figure 11-8.** Band spraying

creases the effective application rate because the same volume of spray is spread over a larger area.

Even flat fan nozzles have operating characteristics, such as droplet size, similar to those of regular flat fan nozzles. They are designed for use at pressures below 60 psi.

### *Hollow Cone Nozzles*

A hollow cone nozzle produces a spray pattern where the liquid is concentrated on the outside of the conical pattern (figure 11-9). More of the spray material is deposited on the edges of the hollow cone spray pattern with less directly under the nozzle. One- or two-piece hollow cone nozzles are available from manufacturers. Two-piece cone (disc and core) nozzles are available with operating pressures from 20 to 500 psi and usually with higher flow capacities than one-piece nozzles. One-piece hollow cone nozzles are available with operating pressures from 40 to 120 psi and typically produce smaller droplets than other hydraulic nozzles at the same operating pressures.

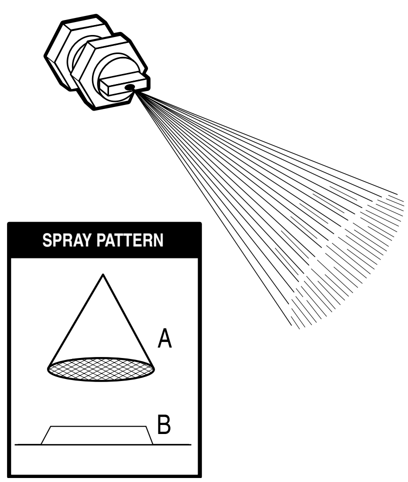



**Figure 11-7.** Even flat fan nozzle spray pattern (A) and spray distribution (B)

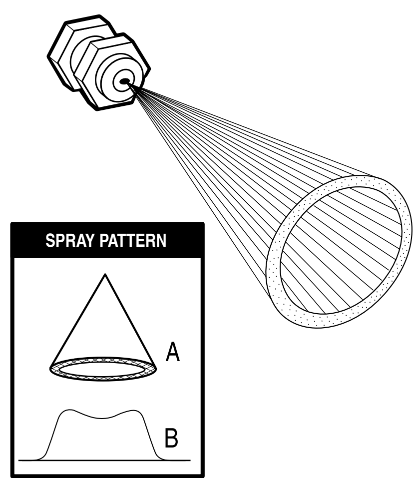



**Figure 11-9.** Hollow cone nozzle spray pattern (A) and spray distribution (B)

Hollow cone nozzles are typically best suited for applying materials like contact insecticides, fungicides, and growth regulators that require good spray coverage on the plant or target surface. Two or three low-volume hollow cone nozzles may also be used in a banding or directed spray operation, where the spray streams from the nozzles are directed around or at the same target (figure 11-10).

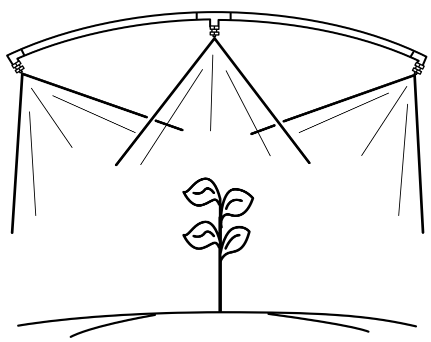


**FIGURE 11-10.** Directed spraying operation using hollow cone nozzles

Because they produce small droplets, hollow cone nozzles are more apt to produce spray drift. Some manufacturers do make special hollow cone nozzles that produce fewer small droplets when used at recommended pressures. Unless operated at high pressures or with additional velocity provided by an airstream, hollow cone nozzles usually cannot provide good spray penetration through deep or dense canopies.

### *Flooding Fan Nozzles*

The flooding fan nozzle sprays a stream of solution at a surface that breaks the stream into a wide pattern of droplets (figure 11-11). The volume of spray produced is greatest directly under the nozzle and on the edges of the spray pattern. The nozzle, which operates at lower pressures of 10–25 psi, produces larger droplets than other nozzle types of similar capacities, and its large orifice resists plugging. The uniformity of the spray distribution and the droplet sizes that flooding nozzles produce at higher pressures are equivalent to those of regular flat fan nozzles.

Flooding fan nozzles are best suited to applying herbicides and fertilizer spray solutions in preemergence broadcast or soil incorporation operations. They are generally not used when good spray coverage is required. Unless the spray pattern is deflected up into the air rather than down to the ground, the flooding fan nozzle produces very little risk of spray drift when operated at low pressures. Some research suggests that these nozzles can be operated at higher pressures to reduce the size of the spray droplets and improve spray coverage; increasing the pressure may also increase the size of the spray pattern. Changing the angle of the nozzle relative to the ground changes the size of the spray pattern. The nozzle position may have to be changed to compensate for pressure changes and ensure uniform spray distribution.

### *Turbo FloodJet™ Nozzles*

Turbo FloodJet nozzles, available from Spraying Systems Company, are similar to standard flooding fan nozzles except they produce a different spray pattern and fewer driftable droplets (figure 11-12). Spray droplets are formed when the spray strikes a surface which deflects the stream into a wide spray pattern, breaking it up into droplets. Under similar operating conditions, the Turbo FloodJet produces droplets 30–50% larger than

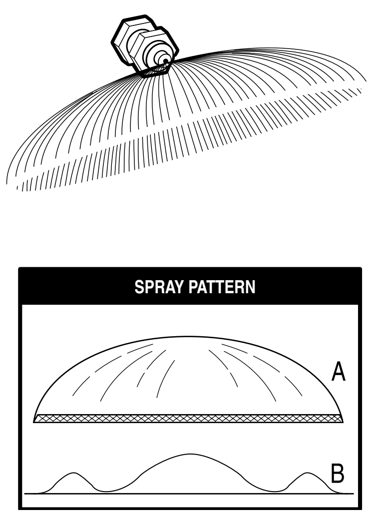



**FIGURE 11-11.** Flooding fan nozzle spray pattern (A) and spray distribution (B)

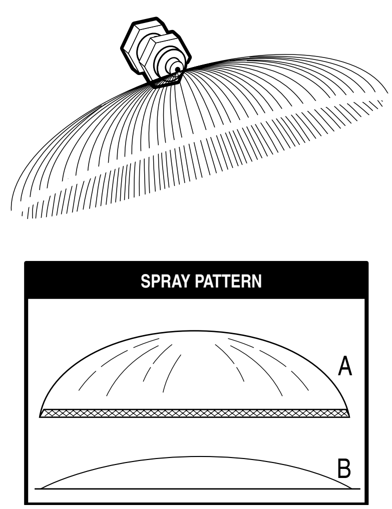



**FIGURE 11-12.** Turbo FloodJet nozzle spray pattern (A) and spray distribution (B)

standard flooding fan nozzles. These nozzles operate at pressures from 10 to 30 psi.

The Turbo FloodJet nozzle also produces a spray pattern more similar to a flat fan pattern, except it is much wider due to the wide-angle discharge. The spray pattern does not distribute higher volumes of spray on the edges of the pattern like the standard flooding fan nozzle.

Because of the large droplets they produce, Turbo FloodJet nozzles are not recommended when good coverage is required. They are best suited for application of preemergence herbicides or postemergence systemic herbicides. The size of the spray pattern can be adjusted slightly by varying the orientation of the nozzle.

### *Twin Fan Nozzles*

The twin fan nozzle operates as a regular flat fan nozzle but applies material through two orifices, thus producing two fan patterns (figure 11-13). Spray distribution from the twin fan nozzle is very similar to that from the regular flat fan nozzle, where most of the spray is distributed directly under the nozzle. This nozzle is usually mounted so that one fan pattern operates forward in the direction of travel and one fan pattern operates away from the direction of travel. The twin fan spray pattern allows targets to be treated from different directions, thus improving spray coverage. Different twin fan nozzles are available with two spray streams set at different angles. The recommended spraying pressure is 30–60 psi.

Twin fan nozzles should be used with caution since they apply half of the spray volume of a regular fan nozzle out of each orifice. They produce more small droplets than a regular flat fan nozzle applying the same flow rate of spray solution. Finer screens or strainers should be used with these nozzles to prevent plugging of the small orifices. Twin fan nozzles are best suited for application of contact pesticides that require good spray coverage. The twin fan spray pattern improves spray penetration through dense foliage and crop residue.

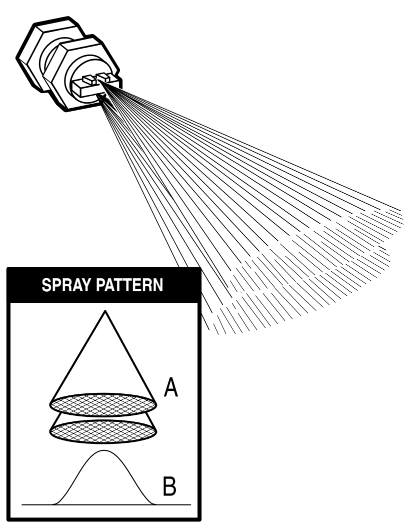



**FIGURE 11-13.** Twin fan nozzle spray pattern (A) and spray distribution (B)

### *Nozzle Life*

As a nozzle wears, its performance deteriorates. The orifice enlarges, which increases the flow rate. As a result, atomization may change, which in turn changes droplet size as well as the distribution of droplet sizes. Wear will also distort droplet distribution patterns.

For long-lasting nozzles, select those made of materials that resist wear and corrosion. Sprayer tips can be made from brass, nylon, plastic, stainless steel, hardened stainless steel, tungsten carbide, or ceramic materials. Brass tips are the least expensive, but the metal is soft and the tips wear rapidly, especially with abrasive sprays such as wettable powders. Nylon tips cost about the same as brass but wear better. Plastic tips wear inconsistently; they tend to last longer than nylon but not as long as stainless steel. Stainless steel and hardened stainless steel tips cost more but wear much better—in the long run, they can be bargains. Stainless steel tips resist abrasion and corrosion and are recommended for applying wettable powders. Tungsten carbide and ceramic tips last very long but may be unavailable for some sprayers.

### *Nozzle Size*

After selecting a nozzle type, determine which size or flow rate is needed. Typically, broadcast or directed nozzle boom sprayers use only one nozzle size across the sprayer. Nozzle sizes should be selected based on the travel speed (MPH) of the sprayer and the width of the area treated by each nozzle so that the desired application rate (GPA) is met. The total required flow through all the nozzles can be calculated with this equation:

$$\text{flow per nozzle (GPM)} = \frac{\text{GPA x MPH x width}}{5{,}940}$$

GPM = gallons per minute
GPA = gallons per acre
MPH = miles per hour
5,940 = a constant to make units consistent
Width = nozzle spacing in inches for broadcast spraying
OR = spray width in inches of one band nozzle
OR = row spacing in inches ÷ number of nozzles per row in directed spraying

If a grower wants to apply 100 gallons per acre and drive 3 miles per hour with a broadcast sprayer using nozzles spaced on 20-inch centers, the required total flow through each nozzle is:

$$\frac{100 \text{ GPA x } 3 \text{ MPH x } 20 \text{ inches}}{5{,}940} = 1.01 \text{ GPM}$$

Once the required nozzle flow rate has been calculated, consult nozzle manufacturers' catalogs to select the nozzle that provides the required output within the operating pressure range of the sprayer. Changing the pressure changes the nozzle flow rate, but adjusting the pressure affects spray droplet size and drift as well as the spray pattern. Adjust pressure to make only small changes in nozzle output; this will avoid significant changes in spray characteristics. Pressure must be increased four times to double the nozzle flow rate, and the change in pressure significantly affects nozzle performance.

Nozzle manufacturers specify how to set up their nozzles to provide a uniform spray distribution. The instructions vary by nozzle type, size, and manufacturer; so different nozzle types should not be mounted on the same boom. Manufacturers code nozzles by type, flow rate, fan angle, operating pressure range, and nozzle material. Each manufacturer has its own codes and descriptions, so it is important to know the meaning of codes when comparing nozzles or selecting replacements. Consult nozzle manufacturers' catalogs to determine the best operating parameters, such as pressure, height, and spacing, for specific nozzles.

### *Air Delivery Systems*

As mentioned previously, some newer boom sprayers are incorporating some form of air system to aid in delivery of spray to the target area. Some air-assist sprayers will direct a sheet of air behind the nozzles. Others will direct air around the nozzle.

Air-assisted boom sprayers have been shown to provide many advantages over traditional boom sprayers. When the air system is properly adjusted and matched to the nozzles, it is possible to increase penetration to denser parts of the canopy, increase coverage on underleaf surfaces, and reduce spray drift. However, in some situations, especially when treating bare ground or small plants, the spray can bounce back up into the air and increase the risk of spray drift. With some air-assist sprayers, the operator can adjust the air speed to better match the canopy conditions and the delivery needs. Some sprayers can be adjusted with regard to the direction of air flow. Directing air and the spray at an angle to the canopy has been shown to increase penetration and provide a more uniform distribution of spray throughout the canopy.

### *Charged Spraying Systems*

Placing an electrical charge on spray droplets has been shown to increase spray deposits and coverage, particularly on the undersides of leaves. There are two main types of charged spraying systems: induction charging and contact charging. The induction charging systems pass small spray droplets through a high-voltage ring or wire. Commercial induction charging systems use a special air atomizing nozzle to produce relatively small droplets. The contact charging systems charge the spray solution before it reaches a standard type of nozzle. Contact charging systems may operate at 40,000 volts, whereas induction charging systems may operate at 1,000 volts.

Charged spray particles tend to repel each other, which causes the spray cloud to expand as it moves through the plant canopy. With properly matched droplet sizes and electrical charges, the particles can also be attracted to the undersides of leaves. Because these sprayers provide increased coverage, they can usually be operated at lower application rates. Electrical charging alone will not necessarily increase penetration. Usually some extra energy must be added to the droplets, such as that provided by air assistance.

## Sprayer Calibration

Calibrating a sprayer means making a "check" or trial run to determine the application rate. Sprayers should be calibrated before new nozzles are used for the first time and whenever pressure or speed is adjusted. Calibration requires only a few minutes and is time well spent. It is necessary to determine the actual application rate of the sprayer in the field because:

1. Chemicals must be applied at the proper rates to be effective and economical. A calibration test determines the application rate with the selected nozzles, pressure, and travel speed. Using more chemical than needed is wasteful and may violate the labeled rates; not using enough results in an ineffective operation and wasted expense for materials and labor.
2. Nozzle catalog values are based on pressure, travel speed, flow rate, and row or nozzle spacing. An inac-

curate pressure gauge or speedometer, wheel slip, friction loss in the plumbing, or other factors may result in nozzle performance not matching catalog values.

3. A grower or operator must know the application rate so that the correct amount of chemical is added to the tank.

## Precalibration

The sprayer must be operating properly before calibration. The following precalibration checks are suggested:

1. Check and clean all nozzles and screens. Replace any that are damaged.
2. Observe nozzle patterns; they should be continuously smooth with no skips or heavy streams. Replace any nozzles that are suspect. If more than one or two need replacing, probably all need replacing.
3. Check the nozzles and their arrangement on the boom for proper spray pattern overlap. Follow manufacturer's recommendations.
4. Check the pressure gauge. Pressure should be stable and at the desired level while spraying. If the gauge fluctuates due to pump pulsations, install a damper between the line and the gauge or use an oil-damped gauge. The gauge will be easier to read and will last longer.

## Calibration

Follow these steps for easy calibration:

1. Select an area similar to field conditions that can be driven through and a second area where the sprayer can be stopped and operated stationary.
2. During calibration, use only water in the spray tank. Results will be very close to actual spray conditions.
3. Make adjustments to obtain the desired pressure (while spraying) and travel speed.
4. Make a calibration test and determine the application rate. Three methods are suggested below.

### Tank Level Calibration Method

After performing the precalibration check and steps 1 through 4 above, follow these steps:

a. Fill the tank completely or to some known level with only water.

b. Spray only a known area of the calibration plot selected and measured in step 1.

c. Return to the filling site (exact location if possible) and accurately measure the amount of water required to refill the tank to the original level in (a) above. An alternative is to weigh the sprayer before and after the calibration test to determine the amount of water sprayed. Water weighs 8.34 pounds per gallon.

   CAUTION: Do not weigh the tractor since its weight will change with fuel consumption.

d. Determine the application rate by dividing the amount of water used by the area sprayed. For example, if 24.5 gallons were applied to 0.25 acre, the application rate is 24.5 gallons ÷ 0.25 acre = 98 gallons per acre. Make adjustments to travel speed or pressure or replace nozzles to achieve the desired application rate.

It should be noted that the above method does not necessarily identify problems with nozzle output or with tractor speed. Other calibration techniques are required to evaluate nozzle condition and travel speed.

### Ounce Calibration Method

This method is different from the above procedure because nozzle output is measured while the sprayer is stationary. It is based on spraying $\frac{1}{128}$ of an acre.

a. Fill sprayer approximately two-thirds full of water.

b. Determine the time in seconds needed to drive through a test distance based on the nozzle spacing in table 11-3.

c. With the sprayer parked, operate at the intended pressure and catch the output of one nozzle in a container marked to the nearest half ounce for the same length of time required to drive through the test course selected above.

d. The ounces of water collected is equal to the application rate in gallons per acre. For example,

**TABLE 11-3.** Course lengths for ounce calibration method

| **Nozzle Spacing (inches)** | 10 | 12 | 20 | 24 | 30 | 40 |
|---|---|---|---|---|---|---|
| **Course Length (feet)** | 408 | 340 | 204 | 170 | 136 | 102 |

if 35 ounces of water are collected during the sampling time for one nozzle, the application rate is 35 gallons per acre.

e. Continue by measuring the outputs of all nozzles on the boom. Replace any nozzle where the output is more than 10% different from the average output of all of the boom nozzles.

The ounce calibration method does not necessarily determine where problems exist if it is found the sprayer is operating at the wrong application rate. The travel speed and nozzle flow rate must be calculated to determine how to correct the sprayer output.

### *Time/Rate Calibration Method*

This method is similar to the ounce calibration method, except the output of each nozzle and travel speed are measured.

a. Fill the sprayer approximately two-thirds full of water.

b. Measure out a 200-foot distance in the field and determine the time, in seconds, necessary for the tractor to travel through the distance with the sprayer operating. The travel speed is calculated with the following equation:

$$\text{travel speed (MPH)} = \left(\frac{\text{200 feet}}{\text{travel time in seconds}}\right) \times 0.682$$

c. Return to the filling site and fill the tank to some known level with water.

d. With the sprayer parked, operate at the intended pressure and catch the output of one nozzle, in a container marked to the nearest half ounce, for 20 to 60 seconds. The collection time depends on the time necessary to fill the container approximately one-half to two-thirds full. The nozzle flow rate is calculated with the following equation:

$$\text{nozzle flow rate (GPM)} = \left(\frac{\text{ounces collected}}{\text{collection time in seconds}}\right) \times 0.469$$

e. Measure the nozzle spacing in inches (width).

f. The application rate can be calculated with the following equation:

$$\text{application rate (GPA)} = \left(\frac{\text{GPM} \times 5{,}940}{\text{MPH} \times \text{width}}\right)$$

g. If the desired application rate is not obtained, adjust travel speed, adjust operating pressure or other flow rate control, or change nozzles. Rerun the test until the desired rate is achieved. Generally, only small changes are practical with pressure regulation. Larger changes are possible with speed control, but major changes usually require a different set of nozzles, except for air-shear or air-atomizing nozzles, where a separate flow control is used.

Once the desired application rate is obtained, record the number, sizes, and location of nozzles on the manifold; operating pressure or flow control setting; tractor speed or tachometer reading; and gear used. If the sprayer is later changed to a different rate but you want to return to the original rate, this information will save time. Also, if an annual check is run at the same conditions and the results are recorded, you will be able to monitor nozzle wear over several years.

## Sprayer Operation

Factors important in sprayer operation include tractor selection and operation, drift control, pump pressure, and driving speed. Practice sprayer operation with only water in the tank until you are completely familiar with all controls and procedures.

### *Tractor Selection*

Tractor selection for operating a sprayer is very important to good spraying. The tractor must have enough power to operate the sprayer at the desired speed, even on the steepest slopes, with a full tank of spray mix. If the sprayer is powered through the tractor PTO, enough power must be available to operate the fan and pump at the rated speed and to transport the sprayer at the desired speed.

Check the sprayer manufacturer's specifications for the smallest tractor needed. Make sure the tractor is heavy enough and properly ballasted to safely handle the sprayer's weight on the steepest terrain to be sprayed, especially if the sprayer is a tractor-mounted unit.

Another factor is travel speed. The tractor should have a gear to provide the desired speed. Older tractors and some smaller ones have only a few gears, so the step between gears is relatively large. Remember that with PTO-powered sprayers, the fuel throttle cannot be used to regulate ground speed, since the engine must be operated to provide 540 rpm at the PTO shaft. In this case, one gear may be too fast and the next one too slow, unless the tractor has a hydrostatic transmission that provides stepless speed control.

## Drift Control

Drift is defined as airborne movement of spray material that reaches nontarget areas. In simple terms, drift is the portion of the spray that misses the target or moves away from the target (plant, soil, or pest) afterward. Obviously, when spraying strawberries, some of the spray mix will not be deposited on the plants. The drift may be liquid droplets, vapor, or both.

Droplet drift is related to droplet size. Large, heavy spray droplets not intercepted by the plants will fall quickly to the ground, while smaller, lighter droplets will stay suspended longer in the air. These small droplets will be carried farther if any wind is present. Drift within the field is inefficient but generally safe. Drift out of the field must be controlled.

Vapor drift from evaporating (volatile) chemicals (for example, 2,4-D) can continue after spraying is finished. Small amounts of highly volatile pesticides can collect and remain undiluted when air is stable; this pesticide can ultimately injure susceptible plants well outside the treated area.

The drift hazard must be balanced with the droplet size and spray pattern required for the application. Use larger nozzles with higher flow rates at lower pressures to reduce the potential for spray drift. If this does not provide adequate coverage, use a higher spray volume to help improve spray coverage. Keep pressure high enough to maintain the spray angle and spray distribution.

Nozzle manufacturers offer several new nozzles and replacement components designed to reduce spray drift without changing sprayer settings. The new designs use additional chambers, orifices, or restrictors to decrease pressure within the nozzle and reduce the number of small droplets produced. Other designs use additional chambers to alter the swirling action of the liquid so fewer small droplets are produced. These nozzles and components that reduce the drift hazard do not alter the overall spray pattern or spray distribution from similar components. Minimizing spray drift may compromise spray coverage.

Spray drift can also be minimized by using low-volatil-ity chemicals that reduce vapor drift. The air speed and direction on air-assist sprayers should be adjusted to minimize spray drift.

Other methods to reduce drift include using antidrift additives and spraying when climatic conditions do not increase drift. Antidrift additives increase the surface tension of the spray at the nozzle orifice so that fewer fine droplets are produced. Climatic conditions such as wind and humidity affect drift. To minimize drift, spray only when the wind speed is less than 5 miles per hour unless adjustments are made to the droplet sizes produced by the sprayer or unless other means such as air delivery are being used to keep more of the spray on target.

It also helps to spray when the relative humidity is high, which reduces water evaporation and prevents droplet size from getting smaller after leaving the sprayer. If at all possible, use chemicals that require large droplets.

Finally, always keep a record of each spray application, including the date, time, material, rate, location, and weather conditions. Contact your state's regulatory agency for more information on pesticide record keeping.

## Pump Pressure

Nozzle pressure and, therefore, pump pressure influence the droplet size produced by hydraulic nozzles. Increased pressure may improve coverage by producing more droplets, but the smaller droplets produced increase the drift potential. Increasing pressure may not necessarily increase the speed of droplets and penetration into the canopy, since smaller droplets slow more quickly. With air-shear nozzles, the pump creates only the flow, not the atomization, so a fairly low pressure will generate a smooth flow through the flow regulators. Always operate a pump within its designed pressure range and according to the manufacturer's recommendations.

## Driving Speed

Travel speed may also affect spray coverage. As ground speed increases, the effective distance to the target increases. Higher travel speeds also cause more distortion of the spray pattern, which results in less uniform spray distribution. Increasing travel speed generally requires the use of larger orifice nozzles to produce higher output and maintain the desired application rate. Higher output nozzles produce larger droplets, which will reduce spray coverage.

## Spraying Equipment for Small Plantings

Although powered sprayers make strawberry spraying easy and fast, they are relatively expensive and must be used on considerable acreage to be economically justified. This acreage may include strawberries or other crops, but the fixed (ownership) costs must be spread over many acres, even for the smaller air-blast units to be feasible (see table 14-7 on page 124). Growers with smaller plantings will need to explore alternative, less expensive spraying equipment.

### *Hand-Held Sprayers*

Hydraulic hand-held sprayers are "handgun" sprayers that may be equipped with single or multiple nozzles (figure 11-14). The multiple nozzle guns are actually miniature hand-held booms. Handguns are connected by a relatively long hose to a powered pump. Most handguns require high pressure, so typically either piston or diaphragm pumps are used.

As with any hydraulic nozzle, the principle of handgun operation is that pressure is used to atomize the spray liquid into droplets. The energy of the droplet's velocity at the nozzle discharge projects the spray to the target. The farther the target is from the handgun, the higher the pressure needed to provide enough velocity to carry droplets to the target. However, as pressure is increased, smaller droplets are produced and they tend to slow more quickly.

Often, two people perform handgun spraying, one operating the handgun and one driving the tractor or other vehicle used to transport the sprayer through the field. This is convenient but increases labor needs. The quality of handgun spraying depends on the operator. Much practice is needed to become skillful enough to obtain thorough coverage for adequate pest control without overspraying and to obtain uniformity in application rate.

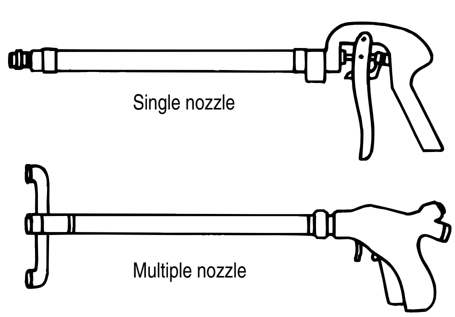



**Figure 11-14.** Hand-held sprayers

Factors such as temperature, fatigue, slope of the terrain, walking surface, and length and weight of the hose can increase the difficulty of handgun spraying.

### *Knapsack Sprayers*

Another sprayer suitable for small plantings up to about $\frac{1}{4}$ acre is the knapsack sprayer (figure 11-15). They are also useful for making spot treatments where the pest problem is not spread across the entire field. This sprayer is entirely manually operated and is carried on the operator's back with shoulder straps. Sprayer parts include the basic parts of most sprayers: a tank to hold the spray mix, a pump or pressurized gas canister to produce pressure and flow, controls to regulate flow, and an atomizer.

Tanks are typically plastic or steel and in the 3- to 5-gallon size range. Some have a mechanical agitator that moves when the pump is used to provide some mixing; others may have jet agitation. Before spraying, the entire sprayer can be shaken to ensure good mixing.

Hand pump sprayers have a built-in piston or diaphragm pump. Some models can be adapted to either left- or right-handed pumping, with the free hand operating the flow control valve and the nozzle. The pumps are positive displacement types and can produce relatively high pressures. There is only a very small chamber where the liquid is under pressure, which makes the sprayer a "pump-as-you-go" system.

The distribution system includes an on/off valve, usually with a pistol-grip handle, and one or more nozzles. The nozzle is often mounted at an angle on a 16- to 20-inch wand to aid spray placement on the plants. Some

**Figure 11-15.** Knapsack sprayer

designs provide for interchangeable nozzle tips so that nozzles can be better matched to the job.

Using a knapsack sprayer to spray strawberries is a time- and labor-intensive method. From the standpoint of equipment investment, the cost is low, but the capacity is also very low. However, where labor is a minimal consideration, such as for many homeowners and hobbyists, the knapsack sprayer is effective if properly used. Since the operator controls the travel speed, variations in application rate similar to those caused by handgun systems can be expected. In addition, extra care should be given to coverage and uniformity because so little water is used as the spray mix carrier and diluent. It is not practical to apply a rate close to 100 gallons per acre with a hand sprayer.

### *Powered Knapsack Sprayer*

Another version of the knapsack sprayer has a very small engine and fan to create a hand-carried air-assist sprayer (figure 11-16). This sprayer is also known as a motorized knapsack mist blower.

Powered knapsack sprayers are equipped with 3- to 5-horsepower engines. Two-stroke cycle engines are used to minimize the weight; however, they require a gasoline/oil mixture for fuel. Operators should follow the manufacturer's recommendation on the oil-to-fuel ratio, which may be given on the fuel tank or its cap. The engines operate at 5,800–8,000 rpm and are noisy—operators should wear ear protection. The sprayers are much heavier than manual models, weighing 17–25 pounds when empty.

**FIGURE 11-16.** Powered knapsack sprayer

The engine operates a centrifugal fan that delivers 200–450 cubic feet of air per minute. The discharge velocity is usually over 200 miles per hour. With this high velocity, air shear nozzles are practical and often used. However, hydraulic orifice and rotary nozzles are also used to form and inject the droplets into the air stream. The air from the fan is fed through a flexible tube with an air nozzle on the end. The operator controls the direction of the air stream to place the spray on the target. Because of the high discharge velocity, the air nozzle should be at least 6 feet from plants. The air stream should be aimed downwind so that natural currents assist in dispersing droplets away from the operator. Spraying into even a slight wind may result in droplets being blown back onto the operator. Care should be taken to avoid overspraying the target, since it is more difficult to observe the spray coverage produced by these sprayers.

Motorized knapsack mist blowers can spray strawberries much faster than manual sprayers. The air stream will assist in delivery and coverage, even at lower application rates. However, the area that can be sprayed is still limited, because, to limit the weight that operators carry, the sprayer tanks are about the same size or even smaller than those on manual sprayers. Therefore, a tankful will cover only a relatively small area, and much time is required to refill the tank and measure chemicals.

## Hand Sprayer Calibration

Hand sprayers need to be calibrated for the same reasons as power sprayers. The operator must first determine the percentage of an acre covered by one tankful of spray mix. By multiplying this percentage by the recommended application rate per acre, the operator can easily calculate the amount of chemical required per tank. Before calibrating a sprayer, operate it with only water to be sure all parts are properly working.

Handguns, manual knapsack sprayers, motorized knapsack sprayers, and other hand sprayers can be calibrated with the following method:

1. Select a calibration plot (row length) that represents $\frac{1}{100}$ to $\frac{1}{20}$ acre. A bigger plot will produce more accurate results. There are 43,560 square feet in an acre; therefore, row length per acre is 43,560 square feet divided by the row spacing (feet). For example, if the strawberries are planted in rows 4 feet apart, then there are 43,560 square feet ÷ 4 feet = 10,890 feet of row per acre. There are approximately 109 feet (10,890 ÷ 100) of row in $\frac{1}{100}$ of an acre, and 545 feet (10,890 ÷ 20) in $\frac{1}{20}$ acre.

2. Fill the sprayer tank with only water and spray the calibration plot at a rate that achieves good plant coverage. This requires good judgment; an inexperienced operator should get help or training from an experienced or trained pesticide applicator. The goal is to provide coverage to the entire plant without reaching the point of runoff (spray mix dripping from plants) to avoid waste and potential pollution.
3. Measure the amount of water required to refill the sprayer tank to the previous level. Calculate the application rate by dividing the amount of water used by the area covered. For example, if 1.5 quarts were applied to $^1/_{100}$ of an acre, the actual application rate is 37.5 gallons per acre (1.5 quarts ÷ 4 quarts per gallon ÷ $^1/_{100}$ acre).

A preferred alternate method for hydraulic handgun sprayers (not mist sprayers) is a modification of the above method.

1. Same as step 1 above.
2. Same as step 2 above, but also determine the time required to spray the calibration plot as measured.
3. With the sprayer in place, spray into a container for the time measured in step 2. Be sure to collect all the water for the exact time period. The water in the container will be the same amount applied to the calibration plot. Calculate the application rate as described in step 3 above.

## Hand Sprayer Operation

Hand sprayers require much more labor to operate than the tractor-powered units, so hand sprayers are limited to small plantings. High application rates similar to those achieved with the powered sprayers are feasible with the powered handgun, because the spray mix is carried by the tractor or a trailer and the pump is powered. However, with knapsack sprayers it is not practical to use such high rates.

A major problem with hand sprayers is the inability of an operator to walk along a row at a uniform rate. Variation in walking speed will vary the application rate. However, an experienced applicator may be able to compensate for variations of plant density in the plant row. For example, if a plant is missing in a row, the operator can skip that space and move immediately to the next plant. Inexperienced operators should practice with water until they can apply a pesticide uniformly at the recommended rate.

Hand sprayers necessarily place the operator near the nozzles and discharge point of the sprayer. This makes operator protection very important. Basic protection includes a hat, long-sleeved shirt, and trousers, or a spray suit. Depending on the toxicity of the chemicals, other protective gear such as a respirator, goggles, waterproof gloves, or waterproof boots may be needed. All operators should read the labels and follow directions for the specific material being applied. The spray should be discharged with the wind so that droplets are carried away from the operator. If spray is directed into the wind, some will be blown back onto the operator.

Drift can be a problem with hand sprayers and may be even more important where lower application rates are used. The spray mix is more concentrated, so any loss means more active ingredient is lost. The best solution is to spray only when winds are slight or blowing at less than 5 miles per hour. Operators should use as low a pressure and as large an orifice as is practical to minimize the number of small droplets formed. Adding a drift control additive to the spray mix may also be helpful.

## Sprayer Maintenance

Like all other equipment, hand sprayers must be kept in good working order to last a long time. Cleaning is especially important because of the chemicals used. A very thorough cleaning should be performed whenever chemicals are changed and at the end of each spraying season. Sprayers must be protected from corrosion and freezing in storage during the off season.

### *Cleaning*

Sprayers must be cleaned to prevent corrosion, cross contamination of pesticides, and crop injury. Trace amounts of one pesticide can react with another or carry over to the next spraying and cause damage. Long exposure to even small amounts of some pesticides can damage sprayer parts, even stainless steel tips and fiberglass tanks. If crops are sprayed that are sensitive to the herbicides used, maintain two sprayers—one for herbicides and one for all other spraying. No cleaning method is perfect, but careful cleaning will remove all but insignificant amounts of insecticides and fungicides.

Always try to end the day or a spraying job with an empty tank to avoid having leftover spray mix. Be careful when disposing of leftover mix or wash water; avoid contaminating water supplies and injuring plants or animals. Do not leave puddles that might be accessible to children, pets, farm animals, or wildlife. Two recommended methods of disposal are collecting the waste in a holding tank and recycling it during the next spraying, or spraying waste on another area with similar plants and problems while being careful to avoid overapplication.

When the sprayers are empty, triple rinse the tanks with clean water, preferably after each day's operation. Also rinse the outside of the sprayer. Before changing pesticides or storing sprayers for the winter, clean sprayers thoroughly with a cleaning solution. Check the label for directions. A good detergent solution will remove most insecticides and fungicides. First, flush the tank with water; then add the cleaning solution to the tank and thoroughly agitate it before flushing again. Always flush with clean water to remove the cleaning solution.

Remove nozzle tips and screens; clean them in a strong detergent solution or kerosene, using a soft brush such as an old toothbrush. Follow the same safety precautions during cleaning as for mixing and application. Use a respirator, waterproof gloves, or other protective gear as directed by pesticide label instructions.

### *Lubrication*

Lubrication may be required, depending on the sprayer design. Some sprayers are built with sealed bearings that do not require additional lubrication. Wear points other than bearings may need to be greased or oiled. Some sprayer parts may need to be coated to prevent corrosion during nonuse periods. Follow the instructions in the owner's manual.

### *Winterizing*

Sprayers must be protected from corrosion and freezing during winter storage. If a sprayer has no rubber parts such as gaskets, diaphragms, or hoses, put new or used engine oil from a gasoline engine in the tank before the final flushing to prevent corrosion. As water is pumped from the sprayer, the oil will leave a protective coating inside the tank, pump, and plumbing. Remove nozzle tips and screens and store them in a can of light oil such as diesel fuel or kerosene to prevent corrosion. Close nozzle openings with duct tape to prevent dirt, insects, or mice from entering.

In all cases, protect the pump. If the pump has rubber parts, disconnect the lines and put automotive antifreeze or radiator rust inhibitor in the inlet and outlet ports. If the pump has no rubber parts, engine oil is satisfactory. Rotate or move the pump several times to completely coat interior surfaces.

During the final cleaning, inspect the hoses, clamps, connections, nozzle tips, and screens for possible replacement. Store the sprayer in a clean, dry building.

CHAPTER 12

# *Harvesting, Handling, and Transporting Fresh Fruit*

Strawberries are among the most perishable of all fruits. They ripen quickly in the field and even faster after harvest. Thus, for fruit to maintain high-quality characteristics such as glossiness, red color, firmness, and freedom from fungal decay for more than a few hours requires special attention to a number of preharvest and postharvest factors. Each grower must consider the importance of these factors in relation to his or her marketing plan. For example, a grower with a pick-your-own operation will not need to pay as much attention to most of these factors as one marketing fruit through wholesale and retail outlets.

## Preharvest Considerations

Preharvest factors that influence berry quality are choice of variety, growing site, plant health and nutrition, and fungicide and pesticide application.

Varieties differ markedly both in storage life and shelf life. Storage life is that time that a strawberry variety will maintain enough quality for marketing. Usually this is seven to ten days at 32˚F. Shelf life refers to the period of time, usually one to two days (at 68˚F), that the berries maintain quality at temperatures close to ambient (for example, at a roadside stand or supermarket).

In a pick-your-own operation, the intensity of flavor that a variety develops on the plant may be the principal consideration. However, as soon as handling operations and the need to store fruit become considerations, both fruit firmness and the ability of a berry to color properly when harvested at less than the full red ripe stage become paramount. Sparkle, Catskill, and Delite strawberries, for example, can no longer compete with the firmer fruit of Allstar, Jewel, or Honeoye in the retail market (see table 3-1 on page 17). Most varieties can redden after harvest; but at least one, Cavendish, sometimes will not ripen uniformly during storage. Fruit of this variety develop a liver-red color on the parts of the fruit that were orange at harvest, whereas areas on the skin that were pale fail to ripen further. These berries are, therefore, less acceptable as a variety for wholesale or retail markets.

Selecting a site that will provide good microclimactic conditions, such as good air drainage, and planting in a row orientation parallel to the prevailing summer winds will maximize plant health and improve the quality of harvested fruit. Proper plant densities will reduce disease pressure on fruit. Rain and dew increase the likeliness of infection by fungi, but this moisture will evaporate more quickly in a sparse canopy with good air circulation. Similarly, proper irrigation management can minimize decay induced from supplemental water; this means irrigating early enough so plants can dry before evening.

Adequate nutrition is also an important component of good storage life. Fruit from plants that are nutritionally stressed will have a shorter storage potential than fruit from healthy plants. It is essential that adequate potassium and calcium be available to the plant and that nitrogen not be too high. A relationship exists between nitrogen availability and fruit softness and susceptibility to gray mold infection in strawberry. Preharvest calcium sprays may result in firmer berries with greater storage potential. A leaf analysis aids in fine-tuning the fertilizer program.

Fungicides applied during bloom and at petal fall can significantly reduce the number of moldy berries in strawberries. Gray mold *(Botrytis cinerea)* readily infects senescent petals and grows from the petals into developing fruit. Affected berries may have no visible signs of infection until harvest. Thus, timely petal fall sprays are essential, especially during damp, humid weather.

Some insects cause only minor physical damage when feeding on the fruit, but even small wounds are sites for fungal infection. Certain insects may spread bacteria and fungi from fruit to fruit. If insecticides are used to control pests, be sure to consider days-to-harvest restrictions.

## Harvest Management

The stage of berry ripeness and handling at harvest are two critical factors in maintaining quality after harvest. Fruit harvested before it is fully ripe will have a longer storage and/or shelf life than those harvested at the fully ripe or overripe stage. Strawberries with a white tip will retain their firmness much longer than those harvested fully ripe and will lose less water during storage. However, there is usually a compromise between flavor and storage potential. Fruits harvested at a less ripe stage are unlikely to develop the same intense flavor as fruits harvested at the fully ripe stage. Selection of appropriate varieties will ensure that adequate flavor is realized.

Fruit quality of fresh market strawberries usually declines as the season progresses. Be sure the marketing channels are open before the first berries ripen, as these berries will likely have the highest quality of the season.

Because strawberries ripen quickly, frequent harvesting of the field (once every two days) is critical. Pickers may need to be trained to identify the proper ripening stage and berry appearance for harvesting. Training pickers is also critical to ensure that harvest is carried out in a way that minimizes damage to berries. Berries should not be touched before harvest. They are extremely fragile and easily damaged during harvest, but the damage may not always be visible until later. Studies in California have shown that the percentage of damaged fruit may vary significantly from one picker to another, and differences may be so great as to mask any other causes of deterioration.

Mixed ripening stages are less attractive in the marketplace. Underripe berries will be slow to develop acceptable color, whereas overripe berries lose their attractive "glossiness" and are susceptible to mold. Once the mold growing on overripe berries sporulates, large amounts of inoculum will be present to infect other ripening fruit. Overripe berries also attract ants, wasps, and other pests. Pick overripe berries off plants and do not dispose of them near the field. It may be more economical in the long run to pay pickers for harvesting rotten as well as marketable fruit. A grower could pay an hourly wage to one worker for harvesting only rotten berries so the other pickers will not contaminate their marketable berries with fungal spores.

Place only marketable berries into commercial containers. Marketable berries are at least 0.2 ounce in size and have no blemishes. Small, overripe, or defective berries can be used for processing. This sorting process is best done in the field so berries are handled only once. Unlike many other fruits, grading standards do not exist for strawberries, so it is less efficient to bring berries to a packing line for sorting and packaging.

Wide, shallow containers are better than deep containers. Check with the buyer to determine what type of container is preferable; each type has advantages and disadvantages. The pulp containers are inexpensive but stain easily. Wooden containers also stain and are expensive. Solid clear plastic containers (polystyrene clamshells) are popular among wholesalers (photo 12-1); they do not stain, they significantly reduce moisture loss when used with a cap, they enable customers to see all the berries they purchase, and they are inexpensive. However, juice can accumulate at the bottom, and it is thought that berries are more difficult to cool in clamshells.

## Postharvest Considerations

Much time and effort can be expended to produce and harvest a good crop of berries, only to have the crop deteriorate before it is sold. This deterioration is caused by respiration of the fruit. Respiration occurs in all living organisms and is the process by which food reserves are converted into energy. In a complex series of reactions, starches and sugars are converted first to organic acids, then to more simple carbon compounds. Oxygen from the surrounding air is used in the reaction, and carbon dioxide and heat are released.

Respiration of fruits results in shrinkage and reduced sweetness. The rate of respiration, or the speed at which fruit deteriorate, can be measured by the amount of carbon dioxide produced per weight of fruit over time (see table 12-1 on page 106).

Berry fruit have much higher rates of respiration than fruit such as oranges and apples, which have considerably greater storage potentials. Conditions that slow the respiration process are low temperatures, high carbon dioxide levels, and low oxygen in the storage chamber.

**Table 12-1.** Respiration rates (mg $CO_2$ $kg^{-1}$ $h^{-1}$) of various fruits stored at different temperatures

| | Temperature (°F) | | | | |
|---|---|---|---|---|---|
| **Commodity** | **32** | **41** | **50** | **59** | **68** |
| Raspberry | 24 | 55 | 92 | 135 | 200 |
| Blackberry | 22 | 33 | 62 | 75 | 155 |
| Strawberry | 15 | 28 | 52 | 83 | 127 |
| Blueberry | 10 | 12 | 35 | 62 | 87 |
| Orange | 3 | 5 | 9 | 5 | 24 |
| Apple | 3 | 5 | 8 | 13 | 20 |

Cooling strawberries after harvest is the most important action a grower can take to maintain fruit quality. Each 10˚F reduction in temperature reduces the respiration rate of fruit by approximately 50% (table 12-1). At 77˚F and 30% relative humidity, fruit will lose water thirty-five times faster than it would at 32˚F and 90% relative humidity. An hour delay in cooling is thought to reduce storage life of fruit by one day. Clearly, prompt cooling and maintenance of proper temperatures and humidity are essential.

## Cooling Methods

Several methods are available to cool horticultural produce: passive or room cooling, forced air cooling, hydrocooling, vacuum cooling, and cooling with liquid ice. The special nature of strawberries limits usable cooling methods to the first two; the method of choice for cooling is forced air cooling. The reason for this becomes quite obvious when comparing the "7/8 cooling time" (the number of hours it takes to remove seven eighths of the field heat) of forced air and passive cooling methods. In the case of passive cooling, the typical 7/8 cooling time for strawberries in 12-quart flats on pallets is nine hours, while the 7/8 cooling time for forced air cooling is ninety minutes—six times shorter.

Passive or room cooling, though relatively slow, can be used by any grower with coldstore facilities. The cooling process can be accelerated by spreading fruit out in the cooler, thereby exposing the tops of flats to cold air circulated by the cooling unit. Still, this method is much slower than forced air. Once cooled, the flats can be stacked and kept cool until the fruit is marketed. Growers can take advantage of night cooling by harvesting fruit as early in the morning as possible.

Forced air cooling involves channeling refrigerated air through the containers holding the fruit (photo 12-2). Large growers may have a separate forced air cooling facility specifically designed for removing field heat, but inexpensive, effective improvisations can be adapted for any cold storage. If a grower only has a walk-in cooler, recently picked flats of berries can be set into a cardboard box that is opened at both ends; a household fan can then be placed at one end of the box to draw air through the flats. Once the berries are cool, flats can be removed from the cardboard and wrapped in plastic.

Operation of a precooling system, whether on a small or large scale, requires that the cooling rate of the fruit be followed by checking flesh temperatures throughout the process. The fan should be cut off when the flesh temperature is within 5˚F of the desired temperature to avoid dehydration of the berries.

The selection of a cooling unit is very important when a cooler is designed. If the temperature difference between the air and the cooling unit is too large, then the condensers will accumulate ice from moisture in the air. This drying of the air would not cause a problem for dry goods but would severely dehydrate fruit. The atmosphere around the fruit should be humid to prevent shrinkage, so a cooler should be able to maintain a relative humidity of 90–95% at 32˚F. These types of coolers are more expensive and less common than those for dry goods. Consult your agricultural engineering specialist for help with selecting a cooling unit and building a storage facility.

Hydrocooling of strawberries has not been recommended in the past because of fear of inducing fungal decay after the berries have been treated with iced water. However, preliminary research in Florida has shown that using chlorinated water for hydrocooling can maintain fruit

### *Components of Forced Air Cooling*

1. **Vented containers** to allow air to flow past fruit
2. **Fan capacity** appropriate to the volume of fruit being cooled (2 cubic feet per minute per pound of fruit)
3. **Air ducts** to deliver cool air to the fruit and warm air back to the coils
4. **Control of escaping air** by plugging gaps and tarping the containers

quality as well as forced-air cooling. With appropriate attention to hygiene, this method may be well suited for small-scale operations such as those in the Northeast.

The temperature in the storage room can be kept as low as 30˚F. Berries will not freeze at or above this temperature because the sugars in the fruit lower the freezing point. Maintaining the storage at a slightly warmer temperature (32˚F) will allow some room for error. However, major shippers report that storage at 40˚F as opposed to 30˚F reduces shelf life by 50%.

Whatever method is used for cooling, condensation can be a problem. Cold fruit removed from storage on a warm day will become moist with condensation very quickly, resulting in loss of "gloss" and development of warm, moist conditions favorable to fungal decay. Condensation can be avoided, however. The best way is to maintain refrigeration during the entire marketing period; but this requires facilities for storage, transport, and display that many small producers do not have.

A simple method to avoid condensation is to cover flats or pallets with plastic before they are brought out from cold storage. The plastic must be left on until the berries warm to a temperature above the dewpoint. Remember that the plastic must be removed if fruits are going to be refrigerated, as leaving the plastic in place will cause condensation to form inside the bag and create an environment for fungal decay.

High carbon dioxide concentrations, typically between 15 and 20%, will reduce fungal decay and help maintain the quality of strawberries. The financial investment required for controlled atmosphere storage and short storage life of berries has limited the use of this storage method to extend strawberry storage life. But small portable units that can extend shelf life by several days are becoming available. Varieties respond very differently to high carbon dioxide atmospheres, however. For example, off-flavor volatiles are low in fruit of Annapolis and Cavendish when they are maintained under a high carbon dioxide atmosphere; other varieties such as Kent, Honeoye, and Governor Simcoe accumulate bad-tasting aldehydes and alcohols. Variety selection will be important if this technology is to be used.

Some large shippers on the West Coast also use a high carbon dioxide atmosphere for maintaining quality during transport. Pallet shrouds are injected with carbon dioxide before export. The scale of operation needs to be large enough to make such technology economically viable, so it is perhaps precluded from use in the Northeast. Research is being conducted on the use of films that develop high carbon dioxide atmospheres that accumulate in the pack, but they are not yet generally available to the industry.

## Transporting Berries to Market

The loss of strawberries (due to decomposition and rot) from harvest to the consumer's table is estimated to be more than 40%. A 14% loss occurs from farmer to wholesaler, a 6% loss occurs from wholesaler to retailer, and a 22% loss occurs from retailer to consumer. Much of these losses are due to poor handling of berries after harvest.

Many steps in the distribution chain can negatively affect fruit quality. A typical handling scheme after the berries are transported from the field and precooled might involve wrapping the flats after precooling, loading them into a refrigerated truck, transporting them to a distribution center, unloading them into the warehouse, loading them into a truck, transporting them to a retail store, unloading them, handling them in the back room, and finally setting up the display. Mishandling, either by rough handling or by poor temperature management, at any point along this route can result in unacceptable berries.

Minimize the number of handling steps from field to display. Berries should remain cold and wrapped during each phase of transportation. Never allow the berries to sit on unrefrigerated loading docks. When loading a truck, stack flats on a palette and away from the truck walls (figure 12-1). Ensure that cold air is free to circulate around the sides of the pallet and across the top and bottom. When flats of fruit are allowed to touch the floor or side walls, temperatures in the flats can rise as much as 20˚F. Do not stack flats directly over the rear wheels, and use strap-

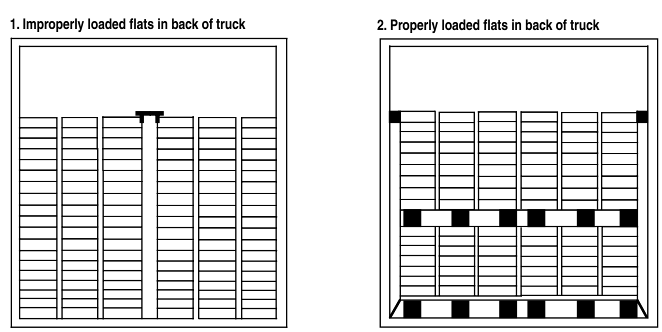



**FIGURE 12-1.** (1) Improper loading of flats within a truck—flats are in contact with the floor and walls; (2) Proper loading—flats are removed from floor and walls and cold air is free to circulate

ping or stretch film around each pallet to stabilize the load. Transit vibrations can be reduced by using trucks equipped with air-suspension systems rather than spring systems.

Truck mechanical refrigeration equipment is designed to maintain temperature but currently lacks the air flow and refrigeration capacity for rapid cooling. Temperature regulating equipment in trucks does not have the accuracy to achieve temperatures below 40°F without danger of freezing. Furthermore, high-density loads are used to minimize transportation costs, even though they inhibit cooling during transit. Therefore, thorough product cooling before loading is very important.

Allow berries to warm only when they are ready for display to consumers and before removing the plastic wrap over the flats. Any condensation will then form on the outside of the plastic wrap rather than on the berries inside.

Often the transportation of berries is beyond the control of the grower. To develop new and distant markets, receivers must be educated in proper handling procedures. Personal contact with the receiver before the first delivery is often useful. In other cases, handling instructions may be attached to the flats.

By selecting appropriate varieties and using proper harvesting and storage techniques, it is possible to maintain quality strawberries for about ten days after harvest.

## Further Reading

Bartsch, J. *Walk-In Cooler Construction.* Cornell Agricultural Engineering Bulletin #453. (For price and availability, contact: Distribution Center, Cornell University, Ithaca, NY 14850.)

Bartsch, J. and G. D. Blanpied. *Refrigeration and Controlled Atmosphere Storage for Horticultural Crops.* NRAES–22. (See page 160 for a description of the book and page 158 for ordering information.)

Fraser, H. W. *Forced-Air Rapid Cooling of Fresh Ontario Fruits and Vegetables,* Bulletin 91-070. 1991. (Available from: Ontario Ministry of Agriculture, Food, and Rural Affairs; Box 8000; Vineland Station; Ontario, Canada L0R 2E0.)

CHAPTER 13

# Marketing Strawberries

The key to marketing strawberries directly to the consumer is recognizing that growers are not just in the business of selling berries; rather, they are in the business of selling the sights, sounds, smells, and atmosphere that are associated with the total purchasing experience. This is the product that growers must promote and market to be competitive—not a low-priced produce item. Supermarkets are able to obtain large volumes of product and sell them for less than the local farmer can. However, supermarkets cannot offer a pleasant farm experience, even though many are now designing the produce section to resemble a farm market and are even featuring photos of local farmers in the stores.

Quality stands above all else in establishing and maintaining a profitable strawberry farm. But quality includes more than just the fruit; it includes the entire experience that is involved with obtaining the berries. For pick-your-own farms, this includes everything from the parking area to the greeter to clean restrooms to weed-free fields. For farm markets, it is the clean, wholesome atmosphere and friendly sales clerk, in addition to the product, that will bring return customers. High-quality fruit from a neat, efficient farm sold in a friendly atmosphere will reap much more profit than poorly handled, unsorted fruit in a cluttered farm stand.

## Pricing

The price charged for the fruit must be fair to both the grower and the customer. For retailing, price is not determined exclusively by supply and demand as it is for other commodities. Strawberry customers often do not shop around for the best price; rather, they develop a loyalty to a particular grower and trust him or her to set a fair price. Fair pricing requires a thorough knowledge of production costs (see chapter 14). When calculating costs, growers must account for labor, including their own. Once production costs are determined, prices can be set that will meet costs and provide a reasonable profit. Of course, if a "fair" price is higher than prevailing market forces, it may not be profitable to grow berries.

Overcharging can result in disgruntled customers, especially if the perceived value of the farm experience is poor, but underpricing can cut deeply into profits. Reducing prices to undercut the competition may seem like a good idea, but in fact it is likely to cause more harm than good. First, a grower reduces profit by reducing price, because usually volume does not increase proportionally (table 13-1). Then, competitors may lower their prices in response, thus setting up a price war that can result in growers selling their crops at below break-even prices. Finally, customers may expect a drop in price later in the season and hold off buying until then, which once again reduces profits.

**Table 13-1.** Relationship among current profit margin, proposed price reduction, and increase in sales volume that would be required to retain the same profit margin

| % Profit Margin | % Price Reduction | % Required Increase in Sales Volume |
|---|---|---|
| 10 | 5 | 100 |
| 15 | 5 | 50 |
| 15 | 10 | 200 |
| 20 | 5 | 33 |
| 20 | 10 | 100 |
| 25 | 5 | 25 |
| 25 | 10 | 67 |

In surveys, both large wholesale buyers and individual customers rank quality and consistency above price in importance. Individual customers in particular do little comparison shopping for produce. Lower-priced produce is often considered lower quality. The main reason customers visit farm markets or pick-your-own operations is to obtain fresh fruit and have a pleasant experience—not to get a break on price. So market forces have less of an impact on the price of direct-marketed strawberries than they do on the price of many other commodities.

## Marketing Options

Invest time into marketing research to determine which marketing option is best for you. Consider the following question: Can you produce a better experience or provide a better service than those presently in the business?

Strawberries are typically sold via one of three marketing channels: customer harvest (pick-your-own); fresh market (retail or wholesale); and processed (frozen, jams, jellies, wines, etc.). Each of these channels has advantages and disadvantages that should be carefully considered. Most growers use more than one marketing channel, which can be an advantage, as the demand in one market can make up for slack periods in another.

### *Pick-Your-Own*

The pick-your-own (PYO) market for strawberries has proven successful for many growers (photo 13-1). Success can be highly dependent on a farm's location. In order to attract enough customers to a PYO farm, the farm is best located within 20 miles of a densely populated area. Competition within that market area should be evaluated carefully. On average, it takes about 350 PYO customers to harvest 1 acre of strawberries (table 13-2). However, this number is influenced by the character of the community. Urban dwellers tend to pick less fruit than people living in the country, and certain ethnic communities traditionally harvest large quantities of berries for freezing or making jellies.

It certainly helps if the fields are on or near a major roadway and easily accessible. However, there are many examples of highly successful PYO farms that are in less-than-ideal locations. Developing a customer base on out-of-the-way farms requires patience, a great deal of promotional effort, and a reputation for providing a pleasant farm experience. For example, farm roads to the fields must be suitable for customer vehicles, or transportation should be supplied. Ample parking space should be available as well as toilet facilities, drinking water, shade,

**Table 13-2.** Estimates of strawberry acres for pick-your-own (PYO) marketing

| Population within a 20-Mile Radius of the Farm (1000s) | Maximum Acres of Berries in a 20-Mile Radius That Can Be Sustained for PYO |
|---|---|
| 5 | 2 |
| 10 | 4 |
| 20 | 8 |
| 30 | 11 |
| 40 | 15 |
| 50 | 18 |
| 60 | 21 |
| 70 | 24 |
| 80 | 27 |
| 100 | 30 |
| 150 | 37 |
| 200 | 44 |
| 300 | 58 |
| 400 | 64 |
| 500 | 70 |
| 600 | 75 |
| 700 | 81 |
| 800 | 86 |
| 900 | 92 |
| 1,000 | 98 |

*Source:* University of Illinois Cooperative Extension Service.

and some seating. Some form of entertainment, especially for children, is becoming standard. Directions and rules should be clearly visible.

Although one of the major advantages of PYO marketing is reduced harvest labor, field supervisors must be employed to direct and help customers in parking, harvesting, and check-out procedures. Supervisors should be courteous and friendly and have a thorough knowledge of the farm. Check-out areas should be neat and efficient. Customers should not have to wait in long lines to pay.

It is generally better to charge by fruit weight than by volume (for example $0.90 per pound versus $1.35 per quart). This will curtail the inevitable arguments as to what constitutes a "full" quart and guarantees a fair price to all. On average, a quart of strawberries weighs 1.5 pounds. Electronic scales can make weighing proceed very quickly. If standard picking containers are supplied to customers, cashiers can easily subtract the weight of the containers and charge only for the fruit. Otherwise, containers must be weighed before customers go into the field. Supplying large picking containers (such as an 8-quart size) versus small containers (such as several 1-quart baskets) usually results in customers picking more fruit, because they tend to want to fill the container they have regardless of its size.

PYO farms are a common source of family recreation. Families tend to pick more fruit, so most operations allow children, but growers must ensure that children are supervised. Allowing children to pick fruit from the outside rows increases the likelihood that they will be advocates for return trips to the farm. It is also a good idea to have alternative amusement for children, such as a playground or petting zoo (figure 13-1).

Growers are strongly advised to consult their insurance agents regarding the potential liabilities involved in a PYO operation and to purchase appropriate coverage.

A strawberry crop should be planned to fit into the overall farm operation. Add other crops suitable for farm retailing so that the customers will come back to the farm many times each year. For example, a strawberry harvest could be followed by raspberries or blueberries; vegetables such as tomatoes, cucumbers, and sweet corn; and, at the end of the season, pumpkins or even Christmas trees. PYO in conjunction with a farm market can be a powerful draw for customers who want convenience, a wide selection of produce, and recreation all at one location. However, if the produce for the farm market is to be grown on location, then a crew independent of the people who manage the PYO component must be hired for harvest.

Provide customers with recipes and instructions on how to handle fruit once it is home. Each year will bring new customers who may not have experience in the use and preparation of strawberries. Recipe books and brochures specific for berries are published by the North American Strawberry Growers Association (see page 162 for more information). In addition, numerous recipes can be found in the following publications:

- *The Strawberry Connection* by Beatrice Buszek, published in 1991 by Nimbus Publishing, Ltd.
- *Creative Recipes for Berries,* published by Salamander Books, London
- *Berries: A Cookbook* by Robert Berkley, published in 1990 by Fireside Books, Simon and Schuster, New York
- *Berries: Cultivation, Decoration, and Recipes* by Mary Forsell, published in 1991 by Bantam Books, New York

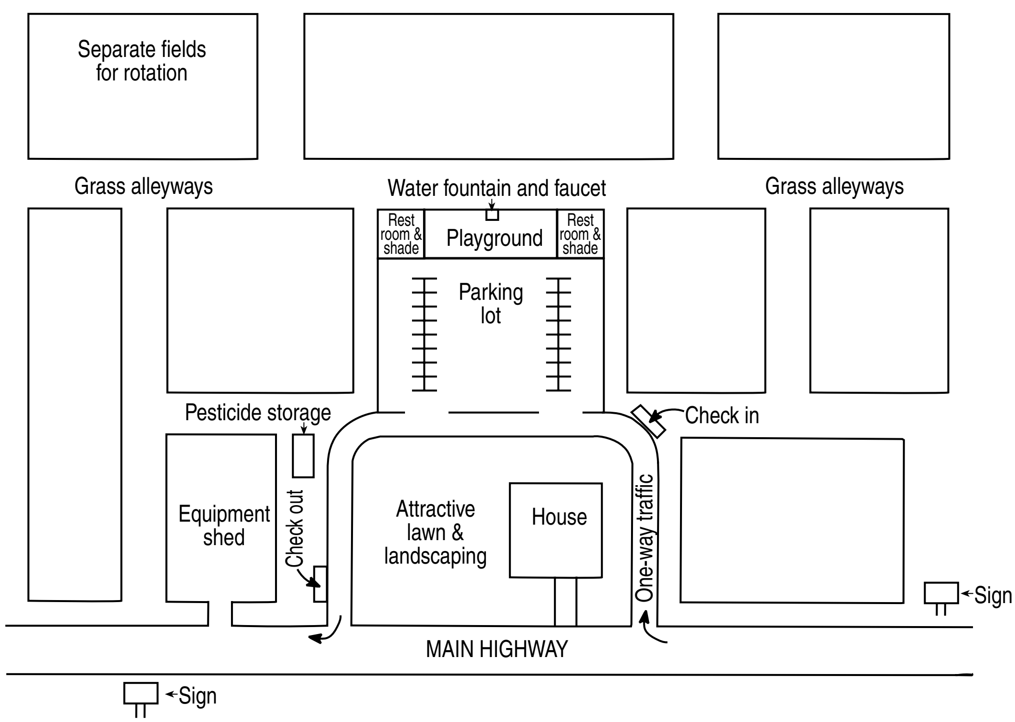



**Figure 13-1.** Map of a typical pick-your-own operation

Providing information about making jams and jellies, or even wine, can increase sales and encourage repeat customers.

## *Fresh Market Retail/Farm Markets*

Selling fresh fruit at retail is a potential option for growers whose operations for some reason are not suitable for PYO. As with PYO, marketing the experience of the farm stand is just as important as marketing the berries themselves. A clean, friendly atmosphere is essential, and consumers appreciate the convenience of being able to purchase food staples such as milk and bread along with their fruits and vegetables. An attractive exterior with a rural flavor is what consumers have come to expect (photo 13-2).

## *Wholesaling*

Wholesaling is another option for growers whose operation is not adapted to customer harvest. Wholesaling involves harvesting large volumes of berries, cooling them to prolong shelf life (chapter 12), and delivering them to a supermarket or warehouse. Buyers must be contacted well before the harvest season to set up delivery schedules, specify container preferences, and discuss payment policies. Some outlets may demand specialized handling or packaging.

Combining wholesaling and direct marketing can be beneficial, as long as one of the markets is not getting the low-quality leftovers of the other. If one buyer is receiving lower-quality fruit, then that should be clearly understood by the buyer, and he or she should pay accordingly.

Obtaining harvest labor is a challenge when wholesaling fresh fruit. Depending on the location, there may be a shortage of willing and capable workers. Some operations have recruited children or senior citizens to harvest fruit; these workers can perform well if they are treated properly by the grower. Using imported labor may be an option for larger operations, but there are numerous state and federal regulations that affect this type of employment. Understanding these requirements demands a considerable amount of time and expense. Contact your state departments of agriculture and labor for information about hiring temporary help and imported labor.

Most growers pay pickers piece-work by the quart or pound, rather than by the hour. Bonuses offered for a certain number of quarts will provide more incentive. Pickers should be trained to harvest only fruit of good quality at the proper stage of ripeness and to properly handle the fruit. Maintaining a good working environment is crucial to keeping good labor. Growers should generate enthusiasm for their farm and products and make workers feel like they are part of a team. Workers' attitudes will show in the quality of the harvested fruit.

### *Reducing the Risk of Microbiological Contamination*

Considering recent concerns over microbiological contamination of fruits and vegetables, take steps to reduce any risks of illness.

- Provide hand-washing areas for customers and workers to use before entering and after leaving the field.
- Ensure that picking containers are clean or washed frequently.
- Do not graze livestock next to irrigation ponds.
- Apply composted manure to fields only at renovation or prior to planting.
- Do not allow animals or pets into the fields prior to or during harvest.

It is best to start picking as early in the morning as possible, provided the fruit is dry, and quit before noon. This will ensure the fruit is picked at its best quality and that pickers are not forced to work during the hottest part of the day.

Postharvest handling of the fruit is a critical part of dealing with the fresh market. Growers must be able to deliver a high-quality crop with a maximum shelf life. This can mean a considerable investment in packing, storage, and transportation facilities (chapter 12).

## *Freezing*

Selling frozen berries is a good way to sell excess fruit that might otherwise be wasted during the peak of the season. Few families have sufficiently large freezers to store all of the fruit they will consume during the off-season, so selling frozen berries can extend the season and add value to the product.

When berries freeze, ice crystals form inside the cells. The expanding ice crystals rupture the cell membranes, so when the berries thaw, they are softer and more flaccid. To reduce the amount of crystallization, mix sliced berries with sugar prior to freezing. The sugar draws water out of the cells, so less is inside to crystallize. Berries frozen in a sugar solution will be more firm upon thawing than those frozen without sugar.

Most berries are packaged in a container with 6 ounces of berries to 4 ounces of concentrated sugar syrup. High-fructose corn syrup is also used (four parts fruit to one part syrup).

Freezing should occur rapidly after harvest to avoid losing flavor and to preserve color. Rapid freezing results in smaller ice crystals than slow freezing. IQF (instantly quick frozen) berries are used in fruit salads, because they maintain their integrity after thawing. Many processing plants have the ability to use IQF technologies.

Individual states have regulations regarding processing of fruit. In some states, freezing is not considered processing, so it does not come under guidelines from the health department. Check with authorities about regulations before attempting to freeze berries for later sale.

## *Processing*

Growing strawberry fruit for processing entails many of the same efforts required for selling fresh fruit, such as contacting buyers, filling orders, and delivering. Growers who process the products themselves must follow appropriate state and federal sanitation and labeling regulations. This may include undergoing regular inspections, purchasing stainless steel equipment, and using water treatment. Contact your state department of agriculture and/or health department for details.

Value-added products, such as jams and jellies, may generate a higher profit margin than fresh fruit, but the inputs are much greater. Labor costs will be higher, and appropriate cooking tools will be needed as well as a steady supply of ingredients, jars, labels, shipping boxes, and so forth.

### *Jams and Jellies*

Jams (made with fruits and seeds), preserves (made with pieces of large fruit), and jellies (made with filtered juice) comprise four ingredients: sugar, fruit, pectin, and acid. A balance among these is important. Fruit naturally contains all four of these, but the amount varies. Therefore, additional amounts must be added to bring the ingredients into balance.

Sugar sweetens the jam, suppresses microbial growth, sets the pectin, and makes the product glisten. The sugar content of a strawberry is generally between 10 and 15%, while the sugar content of a preserve must be between 65 and 69%. Obviously, additional sugar must be added to the fruit to make a preserve. Not all of the added sugar should be sucrose (table sugar) because of its tendency to crystallize. A portion of added sugar should be fructose (from corn syrup) or glucose. If the fruit contains enough acid, sufficient chemical inversion of sucrose will occur during boiling to make some glucose and fructose from the sucrose; this will prevent crystallization. The standard grade of jelly contains 45 parts fruit to 55 parts sugar. The fancy grade is 50/50, while imitation grade is 35/65.

Pectin is part of the cell walls of most fruit, but ripe strawberries have very little and what exists is of poor quality for jam making. Green fruit contains more pectin, and up to 25% of a commercial jam can contain unripe fruit. Still, in most cases commercial pectin must be added for the jelly to set. One pound of a 100-grade pectin will set a gel with 100 pounds of sugar at the proper pH.

Acid balances the sweetness of the sugar and achieves the pH necessary to set the pectin. Fruits supply some acid, although with strawberries, additional citric acid is generally necessary to balance the jelly to a pH of 2.8 to 3.3. The most common cause of a jelly failing to set is insufficient acid.

### *Procedure for Making Preserves and Jellies*

From 2 quarts of unsliced berries (4$^1/_2$ cups sliced). Makes 4 pints of jelly.

1. Remove berry caps, wash fruit, and slice berries.
2. Heat the fruit to near boiling.
3. Add 2 tablespoons of lemon juice and as much pectin as is specificed in the manufacturer's directions (amount of pectin varies with the source). Let simmer for 2 minutes.
4. Add 7 cups sugar.
5. Bring mixture to a full boil for 15–17 minutes or until the temperature reaches 220°F or until the desired soluble solids level (67–69%) is reached.
6. Turn off heat and remove the surface residue.
7. Fill containers with hot jelly, close them, and turn them upside down to sterilize the lid with the hot jelly.

The entire mixture of fruit, acid, pectin, and sugar is boiled to catalyze the chemical reaction from liquid to solid. Boiling drives off some of the water in the mixture and destroys enzymes and microorganisms that would degrade the fruit.

### *Wine*

Wineries may be interested in purchasing local strawberries, as fruit wines are increasing in popularity. The value of wine from a pound of strawberries can be ten times greater than the value of the fresh fruit. In addition, overripe fruit can be used to make strawberry wine, so long as the berries are not too moldy.

To make strawberry wine, you do not need fancy equipment—just a large pot, a fermenting bubbler, wine yeast, a hydrometer, a 5-gallon glass jug, and some cheesecloth. About 30 pounds of strawberries are required for every 5-gallon batch of wine. Berries do not have to be capped prior to fermentation. Strawberries are very fruity and acidic, so water and sugar are added to the berry pulp prior to fermentation to reduce the acidity to about 0.8% and increase the sweetness. If the desired alcohol content is 10%, then add more sugar to the mix to bring the mixture to 20% Brix (2% sugar for each 1% alcohol). In general, for every 2 pounds of strawberries, add 1 pound of sugar and 1 pound (pint) of water. Additional sugar may be required to obtain the desired sweetness.

Next add the wine yeast. Wine yeasts, available from a wine supplier, can tolerate a much higher alcohol content than wild yeasts. Dissolve the yeast in 100˚F water (use 1 gram of yeast for every 1 gallon of liquid), and add it to the fruit-sugar-water mixture. Add the yeast to the mixture within thirty minutes of dissolving so a food source is available to the yeast. Also, be sure the temperature difference between the yeast solution and the fruit mixture is no greater than 5˚F, or the yeasts may be killed. Fermentation should occur at 70˚F for about three to four days. This can occur in an open container, and the mixture should be stirred occasionally.

After three days, strain the mixture through cheesecloth and place it into a 5-gallon glass jug fitted with a fermentation bubbler. After another five to ten days, the wine will have reached an alcohol content of about 10%. When the wine reaches the desired alcohol and residual sugar content, stop the fermentation by placing the wine mixture in a cold room (30˚F) or filtering it. Then decant the mixture and add sulfites and sorbate to prevent oxidation and refermentation.

Strawberry wine can be allowed to ferment until the alcohol content reaches about 17%. However, wine with such a high alcohol content is rather harsh and will require a significant amount of sugar to balance the alcohol. Stopping the fermentation process at 9 to 10% is recommended. Inexpensive kits are available to monitor sugar, acid, and alcohol content. Monitor sugar content daily, as alcohol increases rapidly when fermentation occurs at room temperature.

Strawberry wines sometimes develop an orange color or an off-flavor, but the cause of this is unknown. As with grapes, there may be varietal differences among strawberries in their ability to make high-quality wines, but this has not been studied. A mixture of strawberry varieties likely will produce better wine than a single variety.

Strawberry wine can have excellent color, balance, and flavor properties; however, it can be very unstable and should be consumed soon after bottling or kept refrigerated. Strawberry wine can be mixed with honey wine to produce another value-added product. Novice vintners may want to attend a seminar on wine making for more details on wine production.

To sell wine, you will need a license. The selling of wine is regulated by the state liquor control board and the Bureau of Alcohol, Tobacco, and Firearms.

### *Others Products*

Products such as candies, syrups, dried fruits, flavored vinegars, shrubs, and fruit beers provide other options for selling berries. Most states have marketing conferences for farm products, and the North American Farmers Direct Marketing Association (317 West 38th Street, Vancouver, Washington 98660) has an annual meeting where many good ideas are brought forth.

## Advertising Basics

Advertising is the tool by which potential customers are contacted and attracted to your product. Without it, customers will never know that you exist.

### ***First Impressions***

Customers will first judge a farm and grower by the advertising they see. Advertisements should represent how you want the customers to view your operation, and they should focus on the entire farm experience—not just the price of berries. They should be tasteful and of high quality. The farm should have an attractive logo that is displayed prominently in ads, on signs, and on products; it should be simple enough to be easily recognized. Communicate with drawings rather than words as people may not read long ads. Contact your state department of agriculture to place your farm name and address on lists of farms selling strawberries.

### *Who Are Your Customers?*

If you do not know who your customers are, you may be advertising to the wrong audience. A customer survey is a good way to determine who your customers are. Advertising can then be designed and targeted accordingly. For example, if most of your customers are homemakers with families, then ads should be placed where and when homemakers are likely to see or hear them. Surveys show that most customers come from within 20 miles of a farm. Advertising outside of this area may not pay off. Advertising also should be focused in the densest population areas.

## Forms of Advertising

### *Word-of-Mouth: The Best Form of Advertising*

The best form of advertising is the word-of-mouth recommendation that a satisfied customer passes on to others. The potential benefit from this type of advertising is immense; it will generate lots of customers and many of a farm's best patrons. The quality of the fruit and the farm experience are both part of the perceived value that brings customers back. A bad reputation can develop quietly and ruin a business forever.

To satisfy a customer and make him or her happy enough to recommend a farm to other people, maintain a high-quality product and make buying the product a pleasure.

### *Roadside Signs*

Roadside signs are often the first impression customers get of a farm. Signs should be neat, high-quality, attractive, and easy to read. They should represent the farm and farmers.

Select the color for signs with care. There should be enough contrast between the background and lettering to make the sign easy to read. For example, red or black letters are easy to read against a white background, while yellow letters are difficult to read. Signs and the letters on them should be large enough to be easily read by passing motorists. At 50 mph, a motorist has only three to five seconds to read a sign, so the sign must have only eight words or less to be readable. Letters should be as large as possible, at least 2 inches tall for every 10 mph of posted speed limit. Symbols are often more effective than words. Use pictures or your logo on signs, if possible. Road signs are not the place to display prices. It is more important to catch the customers' attention—let them know what is available and how to get to it. Signs can be effective at directing people to the farm and attract new customers. Some states have strict rules regarding roadside signs; contact your state department of transportation for details.

### *Direct Mailings*

One of the most effective advertising tools is a customer mailing list. This provides a direct line of communication between customers and "their" strawberry farm. A direct mailing sent out at the appropriate time—such as a postcard indicating your opening date, the high quality of your fruit, and your desire to see the customer at your farm—gets better results than nearly any other media. Postcards are an excellent way to introduce new products, crops, or services; provide an update on events at the farm; and discuss the effects of the season's weather on the crop. It is important to make customers feel wanted and a part of the farm.

To establish a mailing list, collect the names and addresses of customers, either when they come to the farm or when they call regarding farm products. Surveys can be used to collect names for a mailing list, ask customers for feedback, and collect information about the consumers such as what newspaper they read or radio station they listen to. This information can then be used to help focus future advertising. Mailing lists of potential customers in a given area may be available for purchase

#### *Signs and Advertising*

- Dark letters on a light background are most legible.
- Letters should be 2 inches high for every 10 mph of posted speed. For example, if the speed is 40 mph, letters should be 8 inches high.
- Signs should be at least 100 yards away from the entrance to the market for every 10 mph of posted speed.

from various companies. Such lists should be targeted for the region near the farm and to the type of customer most likely to be interested in your product.

## The Media

### What Should an Ad Say?

When designing an ad, promote benefits, not prices. Do not simply advertise "Jones' Farm"—that is not what a customer wants to buy. Emphasize the benefits of visiting the farm and the quality, freshness, flavor, and nutritional value of the farm's products. For pick-your-own operations, emphasize the fun, recreation, and education that a trip to the farm provides. The ad should also give directions, list the days and hours of operation, include a phone number, and state whether containers are provided. Price is a relatively low priority among many of today's consumers. Finally, keep ads simple, attractive, and recognizable. Most customers will give an ad only a few seconds of attention.

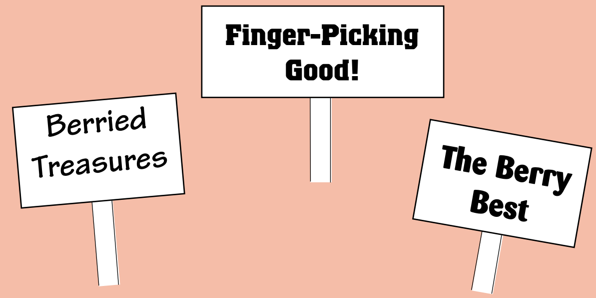
### Newspapers

Many people read the local newspaper daily, so newspapers are a good way to reach customers. Ads should be placed in the newspaper most likely to be read by potential customers for your product. Ads should be located in the section where your clientele is most likely to see them, such as the weekly food, marketplace, or recreation section. Ad space is usually sold by the column inch. A quarter-page ad could cost over $800; but depending on how many people see it, it could be an effective, worthwhile investment. Ads should be kept short and simple to prevent losing the customer's interest. Photos and logos can grab a reader's attention and increase the effectiveness of an ad. Offering coupons in an ad can provide further incentive to customers.

### Radio

Radio is good at creating awareness but may not be effective at directing people to the farm if directions are complicated. Repetition is the key to radio advertising. It is better to buy twenty spots on one station than one spot on twenty stations. The cost of radio advertising varies according to the station, audience size, and broadcast time. Stations should be selected on the basis of what the customers are most likely to listen to. Growers should consider sponsoring morning weather reports, which could be followed by "picking reports" from their farms.

***Advertisements for Berries***




### Television

Television advertising is typically quite expensive. In addition to air time costs, production expenses can be very high. However, prices during some time slots on local channels may be cost-effective if a lot of potential customers are likely to be watching. Daytime ads can be effective at reaching the homemaker and are much less expensive than primetime ads.

## Dealing with the Media

The local news media can provide some of the best advertising at no charge by running a feature story about a farm. Growers should get to know local reporters and give them advance notice about farm activities. Reporters may welcome a public relations story on a strawberry harvest or a local jam-making operation. They should be encouraged with an invitation to the farm or a press release promising good scenes for their cameras.

The most important rule when speaking to the media about your farm is—be positive! Has it been rainy this spring? Then the berries will be exceptionally juicy this year. Has it been dry? Then the berries will be smaller but sweeter. Everyone likes a winner; no one likes a whiner. Consider the following excerpt from a newspaper article about a local farm…

> *The pick-your-own patch looks lush—too lush. The growers are not proud of the vigorous dandelions that are crowding the ripening berries. And they shake their heads as they reflect on a year in which the hired help hurt this year's crop. "You could write a book on the help we've had," said the grower. "One stayed one hour. One planted the strawberries upside down. Few people are willing to work for even $4.00 per hour. I used to work for 50 cents a day!"*

Although some may sympathize with the grower, few will want to visit the farm after reading this article. But the local press can be a great ally. Here is an example of a positive press report:

> *Nothing marks the start of summer better than the strawberry season! Our county is blessed with numerous places to buy and pick fresh, local strawberries. Whether you enjoy berries fresh or frozen or in preserves or pies, they are always delicious and good for you. Here are some of the local farms where you can experience the sweet taste of summer . . .*

Promote a quality farm experience in all interactions with the public—through advertising, interviews with the press, or one-on-one conversations with the customer.

## Timing and Quantity of Advertising

Advertising should be timed around the crop. Light advertising should begin just before the harvest season. Advertising should be heaviest at the beginning of the season, then taper off as the season progresses. Growers should not wait for slack sales to begin advertising.

As a general rule, pick-your-own advertising should be budgeted at 5% of gross sales (up to 10% for a new operation). Keep records of money spent on advertising versus gross sales and number of new customers. Increase the advertising budget if competition in the area is great or if the farm location is far from the target audience. However, do not overdo it—too much advertising lowers returns and may bring in too many customers. Overcrowding and inadequate supplies are sure ways to lose patrons. Advertising is the tool that brings customers to the farm; the quality and perceived value of the farm experience are what brings them back.

CHAPTER 14

# Budgeting

Budgeting is an essential component of strawberry growing. An accurate budget allows you to determine if an investment in strawberries will be profitable, what price you should charge to cover costs, what cash flow will look like over several years, and how changes in production practices will affect the bottom line. In the past, such detailed budgets were tedious and time-consuming to develop. Time spent in the office collecting figures meant less time spent in the field. However, computer technology now makes it possible to determine budgets with little effort.

In this chapter, sample budgets are presented for matted row–grown strawberries based on numbers from northeastern farms. The budgets account for typical costs that a grower might incur as well as costs that many growers do not consider—for example, the cost of a pick-up truck, taxes, and interest on borrowed money. By accounting for these in a budget, a grower can price a product to reflect costs and identify items in the operation that are most costly. A grower can also get a sense of cash flow, payback period, return on investment, and establishment costs and predict the effect a change in price or production will have on profitability. For example, the sample budget analysis in this chapter illustrates that:

1. Establishment costs for an acre of matted row strawberries are about $3,400.
2. A positive cash flow is usually realized after the first harvest.
3. Retailing generally has more profit potential than pick-your-own operations because of the higher price obtained for the product.
4. Break-even prices are typically around $1.00 per quart, regardless of method of sale.

The budget spreadsheets used in this chapter are provided on the floppy disk included with this guide. The spreadsheets are set up to reflect a matted row system since it is most common, but they are sufficiently flexible so that input variables can be modified for other production systems. The spreadsheet template is for use with Microsoft Excel, version 4.0 or higher, or a compatible spreadsheet program. However, you do not need a computer to use the information in this chapter.

A spreadsheet is simply a big table of rows and columns. The columns are labeled from left to right with alphabetical letters. The rows are numbered from top to bottom. The spreadsheet program allows you to manipulate inputs and examine different costs and returns. Mathematical formulas that perform calculations on the numbers in the rows and columns are "hidden" within the spreadsheet. With just a touch of a button, you can insert different numbers into the spreadsheet to better reflect your operation, and the program will instantly project the effect on costs and/or profits. For example, one column might be labeled "price per pound," a second might be "yield per acre," and a third might be "gross returns." If you change the number in the "price per pound" column, the value in the "gross returns" column changes automatically. This technology becomes very useful when the calculations become complex and involve many rows and columns.

## Strawberry Profit Spreadsheet Template

The strawberry profit spreadsheet template (called PROFIT.XLW on the disk) is a Microsoft Excel workbook file to let you calculate the costs and returns of growing strawberries. There are ten spreadsheets over-laid on top of one another and linked together. Assumptions have been made about typical costs, yields, prices, and production operations in use on northeastern farms in 1996. You can customize the sheets to more closely reflect your particular situation by changing numbers in the cells on the various sheets. You can also examine the profitability of different production scenarios by changing the input data.

Start the spreadsheet program and open the PROFIT.XLW file. The table of contents of the workbook will appear across the bottom of the screen. There are ten interlinked spreadsheets in it:

- SUMMARY
- PLANTING
- MATERIALS
- LABOR
- BEARING
- DISCOUNT
- HARVEST
- EQUIPMENT
- PREPLANT
- OVERHEAD

The summary sheet (table 14-1) calculates income per acre (gross revenue), variable and fixed expenses (cost of production), profit or net income, discounted cash flow, and break-even price based on the yields and price per quart that you enter. Starting values (called "default values") have already been entered; they may or may not be accurate for your situation and can be changed easily. The default price is $1.40 per quart, which represents a situation where the grower is selling half the crop retail for $1.80 per quart and half the crop pick-your-own for $1.00 per quart. The price received can be changed on the spreadsheet (cell D3), and the resulting effects on profit will be calculated automatically.

The default yields are zero in the preplant year and the planting year. In the first and second bearing years, the yield is 7,000 quarts per acre; in the third year, it is 4,000 quarts per acre; and in the fourth year, it is 3,000 quarts per acre. Enter your own yields instead (cells B9 to B13).

The discount rate in cell J3 is set to 6%, but you can choose any discount rate between 5 and 11%. If the default is not satisfactory, enter an appropriate rate with two decimal positions (for example, 5% is entered as 0.05). Everything else on the sheet is write-protected and cannot be changed.

"Income per Acre" (cells C9 to C13) calculates gross returns by multiplying the yields you have entered by the price. The next five columns (D through H) calculate variable expenses. The results in these columns are linked to calculations in other spreadsheets and should not be changed. "Total variable costs" (column I) sums up the expenses in the five previous columns. "Fixed costs" (column J) is linked to another spreadsheet. "Total costs" (column K) is the sum of all costs, both fixed and variable, involved in growing strawberries under the given scenario. "Profit or Net Income" (column L) gives a profile of how much money can be made or lost per acre over the life of the strawberry planting. Red numbers in parentheses indicate a negative profit.

Perhaps a more accurate picture of the profitability of growing strawberries is shown in column M, "Discounted Cash Flow." This column takes the net income in the previous column and discounts it to consider the time value of money. This reduces the profit in future years, because a dollar received in the future is less valuable than a dollar in hand today.

The final column in this section (column N) calculates the "Accumulated Net Present Value of Profit." It sums up the discounted cash flow in the previous column. Net Present Value, or NPV, is an economic measure used to evaluate a potential enterprise. If the NPV of an investment is greater than zero, the investment is worthwhile, which means expenses have been covered as well as the cost of tying up money in the investment. This is par-

**TABLE 14-1.** Summary of yields, expenses, profit, and net present value (NPV) of a northeastern strawberry enterprise within a fruit farm (SUMMARY spreadsheet)

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | *Summary for Establishing Strawberries* | | | | | *By Alison DeMarree and Regina Rieckenberg - Cornell Cooperative Extension - 1996* | | | | | | | | |
| 2 | | | | | | | | | | | | | | |
| 3 | **Avg. price received per quart >** | | | **$1.40** | | **Discount Rate You Would Like to Use>** | | | | **6%** | | | | |
| 4 | | | | | | | | | | | | | | |
| 5 | | **Yield** | **Income** | **Variable Expenses** | | | | | | | | **Profit** | **Discounted** | **Accum.** |
| 6 | **Year** | **per A.** | **per A.** | **Labor** | **Service** | **Materials** | **Equip.** | **Comm** | **Total** | **Fixed** | **Total** | **or Net** | **Cash Flow** | **NPV** |
| 7 | | | | | | | | **Harvest** | **Variable** | **Costs** | **Costs** | **Income** | | **of Profit** |
| 8 | Preplant | | | $38 | $0 | $173 | $31 | | $243 | $494 | $736 | ($736) | ($736) | **($736)** |
| 9 | Planting Yr | **0** | $0 | $458 | $0 | $1,128 | $321 | $0 | $1,907 | $801 | $2,708 | ($2,708) | ($2,554) | **($3,291)** |
| 10 | 1st bearing | **7,000** | $9,800 | $543 | $0 | $1,840 | $258 | $1,794 | $4,434 | $800 | $5,233 | $4,567 | $4,064 | **$773** |
| 11 | 2nd bearing | **7,000** | $9,800 | $543 | $0 | $1,683 | $258 | $1,794 | $4,277 | $800 | $5,076 | $4,724 | $3,966 | **$4,739** |
| 12 | 3rd bearing | **4,000** | $5,600 | $543 | $0 | $1,423 | $258 | $1,115 | $3,338 | $800 | $4,137 | $1,463 | $1,159 | **$5,898** |
| 13 | 4th bearing | **3,000** | $4,200 | $543 | $0 | $1,228 | $258 | $773 | $2,801 | $800 | $3,601 | $599 | $448 | **$6,346** |
| 14 | | | | | | | | | | | | | | |
| 15 | | | | Breakeven price > | | $1.00 | | | Net Establishment Costs> | | | $3,444 | | |

ticularly useful for comparing very different kinds of investments—for example, short-term versus long-term.

The final cell of interest in the SUMMARY sheet calculates the break-even price for strawberries under the scenario you have created. In the default scenario, the break-even price is $1.00 per quart. The selling price is $1.40 per quart, which results in a net profit and positive NPV.

## *The LABOR Spreadsheet*

The LABOR sheet (table 14-2) calculates the true cost of hired labor. Enter the hourly wage paid to minimum wage earners; unskilled labor; semi-skilled labor; and skilled labor (such as the owner, operator, or manager) in column D. Social security, workers' compensation insurance, unemployment, and health insurance (if applicable) are calculated; and the total cost of hiring labor is reported in column J. These total hourly costs are linked to the HARVEST labor sheet (table 14-3) and to the PRE-PLANT, PLANTING, and BEARING sheets (tables 14-4 through 14-6). Workers' wages on the LABOR sheet are automatically accounted for in subsequent sheets.

## *The HARVEST Spreadsheet*

The HARVEST sheet (table 14-3) calculates the cost of harvesting strawberries on a per-acre basis using either a piece-work or hourly basis for pay. The top box summarizes "Pre-Harvest Labor." This is the cost of preparing an acre of strawberries for either commercial or pick-your-own harvest. Cells C5, C6, and C7 are the hourly rates for unskilled, semi-skilled and skilled labor, respectively. (*Note:* There is no column A in this spreadsheet. The first column is column B, the second column is column C, and so on.) Hourly rates are linked to the LABOR sheet (table 14-2) and should not be changed here (change them on the LABOR sheet). Fill in cells D5 to F7 with your own numbers. In the default scenario, two unskilled people are assumed to work for one eight-hour day to prepare for harvest. The expense for this is in G5: $95.72. It is also assumed that a skilled worker will oversee the preparation for half a day at a cost of $47.25.

The next box calculates the cost of piece-work labor (harvest labor). Fill in D13 and D14 for piece-work. Cell E13 automatically adds on the indirect costs associated with paying piece-work, such as workers' compensation insurance and withholding. Make sure that the yields in column G are accurate. In the default scenario, half the crop (3,500 quarts in the first and second bearing years, then 2,000 and 1,500 quarts in the next two years) is harvested at a piece-work rate of $0.30 per quart plus $0.01 for supervision (cells D13 to F16). The costs calculated here are copied automatically to the "Commercial Harvest" column (H10 to H13) of the SUMMARY sheet (table 14-1).

The next section of five boxes calculates harvest costs of hourly workers. In the default scenario, half of the crop being harvested pick-your-own will require one person working half time to supervise pickers. (This section can also calculate harvest labor costs if pickers were paid by the hour instead of piece-work rate.) In each section, fill in the shaded boxes with the number of people needed and the average number of hours worked per day. In the default scenario, hourly labor is needed to supervise the pick-your-own harvest—one person working four hours a day for 21 days of harvest. This box could also be used if the whole crop is harvested using hourly labor. The costs calculated here are copied automatically into the SUMMARY sheet (table 14-1).

The next box (B42 to G47) is the "Post-Harvest Labor" expense section. In the default scenario, two unskilled people work for half a day to clean up after harvest for a total expense of $47.86.

The final section (I34 to N41) calculates total harvest labor expenses on a per-quart basis (cells K39 to N39). Advertising and container expenses (copied from the MATERIALS sheet, table 14-9) are added automatically in K41 to N41.

**Table 14-2.** Typical labor costs at various skill levels (LABOR spreadsheet)

| | A | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | *COST OF LABOR AT VARIOUS SKILL LEVELS* | | | | | | | | | |
| 2 | | | | | | | | | | |
| 3 | | | | | . . . . . . . . . . . . . . cost per hour . . . . . . . . . . . . . | | | | | |
| 4 | Avg. | Avg. | | Rates > | 0.0765 | 0.06 | 0.06 | $2,404 | | Total |
| 5 | hours | weeks | | | | Workers | Unemp | Health | | Hourly |
| 6 | per wk | Worked | Type of Labor | Hrly Rate | Soc Sec | Comp | Insurance | Insurance | Other | Cost |
| 7 | | | Minimum Wage | $4.25 | $0.33 | $0.26 | $0.26 | | | $5.09 |
| 8 | 50 | | Unskilled Labor | $5.00 | $0.38 | $0.30 | $0.30 | | | $5.98 |
| 9 | 45 | 50 | Semi-Skilled Labor | $7.00 | $0.54 | $0.42 | $0.42 | | | $8.38 |
| 10 | 48 | 48 | Skilled Labor | $9.00 | $0.69 | $0.54 | $0.54 | $1.04 | | $11.81 |

**TABLE 14-3.** Harvest labor expenses for a strawberry operation over four years' time (HARVEST spreadsheet)

| | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Harvest Labor Expenses | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | |
| 3 | Pre-Harvest Labor | | Avg. hrs | Number | Number | Total labor | | | | | | | |
| 4 | HOURLY LABOR | Rate | per day | of days | of people | expense | | | | | | | |
| 5 | Unskilled | $5.98 | 8 | 1 | 2 | $95.72 | | | | | | | |
| 6 | Semi-skilled | $8.38 | | | | $0.00 | | | | | | | |
| 7 | Skilled | $11.81 | 4 | 1 | 1 | $47.25 | | | | | | | |
| 8 | TOTALS | | | | | $142.97 | | | | | | | |
| 9 | | | | | | | | | | | | | |
| 10 | Harvest Labor | | | Indirect | Adjusted | Yield | Piece Rate Harvest | | | | | | |
| 11 | PIECE RATE JOBS | unit | Rate | costs | Rate | each year | Cost to | Pick | | | | | |
| 12 | | | | | | 0 | $0 | <planting yr | | | | | |
| 13 | Picking | qt. | $0.30 | 0.05895 | $0.36 | 3,500 | $1,291 | < 1st yr | | | | | |
| 14 | Crew Leader | qt | $0.01 | | $0.01 | 3,500 | $1,291 | < 2nd yr | | | | | |
| 15 | | | | | | 2,000 | $738 | < 3rd yr | | | | | |
| 16 | TOTAL / PIECE | | | | $0.37 | 1,500 | $553 | < 4th yr | | | | | |
| 17 | | | | | | | | | | | | | |
| 18 | Harvest Labor: Plntg Yr | | Avg. hrs | Number | Number | Total labor | | Harvest Labor: Year 1 | | Avg. hrs | Number | Number | Total labor |
| 19 | HOURLY LABOR | Rate | per day | of days | of people | expense | | HOURLY LABOR | Rate | per day | of days | of people | expense |
| 20 | Minimum Wage | $5.09 | | | | $0.00 | | Minimum Wage | $5.09 | | | | $0.00 |
| 21 | Unskilled | $5.98 | 0 | 0 | 0 | $0.00 | | Unskilled | $5.98 | 4 | 21 | 1 | $502.53 |
| 22 | Semi-skilled | $8.38 | | | | $0.00 | | Semi-skilled | $8.38 | | | | $0.00 |
| 23 | Skilled (supervisory) | $11.81 | 0 | 0 | 0 | $0.00 | | Skilled (supervisory) | $11.81 | 0 | 0 | 0 | $0.00 |
| 24 | TOTALS | | | | | $0.00 | | TOTALS | | | | | $502.53 |
| 25 | | | | | | | | | | | | | |
| 26 | Harvest Labor: Year 2 | | Avg. hrs | Number | Number | Total labor | | Harvest Labor: Year 3 | | Avg. hrs | Number | Number | Total labor |
| 27 | HOURLY LABOR | Rate | per day | of days | of people | expense | | HOURLY LABOR | Rate | per day | of days | of people | expense |
| 28 | Minimum Wage | $5.09 | | | | $0.00 | | Minimum Wage | $5.09 | | | | $0.00 |
| 29 | Unskilled | $5.98 | 4 | 21 | 1 | $502.53 | | Unskilled | $5.98 | 3 | 21 | 1 | $376.90 |
| 30 | Semi-skilled | $8.38 | | | | $0.00 | | Semi-skilled | $8.38 | 0 | 0 | 0 | $0.00 |
| 31 | Skilled (supervisory) | $11.81 | 0 | 0 | 0 | $0.00 | | Skilled (supervisory) | $11.81 | 0 | 0 | 0 | $0.00 |
| 32 | TOTALS | | | | | $502.53 | | TOTALS | | | | | $376.90 |
| 33 | | | | | | | | | | | | | |
| 34 | Harvest Labor: Year 4 | | Avg. hrs | Number | Number | Total labor | | Harvest labor exp / qt. | plant | 1st yr. | 2nd yr. | 3rd yr. | 4th yr. |
| 35 | HOURLY LABOR | Rate | per day | of days | of people | expense | | Pre-Harvest | $143 | $143 | $143 | $143 | $143 |
| 36 | Minimum Wage | $5.09 | | | | $0.00 | | Harvest | $0 | $503 | $503 | $377 | $220 |
| 37 | Unskilled | $5.98 | 1.75 | 21 | 1 | $219.86 | | Harvest: piecerate | $0 | $1,291 | $1,291 | $738 | $553 |
| 38 | Semi-skilled | $8.38 | | | | $0.00 | | Post-Harvest | $48 | $48 | $48 | $48 | $48 |
| 39 | Skilled (supervisory) | $11.81 | 0 | 0 | 0 | $0.00 | | total | #DIV/0! | 0.2835 | 0.2835 | 0.3264 | 0.3214 |
| 40 | TOTALS | | | | | $219.86 | | | | . . . . labor cost per quart harvested . . . | | | |
| 41 | | | | | | | | + advertising & basket | | 0.3821 | 0.3821 | 0.4464 | 0.4580 |
| 42 | Post-Harvest Labor | | Avg. hrs | Number | Number | Total labor | | | | | | | |
| 43 | HOURLY LABOR | Rate | per day | of days | of people | expense | | | | | | | |
| 44 | Unskilled | $5.98 | 4 | 1 | 2 | $47.86 | | | | | | | |
| 45 | Semi-skilled | $8.38 | | | | $0.00 | | | | | | | |
| 46 | Skilled | $11.81 | | | | $0.00 | | | | | | | |
| 47 | TOTALS | | | | | $47.86 | | | | | | | |

## The PREPLANT Spreadsheet

The PREPLANT sheet (table 14-4) summarizes the tasks and associated costs in the year before planting. Under the default scenario, the grower applies an herbicide; plows, discs, and drags the field; applies lime and nutrients; and seeds a cover crop. Operations can be eliminated simply by entering a zero in the "Machine Hours" or "Labor Hours" column. Fumigation (item 8) is accounted for by entering it as a custom rate service (column I). The costs of owning and operating equipment are copied from the EQUIPMENT sheet (table 14-7). The machine and labor hours entered as defaults are those commonly used when estimating the time required to carry out tasks. Do not change them unless there is a good reason to do so.

The values in the "Materials" column are copied from the MATERIALS sheet (table 14-9) and should not be changed on this sheet (change them on the MATERIALS sheet). The total fixed cost (cell F19), total variable cost (cell K19), and total cost (cell L19) in the preplant year are copied automatically onto the SUMMARY sheet (table 14-1) in columns J, I, and K, respectively.

## The PLANTING Spreadsheet

The PLANTING sheet (table 14-5) summarizes the tasks and associated costs in the planting year. In the default scenario, the grower prepares the ground, sets the plants, applies herbicides at planting, cultivates four times, hand weeds, pulls blossoms, and so on. As with the previous sheet, enter a zero in the "Machine Hours" or "Labor Hours" column for tasks that are not done routinely. As with the PREPLANT sheet (table 14-4), labor; material; and fixed, variable, and total costs are transferred automatically to the SUMMARY sheet (table 14-1).

## The BEARING Spreadsheet

The BEARING sheet (table 14-6) summarizes all the tasks and associated costs in all of the bearing years of the strawberry enterprise. In the default scenario, mulch is removed by hand; herbicides, insecticides, and fungicides are applied according to current pest management recommendations; plants are harvested; and mulch is applied in the fall. As on the previous two sheets, if there are tasks omitted, enter a zero in the "Machine Hours" or "Labor Hours" column. As with the PREPLANT sheet (table 14-4), labor; material; and fixed, variable, and total costs are transferred automatically to the SUMMARY sheet (table 14-1).

## The EQUIPMENT Spreadsheet

The EQUIPMENT sheet (table 14-7 on page 124) calculates the cost per hour of use and the cost of owning machinery. In the default scenario, equipment is purchased new and replaced in the number of years in column C. Equipment is used for tasks other than growing strawberries. Annual hours of use are in column D. Depreciation, interest, insurance, and housing (columns E to H) make up the total fixed cost per hour of use (column I). Repair and fuel and lube (columns J and K) make up the variable costs per hour of use (column L). These costs per hour of use are linked back to the hours of machine use in the PREPLANT, PLANTING, and BEARING sheets (tables 14-4 through 14-6).

Purchase price of equipment and annual hours of use will greatly influence the cost of owning and operating equipment. If your equipment inventory differs significantly from what is listed here, be sure to make changes in columns B, C, and D.

TABLE 14-4. Expenses in the preplant year (PREPLANT spreadsheet)

| | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | *PREPLANT YEAR* | | | | | | | | | | | |
| 2 | | | | | | | | | | | | |
| 3 | Tasks | | | | | Total | Fuel, Oil | Total | | | Total | |
| 4 | | Operation | Month | Mach. | Labor | Fixed | Lube & | Labor | Service | Materials | Variable | Total |
| 5 | | | | Hrs | Hrs | Cost | Repairs | Cost | | | Cost | Cost |
| 6 | 1 | Sample Soil | June | | 0.33 | | | $2.79 | | 12.00 | 14.79 | 14.79 |
| 7 | 2 | Apply Herbicide | June | 0.40 | 0.48 | $4.18 | $2.92 | $4.02 | | 37.37 | 44.31 | 48.49 |
| 8 | 3 | Plow Field | July | 1.10 | 1.33 | $10.68 | $11.77 | $11.14 | | | 22.91 | 33.59 |
| 9 | 4 | Apply Nutrients | July | 0.35 | 0.42 | $3.57 | $2.34 | $3.52 | | 113.88 | 119.73 | 123.30 |
| 10 | 5 | Lime | July | 0.30 | 0.50 | $1.57 | $2.47 | $4.19 | | | 6.66 | 8.22 |
| 11 | 6 | Disc Field | Aug | 0.55 | 0.67 | $12.12 | $5.44 | $5.61 | | | 11.05 | 23.17 |
| 12 | 7 | Drag Field | Aug | 0.45 | 0.54 | $4.77 | $3.89 | $4.52 | | | 8.42 | 13.19 |
| 13 | 8 | Fumigate Field | Sept | | | | | $0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 14 | 9 | Seed Cover Crop | Sept | 0.35 | 0.30 | $3.57 | $2.34 | $2.51 | | 10.00 | 14.85 | 18.42 |
| 15 | | | | | | | | | | | | 0.00 |
| 16 | | | | | | | | | | | | 0.00 |
| 17 | 10 | Annual Overhead | | | | **$453.29** | | | | | | 453.29 |
| 18 | | | | | | | | | | | | |
| 19 | | TOTALS | | 3.50 | 4.57 | $ 493.74 | $ 31.16 | $ 38.30 | $0 | $ 173.25 | $ 242.72 | $ 736.46 |

**Table 14-5.** Expenses in the planting year (PLANTING spreadsheet)

| | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | *PLANTING YEAR* | | | | | | | | | | | |
| 2 | | | | | | | | | | | | |
| 3 | Tasks | | | | | Total | Fuel | Total | | | Total | |
| 4 | | Operation | Month | Mach. | Labor | Fixed | Lube & | Labor | | | Variable | Total |
| 5 | | | | Hours | Hours | Cost | Rprs | Cost | Service | Materials | Cost | Cost |
| 6 | 1 | Plow down cover crop | Apr | 1.10 | 1.33 | $10.68 | $11.77 | $11.14 | | | $22.91 | $33.59 |
| 7 | 2 | Drag Field | Apr | 0.45 | 0.54 | $4.77 | $3.89 | $4.52 | | | $8.42 | $13.19 |
| 8 | 3 | Fertilize | Apr | 0.25 | 0.30 | $2.55 | $1.67 | $2.51 | | $171.50 | $175.68 | $178.23 |
| 9 | 4 | Layout Field | May | 1.00 | 2.00 | $6.67 | $1.63 | $16.75 | | | $18.38 | $25.05 |
| 10 | 5 | Plant berries: plstc mulch | May | 2.50 | 3.50 | $33.96 | $25.65 | $35.33 | | $587.25 | $648.23 | $682.19 |
| 11 | 6 | Apply 1st herbicide | May | 0.40 | 0.48 | $4.18 | $2.92 | $4.02 | | $82.80 | $89.74 | $93.92 |
| 12 | 7 | Set up irrigation | May | 1.00 | 1.10 | $8.88 | $6.61 | $9.21 | | $0.00 | $15.82 | $24.71 |
| 13 | 8 | Irrigate | Jn/Ag | 25.00 | 1.00 | $190.71 | $212.00 | $8.38 | | | $220.38 | $411.09 |
| 14 | 9 | Remove flowers/weed | June | | 13.00 | $0.00 | $0.00 | $77.77 | | | $77.77 | $77.77 |
| 15 | 10 | 1st cultvn &/or insecticide | June | 0.55 | 0.67 | $3.99 | $3.78 | $5.61 | | $7.00 | $16.40 | $20.38 |
| 16 | 11 | Prepare for harvest | June | 0.00 | 0 | $0.00 | $0.00 | $0.00 | | | $0.00 | $0.00 |
| 17 | 12 | Hourly Hrvst/Hrvst Superv | June | 0.00 | 0 | $0.00 | $0.00 | $0.00 | | | $0.00 | $0.00 |
| 18 | 13 | Piece rate harvest | June | 0.00 | 0.00 | $0.00 | $0.00 | $0.00 | | | $0.00 | $0.00 |
| 19 | 14 | Harvest clean-up | July | 0.00 | 0 | $0.00 | $0.00 | $0.00 | | | $0.00 | $0.00 |
| 20 | 15 | 2nd cultvn / sidedress | July | 0.65 | 0.79 | $6.31 | $6.96 | $6.62 | | | $13.57 | $19.88 |
| 21 | 16 | 2nd hand weeding | July | | 13.00 | $0.00 | $0.00 | $77.77 | | | $77.77 | $77.77 |
| 22 | 17 | 3rd cultivation - 2X | July | 1.10 | 1.33 | $7.97 | $6.58 | $11.14 | | | $17.72 | $25.69 |
| 23 | 18 | Remove irrigation | Aug | 1.00 | 1.10 | $8.88 | $6.61 | $9.21 | | | $15.82 | $24.71 |
| 24 | 19 | 3rd hand weeding | Aug | | 13.00 | $0.00 | $0.00 | $77.77 | | | $77.77 | $77.77 |
| 25 | 20 | 4th cultvn /sidedress | Aug | 0.65 | 0.79 | $6.31 | $6.96 | $6.62 | | | $13.57 | $19.88 |
| 26 | 21 | 4th hand weeding | Sept | | 13.00 | $0.00 | $0.00 | $77.77 | | | $77.77 | $77.77 |
| 27 | 22 | 2nd herbicide applied | Nov | 0.40 | 0.48 | $4.18 | $2.92 | $4.02 | | | $6.94 | $11.12 |
| 28 | 23 | Apply straw mulch | Nov | 1.60 | 1.94 | $47.23 | $21.29 | $11.61 | | $262.50 | $295.39 | $342.63 |
| 29 | 24 | Apply Row Cover * | | | | | | $0.00 | | $0.00 | $0.00 | $0.00 |
| 30 | 25 | Custom scouting | | | | | | $0.00 | $0.00 | | $0.00 | $0.00 |
| 31 | 26 | Leaf / Soil Analysis | | | | | | $0.00 | | $17.00 | $17.00 | $17.00 |
| 32 | 27 | Annual Overhead Costs | | | | $453.29 | | | | | | $453.29 |
| 33 | | **Totals** | | **$37.65** | **69.35** | **$800.58** | **$321.22** | **$457.78** | **$0.00** | **$1,128.05** | **$1,907.05** | **$2,707.63** |
| 34 | | | | | with hourly or piece rate harvest> | | | **$457.78** | | | | |

**Table 14-6.** Expenses in the bearing years (BEARING spreadsheet)

| | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | *YEAR OF BEARING* | | | | | | | | | | | |
| 2 | *(Harvest labor and supplies represent 1st year of bearing)* | | | | | | | | | | | |
| 3 | | | | | | Overhead | Variable | Labor & | | | Total | |
| 4 | | | | Mach | Labor | & Fixed | Mach | Harvest | | | Variable | Total |
| 5 | Tasks | Operation | Month | hours | Hours | Mach Exp | Costs | Costs | Service | Materials | Costs | Costs |
| 6 | 1 | Remove mulch | Apr | | 6.00 | | | $35.90 | | | $35.90 | $35.90 |
| 7 | 2 | Apply herbicide | Apr | 0.40 | 0.48 | $4.18 | $2.92 | $4.02 | | $128.78 | $135.72 | $139.90 |
| 8 | 3 | Apply 1st insecticide | Apr | 0.40 | 0.48 | $3.90 | $3.16 | $4.02 | | $36.76 | $43.94 | $47.84 |
| 9 | 4 | Setup / test irrigation | Apr | 0.40 | 0.48 | $3.55 | $2.64 | $2.87 | | | $5.52 | $9.07 |
| 10 | 5 | Frost control | Ap/My | | | $0.00 | $0.00 | $0.00 | | | $0.00 | $0.00 |
| 11 | 6 | 1st hand weeding | May | | 13.00 | $0.00 | $0.00 | $77.77 | | | $77.77 | $77.77 |
| 12 | 7 | Irrigation | May | 20.00 | | $152.57 | $169.60 | $0.00 | | | $169.60 | $322.17 |
| 13 | 8 | Apply 2nd insecticide | May | 0.40 | 0.48 | $3.90 | $3.16 | $4.02 | | | $7.18 | $11.08 |
| 14 | 9 | Apply 3rd spray | May | 0.40 | 0.48 | $3.90 | $3.16 | $4.02 | | $130.50 | $137.68 | $141.58 |
| 15 | 10 | Apply 4th Spray | June | 0.40 | 0.48 | $3.90 | $3.16 | $4.02 | | $50.00 | $57.18 | $61.08 |
| 16 | 11 | Prepare for harvest | June | 1.00 | | $6.67 | $1.63 | $142.97 | | | $144.60 | $151.27 |
| 17 | 12 | Hourly Hrvst/Hrvst Supervsn | June | 3.00 | | $20.01 | $4.89 | $502.53 | | | $507.42 | $527.43 |
| 18 | 13 | Piece rate harvest | June | | 1 | | | $1,291.33 | | $947.00 | $2,238.33 | $2,238.33 |
| 19 | 14 | Harvest clean-up | July | 1.00 | | $6.67 | $1.63 | $47.86 | | | $49.49 | $56.16 |
| 20 | 15 | Apply 5th spray | July | 0.40 | 0.48 | $3.90 | $3.16 | $4.02 | | | $7.18 | $11.08 |
| 21 | 16 | Remove irrigation equip | July | 1.00 | 1.10 | $10.45 | $7.29 | $6.58 | | | $13.87 | $24.32 |
| 22 | 17 | Apply herbicide (2,4-D) | July | 0.40 | 0.48 | $3.90 | $3.16 | $4.02 | | | $7.18 | $11.08 |
| 23 | 18 | Mow | July | 0.50 | 0.61 | $5.49 | $4.01 | $5.11 | | | $9.12 | $14.61 |
| 24 | 19 | Narrow rows w/rototiller | July | 0.55 | 0.67 | $47.83 | $6.58 | $5.61 | | | $12.20 | $60.03 |
| 25 | 20 | Fertilize | July | 0.25 | 0.30 | $2.55 | $1.67 | $2.51 | | $225.00 | $229.18 | $231.73 |
| 26 | 21 | Apply Sinbar/germ. weeds | July | 0.40 | 0.48 | $3.90 | $3.16 | $4.02 | | | $7.18 | $11.08 |
| 27 | 22 | 2nd hand weeding | Aug | | 13.00 | $0.00 | $0.00 | $77.77 | | | $77.77 | $77.77 |
| 28 | 23 | 2nd cultivation w/ sidedress | Aug | 0.65 | 0.79 | $5.14 | $4.67 | $6.62 | | | $11.29 | $16.43 |
| 29 | 24 | 3rd hand weeding | Sept | | 13.00 | $0.00 | $0.00 | $77.77 | | | $77.77 | $77.77 |
| 30 | 25 | 3rd cultivation | Sept | 0.55 | 0.67 | $3.99 | $3.78 | $5.61 | | | $9.40 | $13.38 |
| 31 | 26 | Apply 3rd herbicide | Nov | 0.40 | 0.48 | $3.90 | $3.16 | $4.02 | | | $7.18 | $11.08 |
| 32 | 27 | Apply mulch | Nov | 1.60 | 1.94 | $46.08 | $20.99 | $11.61 | | $262.50 | $295.10 | $341.18 |
| 33 | 28 | Custom Scouting | | | | | | $0.00 | | $30.00 | $30.00 | $30.00 |
| 34 | 29 | Soil/Leaf Analysis | | | | | | $0.00 | | $29.00 | $29.00 | $29.00 |
| 35 | 30 | Annual Overhead Costs | | | | $453.29 | | $542.74 | | | | $453.29 |
| 36 | | **Totals** | | **34.10** | **56.88** | **$800** | **$258** | **$2,337** | **$0** | **$1,840** | **$4,434** | **$5,233** |
| 37 | | | | | | | | | | | | |
| 38 | | * Materials cost represents Year 1 quart baskets on this sheet only, quart basket costs are picked up from the Materials Sheet by year | | | | | | | | | | |
| 39 | | for the SUMMARY sheet. | | | | | | | | | | |

**Table 14-7.** Costs of owning and operating machinery (EQUIPMENT spreadsheet)

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **Equipment Costs per Hour of Operation** | | | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | | | | |
| 3 | | . . . . . . . . . . . . . . . . . . . . . . . . . | | | .Cost per hour of use . . . . . . . . . . | | | . . . . . . . . . . . . . | | . . . . . . | . . . . . . | | | . .Cost to the farm business . . | | |
| 4 | | | **Years** | | | | | | **Total** | | | **Hourly** | **Hourly** | | **Annual** | **Annual** |
| 5 | **Machinery** | **Purchase** | **to** | **Annual** | **Depreciation** | **8.00%** | **1.00%** | **2.00%** | **Fixed** | | **Fuel &** | **Variable** | **Total** | **Annual** | **Fixed** | **Variable** |
| 6 | **Description** | **Price** | **Trade** | **Hours** | | **Interest** | **Insurance** | **Housing** | **Cost** | **Repair** | **Lube** | **Cost** | **Cost** | **Costs** | **Cost** | **Cost** |
| 7 | 60 hp tractor | $20,000 | 15 | 400 | $3.00 | $2.00 | $0.23 | $0.45 | $5.23 | $5.03 | $3.20 | $8.23 | $13.46 | $5,382 | $2,090 | $3,292 |
| 8 | 30 hp tractor | $15,000 | 15 | 250 | $3.60 | $2.40 | $0.27 | $0.54 | $6.27 | $4.38 | $1.60 | $5.98 | $12.25 | $3,063 | $1,568 | $1,495 |
| 9 | Boom Sprayer | $4,000 | 15 | 100 | $2.40 | $1.60 | $0.18 | $0.36 | $4.18 | $1.31 | | $1.31 | $5.49 | $549 | $418 | $131 |
| 10 | PTO Blast Sprayer | $5,000 | 15 | 150 | $2.00 | $1.33 | $0.15 | $0.30 | $3.48 | $1.92 | | $1.92 | $5.40 | $811 | $523 | $288 |
| 11 | 7' Rotary Mower | $3,500 | 10 | 100 | $3.15 | $1.40 | $0.16 | $0.32 | $4.71 | $2.04 | | $2.04 | $6.75 | $675 | $471 | $204 |
| 12 | Spreader | $1,500 | 15 | 40 | $2.25 | $1.50 | $0.17 | $0.34 | $3.92 | $0.70 | | $0.70 | $4.62 | $185 | $157 | $28 |
| 13 | 7' Plow | $2,000 | 10 | 60 | $3.00 | $1.33 | $0.15 | $0.30 | $4.48 | $2.47 | | $2.47 | $6.95 | $417 | $269 | $148 |
| 14 | 8' Harrow | $800 | 10 | 20 | $3.60 | $1.60 | $0.18 | $0.36 | $5.38 | $0.42 | | $0.42 | $5.80 | $116 | $108 | $8 |
| 15 | 9" Disc | $2,500 | 10 | 20 | $11.25 | $5.00 | $0.56 | $1.13 | $16.81 | $1.66 | | $1.66 | $18.47 | $369 | $336 | $33 |
| 16 | Transplanter | $4,000 | 15 | 50 | $4.80 | $3.20 | $0.36 | $0.72 | $8.36 | $2.03 | | $2.03 | $10.39 | $520 | $418 | $102 |
| 17 | PTO Rotovator | $3,000 | 10 | 5 | $54.00 | $24.00 | $2.70 | $5.40 | $80.70 | $5.99 | | $5.99 | $86.69 | $433 | $404 | $30 |
| 18 | Landscape Mulcher | $2,500 | 12 | 15 | $12.50 | $6.67 | $0.75 | $1.50 | $19.92 | $4.91 | $1.60 | $6.51 | $26.43 | $396 | $299 | $98 |
| 19 | Utility Trailer | $2,500 | 15 | 100 | $1.50 | $1.00 | $0.11 | $0.23 | $2.61 | $0.63 | | $0.63 | $3.24 | $324 | $261 | $63 |
| 20 | Hay Rake | $1,500 | 15 | 5 | $18.00 | $12.00 | $1.35 | $2.70 | $31.35 | $1.74 | | $1.74 | $33.09 | $165 | $157 | $9 |
| 21 | Cultivator | $1,500 | 15 | 160 | $0.56 | $0.38 | $0.04 | $0.08 | $0.98 | $0.90 | | $0.90 | $1.88 | $301 | $157 | $144 |
| 22 | Side Dresser | $500 | 15 | 80 | $0.38 | $0.25 | $0.03 | $0.06 | $0.65 | $0.31 | | $0.31 | $0.96 | $77 | $52 | $25 |
| 23 | Fumigator | $3,500 | 15 | 20 | $10.50 | $7.00 | $0.79 | $1.58 | $18.29 | $2.17 | | $2.17 | $20.46 | $409 | $366 | $43 |
| 24 | 1/2 ton Pickup | $12,000 | 6 | 350 | $5.14 | $1.37 | $0.15 | $0.31 | $6.67 | $1.63 | | $1.63 | $8.30 | $2,905 | $2,334 | $571 |
| 25 | Misc. Tools | $2,500 | 10 | 100 | $2.25 | $1.00 | $0.11 | $0.23 | $3.36 | $0.91 | | $0.91 | $4.27 | $427 | $336 | $91 |
| 26 | Friday Hoe | $3,000 | 15 | 50 | $3.60 | $2.40 | $0.27 | $0.54 | $6.27 | $0.91 | | $0.91 | $7.18 | $359 | $314 | $46 |
| 27 | PTO irrigation pump | $4,000 | 15 | 500 | $0.48 | $0.32 | $0.04 | $0.07 | $0.84 | $0.25 | | $0.25 | $1.09 | $543 | $418 | $125 |
| 28 | 3 in. Irrigation pipe | $1,500 | 15 | 100 | $0.90 | $0.60 | $0.07 | $0.14 | $1.57 | | | $0.00 | $1.57 | $157 | $157 | $0 |
| 29 | Cash Register | $700 | 8 | 400 | $0.20 | $0.07 | $0.01 | $0.02 | $0.27 | | | $0.00 | $0.27 | $110 | $110 | $0 |
| 30 | Scale | $300 | 8 | 400 | $0.08 | $0.03 | $0.00 | $0.01 | $0.12 | | | $0.00 | $0.12 | $47 | $47 | $0 |
| 31 | | | | | | | | | | | | | | | | |
| 32 | Annual Cost to Farm Business > | | | | | | | | | | | | | **$18,740** | $11,767 | $6,973 |
| 33 | **Cost of owning & operating machinery per acre >** | | | | | | | | | | | | | **$77.12** | $48.42 | $28.69 |

## *The OVERHEAD Spreadsheet*

The OVERHEAD sheet (table 14-8) calculates the true cost of owning land used in strawberry production. The assumption used is that farm size is 243 acres; real estate taxes, other land rental, utilities, and other overhead costs are as listed in column B. The default figures are taken from the *Fruit Farm Business Summary of New York State* and represent the typical situation there. Change figures in column B to more closely represent your costs. The $453 per acre overhead cost in the default scenario appears on the PREPLANT, PLANTING, and BEARING sheets (tables 14-4 through 14-6).

## *The MATERIALS Spreadsheet*

The MATERIALS sheet (table 14-9 on page 126) allows you to track prices of fertilizers, chemicals, plants, picking materials, and so on. The default numbers are taken from current supplier prices. The recommended use rate of the material is in column B, units are in column C, and the cost per unit is in column D. For example, in the default scenario, lime will be applied at 2 tons per acre at a cost of $22.00 per ton. Columns B and D are not write-protected and can be changed.

The materials cost in each year is calculated in the next twelve columns. The number of applications of each material can be entered in the year it is used. For example, Sevin 50WP (line 15) is used at 2 pounds per acre and costs $3.50 per pound. It is applied once in the planting year for leaf hoppers and once in each of the bearing years for a cost of $7.00 per acre per year. This $7.00 cost in each year is added to the other materials' costs in that year. In the planting year, for example, our $7.00 cost for Sevin insecticide is added to the other material costs in the planting year (column H) and totaled in cell H81. The individual material's costs are copied automatically onto the PREPLANT, PLANTING, and BEARING sheets (tables 14-4 through 14-6), and the totals appear on the SUMMARY sheet (table 14-1).

**Table 14-8.** Overhead costs of a typical fruit farm in the Northeast (OVERHEAD spreadsheet)

| | A | B | C |
|---|---|---|---|
| 1 | OVERHEAD COSTS | | |
| 2 | | | |
| 3 | Number of fruit and/or crop acres: | 243 | |
| 4 | | | |
| 5 | | | |
| 6 | | Total Farm | per |
| 7 | Overhead Expenses | Expenses | crop acre |
| 8 | | | |
| 9 | Real estate taxes | $9,012 | $37.09 |
| 10 | Land rental | $10,972 | $45.15 |
| 11 | Utilities | $6,054 | $24.91 |
| 12 | Legal & accounting expenses | $1,200 | $4.94 |
| 13 | Membership, subscriptions | $500 | $2.06 |
| 14 | Office expenses | $1,400 | $5.76 |
| 15 | Miscellaneous expense | $6,516 | $26.81 |
| 16 | General shop supplies & heat | $4,250 | $17.49 |
| 17 | Labor housing expense | $1,250 | $5.14 |
| 18 | Interest on operating capital | $26,990 | $111.07 |
| 19 | Management fee | $42,006 | $172.86 |
| 20 | | | $0.00 |
| 21 | | | $0.00 |
| 22 | TOTAL OVERHEAD EXPENSE | $110,150 | $453.29 |

## *The DISCOUNT Spreadsheet*

A discount rate (table 14-10 on page 127) represents the real rate of interest (the interest rate minus the average rate of inflation) plus a percentage to indicate the relative risk of the venture. If today's interest rate is 8% and the rate of inflation is 3%, then the real rate of interest would be 5%. Discounting represents the opportunity cost of investing in the business instead of putting the money in the bank.

Risk is also included in the discount rate. For someone who is experienced in growing and marketing strawberries, risks are relatively low, perhaps 1%. In the example here we are using a 6% discount rate (5% real rate of interest plus 1% risk). A discount interest rate of 9% would indicate a high-risk venture (5% real rate of interest plus 4% risk). A grower with no experience growing or marketing a highly perishable product such as strawberries should use a higher discount rate (8 or 9%).

You can perform a sensitivity analysis by changing the discount rate and comparing the new "Accumulated Net Present Value of Profit" with the original.

# "What If?" Scenarios

The strawberry budget spreadsheet template allows you to run "What if?" scenarios. With the change of a few assumptions in yield, price, cost of inputs, and other factors, you can see the net effect on the bottom line. You can evaluate marketing strategies like selling everything pick-your-own versus harvesting everything and retailing it. You can also evaluate different planting systems like the ribbon row system or production innovations like using row covers. Evaluating the potential impact of changes before they are implemented is an important use of this tool.

## *The Default Scenario*

In the default scenario, a matted row system is planted at 4 feet by 18 inches (7,250 plants per acre). Yields are 7,000 quarts per acre (10,500 pounds) in the first and second bearing years and then 4,000 quarts per acre (6,000 pounds) and 3,000 quarts per acre (4,500 pounds)

**TABLE 14-9.** Costs of materials used in strawberry production (MATERIALS spreadsheet)

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **MATERIAL USE** | | | | . . Preplant . . | | . . Planting Yr. . | | . . 1st Bearing . . | | . 2nd Bearing . | | . 3rd Bearing . . | | . 4th Bearing . . | |
| 2 | | | | Cost | No. of | Cost | No. of | Cost | No. of | Cost | No. of | Cost | No. of | Cost | No. of | Cost |
| 3 | Material | Rate | unit | per unit | Applic. | per A. | Applic. | per A. | Applic. | per A. | Applic. | per A. | Applic. | per A. | Applic. | per A. |
| 4 | **FERTILIZERS** | | | | | | | | | | | | | | | |
| 5 | Lime | 2.00 | tons | $22.00 | 1 | $44.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 6 | Superphosphate | 500 | lbs. | $0.12 | 1 | $59.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 7 | Muriate of Potash | 150 | lbs. | $0.07 | 1 | $10.88 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 8 | Sulpomag | 500 | lbs. | $0.12 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 9 | 10-10-10 | 300 | lbs. | $0.25 | | $0.00 | 2 | $150.00 | 3 | $225.00 | 3 | $225.00 | 3 | $225.00 | 2 | $150.00 |
| 10 | Calcium nitrate | 200 | lbs. | $0.11 | | $0.00 | 1 | $21.50 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 11 | Ammonium nitrate | 300 | LBS | $0.90 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 12 | | | | | | | | | | | | | | | | |
| 13 | TOTAL FERTILIZERS | | | | 3 | $114 | 3 | $172 | 3 | $225 | 3 | $225 | 3 | $225 | 2 | $150 |
| 14 | **INSECTICIDES** | | | | | | | | | | | | | | | |
| 15 | Sevin 50 WP | 2.00 | lb | $3.50 | | $0.00 | 1 | $7.00 | 1 | $7.00 | 1 | $7.00 | 1 | $7.00 | 1 | $7.00 |
| 16 | Guthion 50 WP | 1.00 | lb | $8.50 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 17 | Lorsban 4EC | 2.00 | pt | $6.50 | | $0.00 | | $0.00 | 1 | $13.00 | 1 | $13.00 | 1 | $13.00 | 1 | $13.00 |
| 18 | Methoxychlor 50WP | 2.50 | lbs | $3.40 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 19 | Malathion 25 WP | 4.00 | lb | $1.94 | | $0.00 | | $0.00 | 1 | $7.76 | 1 | $7.76 | 1 | $7.76 | 1 | $7.76 |
| 20 | Thiodan 3EC | 1.00 | qt | $9.00 | | $0.00 | | $0.00 | 1 | $9.00 | 1 | $9.00 | 1 | $9.00 | 1 | $9.00 |
| 21 | Dibrom 8EC | 1.00 | qt | $20.95 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 22 | | | | | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 23 | TOTAL INSECTICIDES | | | | 0 | $0.00 | 1 | $7.00 | 4 | $36.76 | 4 | $36.76 | 4 | $36.76 | 4 | $36.76 |
| 24 | **FUNGICIDES** | | | | | | | | | | | | | | | |
| 25 | Captan 50WP | 3.00 | lbs | $2.50 | | $0.00 | | $0.00 | 1 | $7.50 | 1 | $7.50 | 1 | $7.50 | 1 | $7.50 |
| 26 | Benlate 50 WP | 0.50 | lbs | $16.00 | | $0.00 | | $0.00 | 1 | $8.00 | 1 | $8.00 | 1 | $8.00 | 1 | $8.00 |
| 27 | Ronilan 50WP | 2.00 | lbs | $20.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 28 | Rovral 50WP | 2.00 | lbs | $20.00 | | $0.00 | | $0.00 | 1 | $40.00 | 1 | $40.00 | 1 | $40.00 | 1 | $40.00 |
| 29 | Thiram 65 WP | 3.00 | lbs | $6.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 30 | Ridomil 2E | 0.50 | gal | $150 | | $0.00 | | $0.00 | 1 | $75.00 | 1 | $75.00 | 1 | $75.00 | 1 | $75.00 |
| 31 | Aliette | 3.00 | lbs | $17.50 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 32 | | | | | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 33 | TOTAL FUNGICIDES | | | | 0 | $0.00 | 0 | $0.00 | 4 | $130.50 | 4 | $130.50 | 4 | $130.50 | 4 | $130.50 |
| 34 | **MITICIDES** | | | | | | | | | | | | | | | |
| 35 | Kelthane 4EC | 1.00 | lb | $50.00 | | $0.00 | | $0.00 | 1 | $50.00 | 1 | $50.00 | 1 | $50.00 | 1 | $50.00 |
| 36 | Vendex 4L | 2.00 | pt | $24.38 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 37 | | | | | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 38 | TOTAL MITICIDES | | | | 0 | $0.00 | 0 | $0.00 | 1 | $50.00 | 1 | $50.00 | 1 | $50.00 | 1 | $50.00 |
| 39 | **ADJUVANTS** | | | | | | | | | | | | | | | |
| 40 | Charger E | 16.00 | oz | $0.11 | 1 | $1.82 | | $0.00 | 1 | $1.82 | 1 | $1.82 | 1 | $1.82 | 1 | $1.82 |
| 41 | Regulaid | 0.25 | lb | $7.73 | | $0.00 | | $0.00 | 1 | $1.93 | 1 | $1.93 | 1 | $1.93 | 1 | $1.93 |
| 42 | Kinetic | 4.00 | oz | $0.74 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 43 | TOTAL ADJUVANTS | | | | 1 | $1.82 | 0 | $0.00 | 2 | $3.76 | 2 | $3.76 | 2 | $3.76 | 2 | $3.76 |
| 44 | | | | | | | | | | | | | | | | |
| 45 | **HERBICIDES** | | | | | | | | | | | | | | | |
| 46 | Roundup | 2.50 | qt | $12.13 | 1 | $30.33 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 47 | Sinbar 80WP | 4.00 | oz | $1.60 | | $0.00 | 1 | $6.40 | 2 | $12.80 | 2 | $12.80 | 2 | $12.80 | 2 | $12.80 |
| 48 | Devrinol 50 DF | 8.00 | lbs | $9.00 | | $0.00 | 1 | $72.00 | 1 | $72.00 | 1 | $72.00 | 1 | $72.00 | 1 | $72.00 |
| 49 | Dacthal 75WP | 10.00 | lbs | $7.15 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 50 | Gramoxone | 1.50 | pts | $4.50 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 51 | 2,4-D Formula 40 | 2.5 | pts | $2.09 | 1 | $5.23 | | $0.00 | 1 | $5.23 | 1 | $5.23 | 1 | $5.23 | 1 | $5.23 |
| 52 | Poast | 2.5 | pts | $14.00 | | $0.00 | | $0.00 | 1 | $35.00 | 1 | $35.00 | 1 | $35.00 | 1 | $35.00 |
| 53 | Fusilade 2000 | 8 | oz | $0.55 | | $0.00 | 1 | $4.40 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 54 | TOTAL HERBICIDES | | | | 2 | $35.55 | 3 | $82.80 | 5 | $125.03 | 5 | $125.03 | 5 | $125.03 | 5 | $125.03 |
| 55 | Soil sample | 1 | | $12.00 | 1 | $12.00 | | $0.00 | 1 | $12.00 | 1 | $12.00 | 1 | $12.00 | 1 | $12.00 |
| 56 | Leaf Analysis | 1 | | $17.00 | | $0.00 | 1 | $17.00 | 1 | $17.00 | 1 | $17.00 | 1 | $17.00 | 1 | $17.00 |
| 57 | Fumigation - custom applied | | | $1,500 | | $0 | | $0 | | $0 | | $0 | | $0 | | $0 |
| 58 | Lime - custom applied | | | $30.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 59 | Custom scouting | 1 | | $30.00 | | $0.00 | | $0.00 | 1 | $30.00 | 1 | $30.00 | 1 | $30.00 | 1 | $30.00 |
| 60 | | | | | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 61 | Ground cover seed | 100 | lbs | $0.10 | 1 | $10.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 62 | Strawberry plants | 7250 | plant | $0.08 | | $0.00 | 1 | $587.25 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 63 | Straw | 150 | bales | $1.75 | | $0.00 | 1 | $262.50 | 1 | $262.50 | 1 | $262.50 | 1 | $262.50 | 1 | $262.50 |
| 64 | Row cvr:plntg yr only | 1 | acre | $1,200 | | | | $0 | | | | | | | | |
| 65 | Plastic mulch | | | | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 66 | **U-PICK MATERIALS** | | | | | | | | | | | | | | | |
| 67 | Flags | 1 | ea. | $0.07 | | $0.00 | | $0.00 | 100 | $7.00 | | $0.00 | | $0.00 | | $0.00 |
| 68 | Carriers | 1 | ea. | $5.00 | | $0.00 | | $0.00 | 30 | $150.00 | | $0.00 | | $0.00 | | $0.00 |
| 69 | quarts | 1 | ea. | $0.07 | | $0.00 | 0 | $0.00 | 7,000 | $490.00 | 7,000 | $490.00 | 4,000 | $280.00 | 3,000 | $210.00 |
| 70 | U-pick flats | 1 | ea. | $0.50 | | $0.00 | | $0.00 | 200 | $100.00 | 200 | $100.00 | 100 | $50.00 | | $0.00 |
| 71 | | 1 | ea. | | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 72 | | 1 | ea. | | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 73 | aprons | 1 | ea. | $5.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 74 | Advertising /promo | 1 | ea. | $200 | | $0.00 | | $0.00 | 1 | $200.00 | 1 | $200.00 | 1 | $200.00 | 1 | $200.00 |
| 75 | TOTAL PICKING MATERIALS | | | | 0 | $0.00 | 0 | $0.00 | 7331 | $947.00 | 7201 | $790.00 | 4101 | $530.00 | 3001 | $410.00 |
| 76 | **IRRIGATION EQUIP** | | | | | | | | | | | | | | | |
| 77 | Trickle tape | 1 | | | 1 | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 78 | emitters | | | | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 79 | | | | | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 | | $0.00 |
| 80 | TOTAL IRRIGATION MATERIALS | | | | 1 | $0.00 | 0 | $0.00 | 0 | $0.00 | 0 | $0.00 | 0 | $0.00 | 0 | $0.00 |
| 81 | **TOTAL MATERIALS** | | | | 9 | $173 | 10 | $1,128 | 7354 | $1,840 | 7224 | $1,683 | 4124 | $1,423 | 3023 | $1,228 |

**Table 14-10.** Discount rates

| **Present Value of $1.00** | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| Year | 5% | 6% | 7% | 8% | 9% | 10% | 11% |
| 1 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 2 | 0.9524 | 0.9434 | 0.9346 | 0.9259 | 0.9174 | 0.9091 | 0.9009 |
| 3 | 0.9070 | 0.8900 | 0.8734 | 0.8573 | 0.8417 | 0.8264 | 0.8116 |
| 4 | 0.8638 | 0.8396 | 0.8163 | 0.7938 | 0.7722 | 0.7513 | 0.7312 |
| 5 | 0.8227 | 0.7921 | 0.7629 | 0.7350 | 0.7084 | 0.6830 | 0.6587 |
| 6 | 0.7835 | 0.7473 | 0.7130 | 0.6806 | 0.6499 | 0.6209 | 0.5935 |
| 7 | 0.7462 | 0.7050 | 0.6663 | 0.6302 | 0.5963 | 0.5645 | 0.5346 |

in the next two years. Half the crop is harvested piece-work at $0.30 per quart and sold retail for $1.80 per quart. The other half is harvested pick-your-own and sold for $1.00 per quart. The average price from selling half at $1.80 per quart and half at $1.00 per quart is $1.40 per quart. If we assume that pick-your-own can be supervised with one full-time person for every two acres for three weeks during the early harvest years, then in this scenario we assume one person for four hours per day for three weeks of harvest on the HARVEST labor sheet (table 14-3). Highlights from the SUMMARY sheet output for the default scenario are in table 14-1 (page 119).

Projections are that it costs $736 per acre in the preplant year and $2,708 in the planting year to establish strawberries. Net returns are $4,567 per acre in the first bearing year; $4,724 in the second; $1,463 in the third; and $599 in the fourth bearing year. The accumulated net present value of the enterprise is $6,346, making it a good investment. The break-even price under the default assumptions is $1.00 per quart. Note that as yield drops off in the third and fourth bearing years, profit drops off significantly. In fact, the fourth bearing year contributes very little ($599) to the accumulated NPV of the enterprise. One would seriously have to consider not fruiting the bed a fourth year and instead renewing it after the third fruiting under this particular set of assumptions.

## *Pick-Your-Own*

Tables 14-11 and 14-12 (on page 128) show the hypothetical result of harvesting the entire crop as pick-your-own (PYO) instead of half being commercially harvested. All inputs are exactly the same as the default scenario, except that there will be no piece-work labor to pick the berries and twice as much harvest supervision labor to oversee PYO. Also, 10% less yield was assumed, since PYO customers leave some fruit out in the field, and this portion will not be cleaned up by piece-work. The price is set at $1.00 per quart. If the whole crop is sold PYO, then profit is less than with the default scenario. Net return in the first bearing year is $1,904 per acre (versus $4,567 with 50% commercial harvesting). In the third and four years, the lower price combined with the lower yield actually result in negative net returns. The accumulated NPV of the enterprise is still positive by the third year, but it would be higher if the enterprise was discontinued after the second fruiting year. Also, the selling price of $1.00 per quart ($0.65 per pound) is probably too low to sustain a PYO operation.

**Table 14-11.** Summary budget for a pick-your-own marketing scenario

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ***Summary for Establishing Strawberries*** | | | | | *By Alison DeMarree and Regina Rieckenberg - Cornell Cooperative Extension - 1996* | | | | | | | | |
| 2 | | | | | | | | | | | | | | |
| 3 | **Avg. price received per quart >** | | | **$1.00** | | **Discount Rate You Would Like to Use>** | | | | **6%** | | | | |
| 4 | | | | | | | | | | | | | | |
| 5 | | **Yield** | **Income** | **Variable Expenses** | | | | | | | | **Profit** | **Discounted** | **Accum.** |
| 6 | **Year** | **per A.** | **per A.** | **Labor** | **Service** | **Materials** | **Equip.** | **Comm** | **Total** | **Fixed** | **Total** | **or Net** | **Cash Flow** | **NPV** |
| 7 | | | | | | | | **Harvest** | **Variable** | **Costs** | **Costs** | **Income** | | **of Profit** |
| 8 | Preplant | | | $38 | $0 | $173 | $31 | | $243 | $494 | $736 | ($736) | ($736) | **($736)** |
| 9 | Planting Yr | **0** | $0 | $458 | $0 | $1,128 | $321 | $0 | $1,907 | $801 | $2,708 | ($2,708) | ($2,554) | **($3,291)** |
| 10 | 1st bearing | **6,300** | $6,300 | $543 | $0 | $1,791 | $258 | $1,005 | $3,596 | $800 | $4,396 | $1,904 | $1,695 | **($1,596)** |
| 11 | 2nd bearing | **6,300** | $6,300 | $543 | $0 | $1,634 | $258 | $1,005 | $3,439 | $800 | $4,239 | $2,061 | $1,731 | **$135** |
| 12 | 3rd bearing | **3,600** | $3,600 | $543 | $0 | $1,395 | $258 | $754 | $2,949 | $800 | $3,748 | ($148) | ($118) | **$17** |
| 13 | 4th bearing | **2,700** | $2,700 | $543 | $0 | $1,207 | $258 | $440 | $2,447 | $800 | $3,246 | ($546) | ($408) | **($391)** |
| 14 | | | | | | | | | | | | | | |
| 15 | | | | **Breakeven price >** | | **$0.98** | | | Net Establishment Costs> | | | $3,444 | | |

**Table 14-12.** Labor summary for a pick-your-own marketing scenario

| | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | *Harvest Labor Expenses* | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | |
| 3 | **Pre-Harvest Labor** | | **Avg. hrs** | **Number** | **Number** | **Total labor** | | | | | | | |
| 4 | **HOURLY LABOR** | **Rate** | **per day** | **of days** | **of people** | **expense** | | | | | | | |
| 5 | Unskilled | $5.98 | 8 | 1 | 2 | $95.72 | | | | | | | |
| 6 | Semi-skilled | $8.38 | | | | $0.00 | | | | | | | |
| 7 | Skilled | $11.81 | 4 | 1 | 1 | $47.25 | | | | | | | |
| 8 | **TOTALS** | | | | | **$142.97** | | | | | | | |
| 9 | | | | | | | | | | | | | |
| 10 | **Harvest Labor** | | | **Indirect** | **Adjusted** | **Yield** | **Piece Rate Harvest** | | | | | | |
| 11 | **PIECE RATE JOBS** | **unit** | **Rate** | **costs** | **Rate** | **each year** | **Cost to** | **Pick** | | | | | |
| 12 | | | | | | 0 | $0 | **<planting yr** | | | | | |
| 13 | Picking | qt. | $0.30 | 0.05895 | $0.36 | 0 | $0 | **< 1st yr** | | | | | |
| 14 | Crew Leader | qt | $0.01 | | $0.01 | 0 | $0 | **< 2nd yr** | | | | | |
| 15 | | | | | | 0 | $0 | **< 3rd yr** | | | | | |
| 16 | **TOTAL / PIECE** | | | | **$0.37** | 0 | $0 | **< 4th yr** | | | | | |
| 17 | | | | | | | | | | | | | |
| 18 | **Harvest Labor: Plntg Yr** | | **Avg. hrs** | **Number** | **Number** | **Total labor** | | **Harvest Labor: Year 1** | | **Avg. hrs** | **Number** | **Number** | **Total labor** |
| 19 | **HOURLY LABOR** | **Rate** | **per day** | **of days** | **of people** | **expense** | | **HOURLY LABOR** | **Rate** | **per day** | **of days** | **of people** | **expense** |
| 20 | Minimum Wage | $5.09 | | | | $0.00 | | Minimum Wage | $5.09 | | | | $0.00 |
| 21 | Unskilled | $5.98 | 0 | 0 | 0 | $0.00 | | Unskilled | $5.98 | 4 | 21 | 2 | $1,005.06 |
| 22 | Semi-skilled | $8.38 | | | | $0.00 | | Semi-skilled | $8.38 | | | | $0.00 |
| 23 | Skilled (supervisory) | $11.81 | 0 | 0 | 0 | $0.00 | | Skilled (supervisory) | $11.81 | 0 | 0 | 0 | $0.00 |
| 24 | **TOTALS** | | | | | **$0.00** | | **TOTALS** | | | | | **$1,005.06** |
| 25 | | | | | | | | | | | | | |
| 26 | **Harvest Labor: Year 2** | | **Avg. hrs** | **Number** | **Number** | **Total labor** | | **Harvest Labor: Year 3** | | **Avg. hrs** | **Number** | **Number** | **Total labor** |
| 27 | **HOURLY LABOR** | **Rate** | **per day** | **of days** | **of people** | **expense** | | **HOURLY LABOR** | **Rate** | **per day** | **of days** | **of people** | **expense** |
| 28 | Minimum Wage | $5.09 | | | | $0.00 | | Minimum Wage | $5.09 | | | | $0.00 |
| 29 | Unskilled | $5.98 | 4 | 21 | 2 | $1,005.06 | | Unskilled | $5.98 | 3 | 21 | 2 | $753.80 |
| 30 | Semi-skilled | $8.38 | | | | $0.00 | | Semi-skilled | $8.38 | 0 | 0 | 0 | $0.00 |
| 31 | Skilled (supervisory) | $11.81 | 0 | 0 | 0 | $0.00 | | Skilled (supervisory) | $11.81 | 0 | 0 | 0 | $0.00 |
| 32 | **TOTALS** | | | | | **$1,005.06** | | **TOTALS** | | | | | **$753.80** |
| 33 | | | | | | | | | | | | | |
| 34 | **Harvest Labor: Year 4** | | **Avg. hrs** | **Number** | **Number** | **Total labor** | | **Harvest labor exp / qt.** | **plant** | **1st yr.** | **2nd yr.** | **3rd yr.** | **4th yr.** |
| 35 | **HOURLY LABOR** | **Rate** | **per day** | **of days** | **of people** | **expense** | | Pre-Harvest | $143 | $143 | $143 | $143 | $143 |
| 36 | Minimum Wage | $5.09 | | | | $0.00 | | Harvest | $0 | $1,005 | $1,005 | $754 | $440 |
| 37 | Unskilled | $5.98 | 1.75 | 21 | 2 | $439.71 | | Harvest: piecerate | $0 | $0 | $0 | $0 | $0 |
| 38 | Semi-skilled | $8.38 | | | | $0.00 | | Post-Harvest | $48 | $48 | $48 | $48 | $48 |
| 39 | Skilled (supervisory) | $11.81 | 0 | 0 | 0 | $0.00 | | **total** | **#DIV/0!** | **0.1898** | **0.1898** | **0.2624** | **0.2335** |
| 40 | **TOTALS** | | | | | **$439.71** | | | | **. . . . labor cost per quart harvested . . .** | | | |
| 41 | | | | | | | | **+ advertising & basket** | | **0.2916** | **0.2916** | **0.3880** | **0.3776** |
| 42 | **Post-Harvest Labor** | | **Avg. hrs** | **Number** | **Number** | **Total labor** | | | | | | | |
| 43 | **HOURLY LABOR** | **Rate** | **per day** | **of days** | **of people** | **expense** | | | | | | | |
| 44 | Unskilled | $5.98 | 4 | 1 | 2 | $47.86 | | | | | | | |
| 45 | Semi-skilled | $8.38 | | | | $0.00 | | | | | | | |
| 46 | Skilled | $11.81 | | | | $0.00 | | | | | | | |
| 47 | **TOTALS** | | | | | **$47.86** | | | | | | | |

## *Picking and Selling*

On the other end of the spectrum is a marketing strategy where the whole crop is harvested and sold at retail (table 14-13 below and table 14-14 on page 130). Here the assumption is that the crop will be picked entirely with piece-work labor at $0.30 per quart (plus $0.01 for supervision). Yields are the same as in the default scenario and a price is set at $1.80 per quart. In reality, if the whole crop was being retailed, there would probably be some type of sales cost (putting up a stand, staffing it, and so on), but this was not included. As with the first two scenarios, the establishment cost of the enterprise is $736 in the preplant year and $2,708 in the planting year. Because of the higher price received per quart, profits in the first and second year are significantly higher than either of the first two scenarios. The enterprise continues to stay quite profitable even in the third and fourth bearing year, for an accumulated NPV of $11,453. This is better for the grower than selling the same amount for $1.00 per quart through PYO.

## *Ribbon Rows*

In the ribbon row scenario, plant spacing is three times more narrow (6-inch versus 18-inch spacing), harvesting includes a small 2,000-quart-per-acre crop in the planting year, a 30% higher yield is obtained in what is normally the first fruiting year, and after that the planting essentially becomes a matted row. Ribbon row results can be compared directly to the default scenario (table 14-15 on page 131). Note that the yield in the planting year offsets the cost of the additional plants. In the main bearing year, the increased yield results in a very high profit of $6,972 per acre. The accumulated NPV reveals that this planting system is even more profitable than our default scenario.

## *Row Covers*

In our row covers scenario, 20% of the commercially harvested crop is assumed to be earlier and sold for $2.30 per quart. That makes the weighted average price for the season $1.45 per quart. Also included is a one-time expenditure of $1,200 per acre in the first bearing year to buy the row cover and no increase in yield. (Most studies find that yields are increased between 10 and 30%, depending on the year.) All other assumptions are unchanged from the default scenario. The additional income from the weighted season average price of $1.45 per quart does not offset the cost of the row cover. However, if one obtains a yield increase from the use of row covers, receives a higher price for earlier fruit, or sells a higher percentage at retail, then the result is a significantly higher accumulated NPV. For example, a 10% yield increase will more than offset the cost of the row cover (table 14-15 on page 131).

An advantage of this type of budget analysis is that it estimates the minimal response one needs to pay for an investment—in this case, a higher price for 20% of the early harvested fruit and a yield increase of 10%. One can change the yield while leaving the price unchanged to determine the "break-even" yield for row covers (that is, how much additional yield is needed from the row covers to make the NPV at least as large as the NPV for the default scenario).

## *Organic Production Scenario*

Assumptions for organic matted row production were: (1) There were no costs for synthetic inputs such as fertilizers and pesticides. (2) Yields were reduced by 30 to 70%, with the greatest decrease in later years. For example, in fruiting years one through four, conventional

**Table 14-13.** Summary budget for a retail marketing scenario

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | *Summary for Establishing Strawberries* | | | | | *By Alison DeMarree and Regina Rieckenberg - Cornell Cooperative Extension - 1996* | | | | | | | | |
| 2 | | | | | | | | | | | | | | |
| 3 | Avg. price received per quart > | | | $1.80 | | Discount Rate You Would Like to Use> | | | | 6% | | | | |
| 4 | | | | | | | | | | | | | | |
| 5 | | Yield | Income | Variable Expenses | | | | | | | | Profit | Discounted | Accum. |
| 6 | Year | per A. | per A. | Labor | Service | Materials | Equip. | Comm | Total | Fixed | Total | or Net | Cash Flow | NPV |
| 7 | | | | | | | | Harvest | Variable | Costs | Costs | Income | | of Profit |
| 8 | Preplant | | | $38 | $0 | $173 | $31 | | $243 | $494 | $736 | ($736) | ($736) | **($736)** |
| 9 | Planting Yr | 0 | $0 | $458 | $0 | $1,128 | $321 | $0 | $1,907 | $801 | $2,708 | ($2,708) | ($2,554) | **($3,291)** |
| 10 | 1st bearing | 7,000 | $12,600 | $543 | $0 | $1,840 | $258 | $2,583 | $5,223 | $800 | $6,022 | $6,578 | $5,854 | **$2,563** |
| 11 | 2nd bearing | 7,000 | $12,600 | $543 | $0 | $1,683 | $258 | $2,583 | $5,066 | $800 | $5,865 | $6,735 | $5,655 | **$8,218** |
| 12 | 3rd bearing | 4,000 | $7,200 | $543 | $0 | $1,423 | $258 | $1,476 | $3,699 | $800 | $4,498 | $2,702 | $2,140 | **$10,358** |
| 13 | 4th bearing | 3,000 | $5,400 | $543 | $0 | $1,228 | $258 | $1,107 | $3,135 | $800 | $3,934 | $1,466 | $1,095 | **$11,453** |
| 14 | | | | | | | | | | | | | | |
| 15 | | | | Breakeven price > | | $1.10 | | | Net Establishment Costs> | | | $3,444 | | |

**TABLE 14-14.** Labor summary for a retail marketing scenario

| | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | *Harvest Labor Expenses* | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | |
| 3 | **Pre-Harvest Labor** | | **Avg. hrs** | **Number** | **Number** | **Total labor** | | | | | | | |
| 4 | **HOURLY LABOR** | **Rate** | **per day** | **of days** | **of people** | **expense** | | | | | | | |
| 5 | Unskilled | $5.98 | 8 | 1 | 2 | $95.72 | | | | | | | |
| 6 | Semi-skilled | $8.38 | | | | $0.00 | | | | | | | |
| 7 | Skilled | $11.81 | 4 | 1 | 1 | $47.25 | | | | | | | |
| 8 | **TOTALS** | | | | | **$142.97** | | | | | | | |
| 9 | | | | | | | | | | | | | |
| 10 | **Harvest Labor** | | | **Indirect** | **Adjusted** | **Yield** | **Piece Rate Harvest** | | | | | | |
| 11 | **PIECE RATE JOBS** | **unit** | **Rate** | **costs** | **Rate** | **each year** | **Cost to** | **Pick** | | | | | |
| 12 | | | | | | 0 | $0 | **<planting yr** | | | | | |
| 13 | Picking | qt. | $0.30 | 0.05895 | $0.36 | 7,000 | $2,583 | **< 1st yr** | | | | | |
| 14 | Crew Leader | qt | $0.01 | | $0.01 | 7,000 | $2,583 | **< 2nd yr** | | | | | |
| 15 | | | | | | 4,000 | $1,476 | **< 3rd yr** | | | | | |
| 16 | **TOTAL / PIECE** | | | | **$0.37** | 3,000 | $1,107 | **< 4th yr** | | | | | |
| 17 | | | | | | | | | | | | | |
| 18 | **Harvest Labor: Plntg Yr** | | **Avg. hrs** | **Number** | **Number** | **Total labor** | | **Harvest Labor: Year 1** | | **Avg. hrs** | **Number** | **Number** | **Total labor** |
| 19 | **HOURLY LABOR** | **Rate** | **per day** | **of days** | **of people** | **expense** | | **HOURLY LABOR** | **Rate** | **per day** | **of days** | **of people** | **expense** |
| 20 | Minimum Wage | $5.09 | | | | $0.00 | | Minimum Wage | $5.09 | | | | $0.00 |
| 21 | Unskilled | $5.98 | 0 | 0 | 0 | $0.00 | | Unskilled | $5.98 | 4 | 21 | 0 | $0.00 |
| 22 | Semi-skilled | $8.38 | | | | $0.00 | | Semi-skilled | $8.38 | | | | $0.00 |
| 23 | Skilled (supervisory) | $11.81 | 0 | 0 | 0 | $0.00 | | Skilled (supervisory) | $11.81 | 0 | 0 | 0 | $0.00 |
| 24 | **TOTALS** | | | | | **$0.00** | | **TOTALS** | | | | | **$0.00** |
| 25 | | | | | | | | | | | | | |
| 26 | **Harvest Labor: Year 2** | | **Avg. hrs** | **Number** | **Number** | **Total labor** | | **Harvest Labor: Year 3** | | **Avg. hrs** | **Number** | **Number** | **Total labor** |
| 27 | **HOURLY LABOR** | **Rate** | **per day** | **of days** | **of people** | **expense** | | **HOURLY LABOR** | **Rate** | **per day** | **of days** | **of people** | **expense** |
| 28 | Minimum Wage | $5.09 | | | | $0.00 | | Minimum Wage | $5.09 | | | | $0.00 |
| 29 | Unskilled | $5.98 | 4 | 21 | 0 | $0.00 | | Unskilled | $5.98 | 3 | 21 | 0 | $0.00 |
| 30 | Semi-skilled | $8.38 | | | | $0.00 | | Semi-skilled | $8.38 | 0 | 0 | 0 | $0.00 |
| 31 | Skilled (supervisory) | $11.81 | 0 | 0 | 0 | $0.00 | | Skilled (supervisory) | $11.81 | 0 | 0 | 0 | $0.00 |
| 32 | **TOTALS** | | | | | **$0.00** | | **TOTALS** | | | | | **$0.00** |
| 33 | | | | | | | | | | | | | |
| 34 | **Harvest Labor: Year 4** | | **Avg. hrs** | **Number** | **Number** | **Total labor** | | **Harvest labor exp / qt.** | **plant** | **1st yr.** | **2nd yr.** | **3rd yr.** | **4th yr.** |
| 35 | **HOURLY LABOR** | **Rate** | **per day** | **of days** | **of people** | **expense** | | Pre-Harvest | $143 | $143 | $143 | $143 | $143 |
| 36 | Minimum Wage | $5.09 | | | | $0.00 | | Harvest | $0 | $0 | $0 | $0 | $0 |
| 37 | Unskilled | $5.98 | 1.75 | 21 | 0 | $0.00 | | Harvest: piecerate | $0 | $2,583 | $2,583 | $1,476 | $1,107 |
| 38 | Semi-skilled | $8.38 | | | | $0.00 | | Post-Harvest | $48 | $48 | $48 | $48 | $48 |
| 39 | Skilled (supervisory) | $11.81 | 0 | 0 | 0 | $0.00 | | **total** | **#DIV/0!** | **0.3962** | **0.3962** | **0.4167** | **0.4326** |
| 40 | **TOTALS** | | | | | **$0.00** | | | | **. . . . labor cost per quart harvested . . .** | | | |
| 41 | | | | | | | | **+ advertising & basket** | | **0.4948** | **0.4948** | **0.5367** | **0.5692** |
| 42 | **Post-Harvest Labor** | | **Avg. hrs** | **Number** | **Number** | **Total labor** | | | | | | | |
| 43 | **HOURLY LABOR** | **Rate** | **per day** | **of days** | **of people** | **expense** | | | | | | | |
| 44 | Unskilled | $5.98 | 4 | 1 | 2 | $47.86 | | | | | | | |
| 45 | Semi-skilled | $8.38 | | | | $0.00 | | | | | | | |
| 46 | Skilled | $11.81 | | | | $0.00 | | | | | | | |
| 47 | **TOTALS** | | | | | **$47.86** | | | | | | | |

yields were set at 7,000; 7,000; 4,000; and 3,000 quarts per acre, whereas organic yields were set at 5,000; 4,000; 2,000; and 1,000 quarts per acre. (3) One hundred four hours of labor were assigned to weed the organic fields (compared to 52 hours per year for the default scenario). (4) All fruit was hand-harvested for sale and prices were set at $2.00 per quart. (5) Plants were fruited for only two years.

The break-even price for the conventional retail marketing scenario was $1.10 per quart (table 14-13), whereas the break-even price for the organic strawberries was 34% higher at $1.47 per quart (table 14-16). By the fourth bearing year, however, organic strawberries were losing money. This supports the practice of many organic growers of fruiting fields for only two years. If fields are rotated out of strawberries after two fruiting years, then a positive cash balance is obtained.

The enterprise budget for organic strawberries does not include the costs of a fallow period between cropping cycles. On the other hand, the fixed costs of both systems were set at equivalent values, even though an organic grower is likely to have less equipment (for example, no herbicide sprayer). Organic strawberry production can be as profitable as conventional production if the price differential for fruit approaches 35 to 40%.

**Table 14-15.** Highlights of SUMMARY sheet output under different "What if?" scenarios

| Variable | Default | PYO | Picked | Ribbon Row | Row Covers | Row Covers with 10% Yield Increase |
|---|---|---|---|---|---|---|
| Price | $1.40/qt | $1.00/qt | $1.80/qt | $1.40/qt | $1.45/qt | $1.45/qt |
| **Profit** | | | | | | |
| Preplant | ($736) | ($736) | ($736) | ($736) | ($736) | ($736) |
| Planting | ($2,708) | ($2,708) | ($2,708) | ($1,811) | ($2,708) | ($3,908) |
| 1st bearing | $4,567 | $1,904 | $6,578 | $6,972 | $2,928 | $5,883 |
| 2nd bearing | $4,724 | $2,061 | $6,735 | $4,724 | $4,285 | $6,040 |
| 3rd bearing | $1,463 | ($148) | $2,702 | $1,463 | $1,302 | $2,215 |
| 4th bearing | $599 | ($546) | $1,466 | $599 | $416 | $1,163 |
| Accumulated NPV | $6,346 | $(391) | $11,453 | $9,333 | $4,254 | $8,507 |
| Break-even price | $1.00 | $0.94 | $1.10 | $0.93 | $1.17 | $0.97 |

**Table 14-16.** Summary budget for an organic production and retail marketing scenario

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | *Summary for Establishing Strawberries* | | | | | | | *By Alison DeMarree and Regina Rieckenberg - Cornell Cooperative Extension - 1996* | | | | | | |
| 2 | | | | | | | | | | | | | | |
| 3 | Avg. price received per quart > | | | $2.00 | | | | Discount Rate You Would Like to Use> | | 6% | | | | |
| 4 | | | | | | | | | | | | | | |
| 5 | | Yield | Income | Variable Expenses | | | | | | | | Profit | Discounted | Accum. |
| 6 | Year | per A. | per A. | Labor | Service | Materials | Equip. | Comm | Total | Fixed | Total | or Net | Cash Flow | NPV |
| 7 | | | | | | | | Harvest | Variable | Costs | Costs | Income | | of Profit |
| 8 | Preplant | | | $38 | $0 | $125 | $31 | | $194 | $494 | $688 | ($688) | ($688) | ($688) |
| 9 | Planting Yr | 0 | $0 | $689 | $0 | $867 | $321 | $0 | $1,877 | $801 | $2,677 | ($2,677) | ($2,526) | ($3,214) |
| 10 | 1st bearing | 5,000 | $10,000 | $744 | $0 | $1,129 | $258 | $1,845 | $3,975 | $800 | $4,774 | $5,226 | $4,651 | $1,437 |
| 11 | 2nd bearing | 4,000 | $8,000 | $744 | $0 | $902 | $258 | $1,476 | $3,379 | $800 | $4,178 | $3,822 | $3,209 | $4,645 |
| 12 | 3rd bearing | 2,000 | $4,000 | $744 | $0 | $712 | $258 | $738 | $2,451 | $800 | $3,251 | $749 | $594 | $5,239 |
| 13 | 4th bearing | 1,000 | $2,000 | $744 | $0 | $592 | $258 | $369 | $1,962 | $800 | $2,762 | ($762) | ($569) | $4,670 |
| 14 | | | | | | | | | | | | | | |
| 15 | | | | Breakeven price > | | $1.47 | | | Net Establishment Costs> | | | $3,365 | | |

APPENDIX A

# *Key to Common Strawberry Pests and Problems*

*(Photo references are in parentheses.)*

## PLANTS ARE WILTING AND COLLAPSING.

### Younger Plantings

Outer leaves die first. Previous crop was potatoes or other solanaceous crop. Symptoms occur in the planting year.

▶ Verticillium *wilt (photo 9-18)*

Roots are stubby. Fat, white insect larvae can be found in the soil surrounding the roots.

▶ *Grubs (photo 8-31)*

New plants exhibit poor growth. Crowns are brown on the interior.

▶ *Storage was too cold*

New plants exhibit poor growth. Leaves were long and white at planting, then dry up.

▶ *Storage was too warm*

### Older Plantings

Roots are stubby, and reddish frass surrounds the crown. Some leaves have notches chewed in them. Small, white, legless larvae can be found around the roots.

▶ *Root weevils (photo 8-26)*

Plants collapse near harvest. Many roots are blackened,

…and cores of remaining white roots are red.

▶ *Red stele (photo 9-15)*

…and remaining white roots have black lesions on them; cores remain white.

▶ *Black root rot (photo 9-17)*

Plants exhibit poor growth in early spring. Flowering is sparse. Crown interior is brown.

▶ *Winter injury (photo 5-2)*

## LEAVES ARE COLORED, SPOTTED, OR NECROTIC.

### Leaves Appear Yellow, and Growth Is Stunted

Yellow coloration appears in interveinal areas,

…and soil pH is over 6.5.

▶ *Iron chlorosis (photo 7-10)*

…and weeds show similar symptoms. Herbicide was applied recently.

▶ *Herbicide injury (photo 10-4)*

Yellow coloration appears in veinal areas,

…and herbicide was applied recently.

▶ *Herbicide injury (photo 10-3)*

…and margins of leaves are yellow.

▶ *Leafhopper injury (photo 8-20)*

### Leaves Are Bronzed

Undersides of leaves have “cobwebs.”

▶ *Mites (photo 8-14)*

### Leaves Are Red

Plants have not been fertilized adequately.

▶ *Nitrogen deficiency (photo 7-2)*

Margins of reddish-purple, wedge-shaped areas are distinct.

▶ *Leaf scorch (photo 9-11)*

### Leaves Have Spots

Spots are angular and appear water-soaked.

▶ *Angular leaf spot (photo 9-7)*

Brown spots are circular and surrounded by a purple margin.

▶ *Leaf spot (photo 9-10)*

### Leaves Are Burned

Leaves exhibit marginal burning

…and the planting was fertilized recently.

▶ *Fertilizer burn*

…and the soil is sandy.

▶ *Potassium deficiency (photo 7-4)*

Leaves exhibit interveinal necrosis.

▶ *Herbicide injury (photo 10-4) or magnesium deficiency (photo 7-9)*

## LEAVES ARE CURLED.

### Upwards

Undersides of leaves have a whitish cast.

▶ *Powdery mildew (photo 9-13)*

Conditions have been dry and cool.

▶ *Calcium deficiency (photo 7-6)*

Young leaves near the crown are distorted.

▶ *Cyclamen mite (photo 8-17)*

### Downwards (Especially in Young Plantings)

▶ *Aphids*

## FLOWERS HAVE A BLACKENED CENTER.

▶ *Frost injury (photo 5-5)*

## FRUIT ARE NUBBY AT THE TIPS.

▶ *Tarnished plant bug (photo 8-3)*

## FRUIT ARE DETERIORATING PRIOR TO HARVEST.

### Fruit Exhibit Brown, Water-Soaked Spots and a Grayish Mold

▶ *Gray mold (photo 9-2)*

### Fruit Exhibit a Dry Rot Prior to Harvest and Have Bad Flavor

▶ *Leather rot (photo 9-4)*

### Fruit Show Sunken Black Spots after Warm, Wet Weather

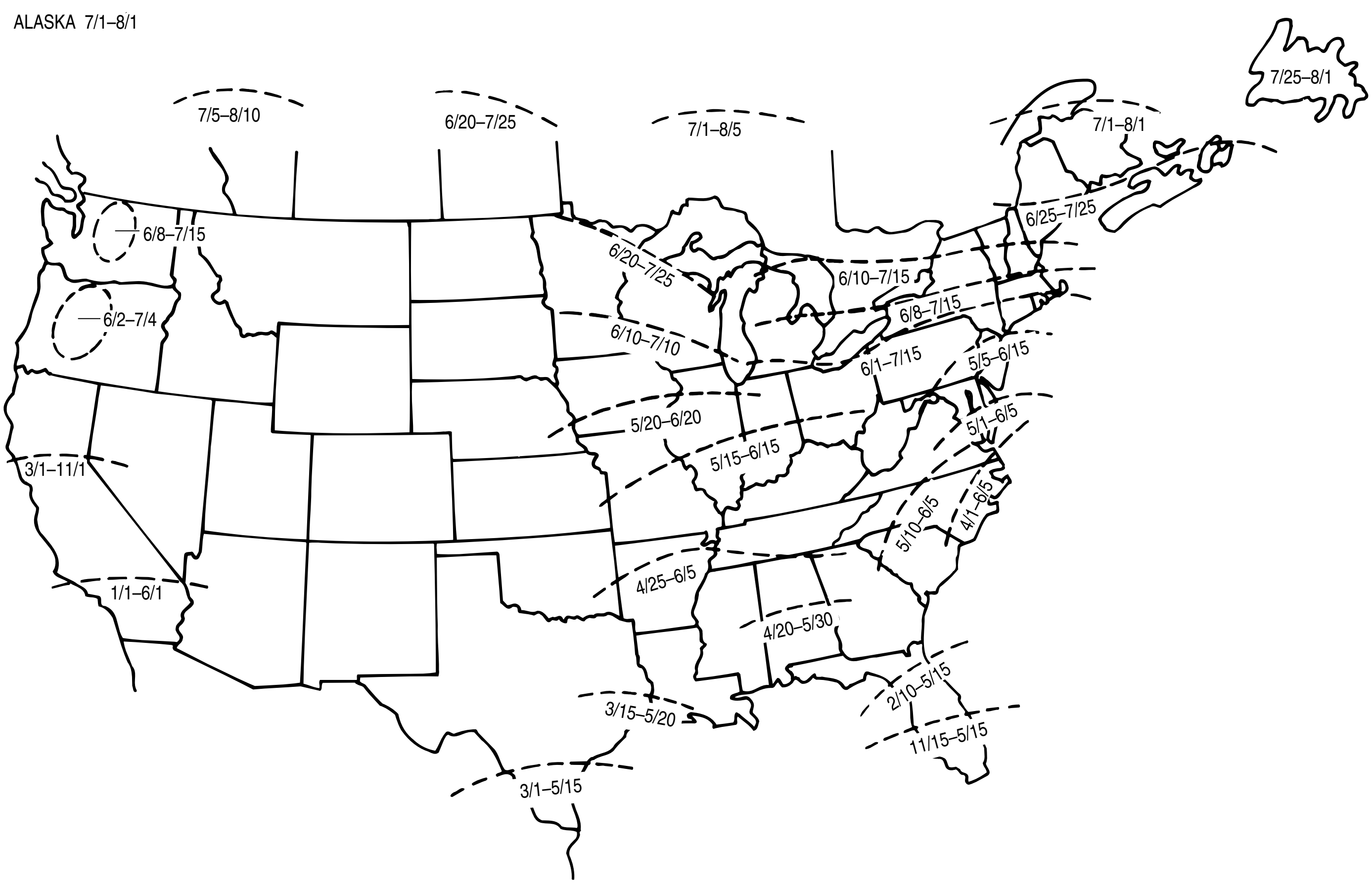
▶ *Anthracnose (photo 9-5)*

### Upper Sides of Berries Exhibit a Water-Soaked, Bleached-Out Appearance

▶ *Sunscald (photo 9-1)*

APPENDIX B

# Approximate Strawberry Ripening Seasons in the United States




*Source:* North American Strawberry Growers Association

# *Photographs*

**Photo 1-1**
Wild *Fragaria virginiana* in its native habitat
(M. Pritts)

**Photo 2-1**
Raised beds are often used for strawberries
(M. Pritts)

**Photo 2-2**
Ideal sandy loam soil
(M. Pritts)

**Photo 2-3**
Fumigation with methyl bromide-chloropicrin
(M. Pritts)

**Photo 4-1**
Dormant strawberry crowns commonly used for spring planting (D. Handley)

**Photo 4-2**
Planting with a three-row transplanter (M. Pritts)

**Photo 4-3**
Removing flowers from new plants to promote runnering (M. Pritts)

**Photo 4-4**
Runners are produced after planting under long days of summer (D. Handley)

**Photo 4-5**
Runners fill in the matted row (M. Pritts)

**Photo 4-6**
Matted rows are narrowed (M. Pritts)

**Photo 4-7**
Weeds can quickly overtake a strawberry planting
(M. Pritts)

**Photo 4-8**
Overhead irrigation often is used for strawberries
(M. Pritts)

**Photo 4-9**
Plants are mulched with straw for winter
(M. Pritts)

**Photo 4-10**
Mulch is raked into the alleyways after winter
(M. Pritts)

**Photo 4-11**
Flowers can be protected from frost with
overhead irrigation (M. Pritts)

**Photo 4-12**
Leaves are removed after harvest as part of the
renovation process (D. Handley)

**Photo 4-13**
Rows are narrowed as part of the renovation process
(D. Handley)

**Photo 4-14**
Strawberry field after renovation in late July
(D. Handley)

**Photo 4-15**
Ribbon row planting system in the first year
(M. Pritts)

**Photo 4-16**
Ribbon row system in the second year
(M. Pritts)

**Photo 4-17**
Raised beds and black plastic used for annual plasticulture
(M. Pritts)

**Photo 4-18**
Fall-planted strawberries on plastic
(M. Pritts)

**Photo 4-19**
Row covers used in a strawberry field
(F. Wiles)

**Photo 4-20**
Dayneutral planting on black plastic
(M. Pritts)

**Photo 4-21**
Dayneutral planting on white plastic
(M. Pritts)

**Photo 4-22**
Dayneutral planting mulched with straw
(M. Pritts)

**Photo 4-23**
Fruiting dayneutral plant in October
(M. Pritts)

**Photo 4-24**
Outdoor vertical growing system
(M. Pritts)

**Photo 4-25**
Plastic tunnels over strawberries
(M. Pritts)

**Photo 4-26**
Greenhouse culture
(M. Pritts)

**Photo 4-27**
Tristar in the greenhouse
(M. Pritts)

**Photo 4-28**
Strawberry production in peat bags
(M. Pritts)


**Photo 4-29**
Bumble bee hive in the greenhouse
(M. Pritts)

**Photo 5-1**
Mild winter injury to crown
(M. Pritts)


**Photo 5-2**
Severe winter injury to crown
(B. Boyce)

**Photo 5-3**
Mulcher spreading straw from round bales
(M. Pritts)

**Photo 5-4**
Field in spring with row cover applied
(F. Wiles)

**Photo 5-5**
Frost injury (left) to a strawberry flower
(M. Pritts)

**Photo 6-1**
Standard overhead irrigation nozzle and riser for strawberries
(D. Handley)

**Photo 6-2**
Guttation in a strawberry leaf
(M. Pritts)


**Photo 7-1**
Nitrogen deficiency in a leaf
(G. May)

**Photo 7-2**
Nitrogen deficiency in a field
(G. May)

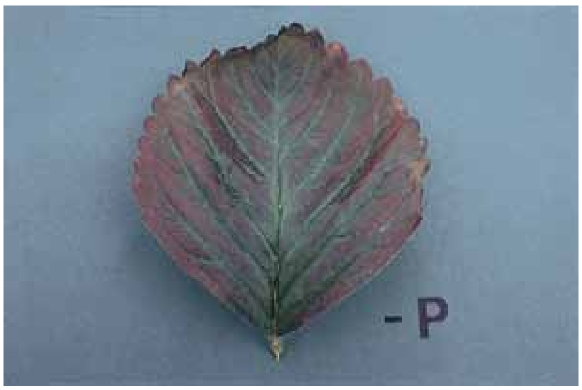



**Photo 7-3**
Phosphorus deficiency
(G. May)

**Photo 7-4**
Potassium deficiency
(G. May)

**Photo 7-5**
Sulfur deficiency
(G. May)

**Photo 7-6**
Mild calcium deficiency in a leaf
(G. May)

**Photo 7-7**
Severe calcium deficiency in a leaf
(G. May)

**Photo 7-8**
Calcium deficiency in a runner
(G. May)


**Photo 7-9**
Magnesium deficiency
(G. May)

**Photo 7-10**
Iron deficiency
(G. May)

**Photo 7-11**
Root system with adequate boron
(G. May)

**Photo 7-12**
Root system without adequate boron
(G. May)


**Photo 7-13**
Asymmetrical leaf growth without adequate boron
(G. May)

**Photo 7-14**
Boron deficiency symptoms in fruit
(G. May)

**Photo 8-1**
Tarnished plant bug adult
(NYSAES)

**Photo 8-2**
Tarnished plant bug nymph
(NYSAES)

**Photo 8-3**
Damage from tarnished plant bug
(NYSAES)

**Photo 8-4**
Strawberry clipper adult
(NYSAES)

**Photo 8-5**
Strawberry clipper damage
(D. Handley)

**Photo 8-6**
Strawberry sap beetle larva
(R. Williams)

**Photo 8-7**
Strawberry sap beetle adult
(R. Williams)

**Photo 8-8**
Sap beetle adult
(NYSAES)

**Photo 8-9**
Thrips damage to fruit
(D. Handley)

**Photo 8-10**
Slug damage
(J. Dill)

**Photo 8-11**
Bird damage to fruit
(A. Wise)

**Photo 8-12**
Strawberry leaf roller
(J. Dill)

**Photo 8-13**
Two-spotted spider mites
(NYSAES)

**Photo 8-14**
Mite damage to leaf
(D. Handley)

**Photo 8-15**
Beneficial predatory mite
(J. Nyrop)

**Photo 8-16**
Cyclamen mite
(NYSAES)

**Photo 8-17**
Cyclamen mite damage
(D. Handley)

**Photo 8-18**
Aphids
(J. Dill)

**Photo 8-19**
The ladybird beetle larva is a predator on aphids
(NYSAES)

**Photo 8-20**
Leafhopper damage
(M. Pritts)

**Photo 8-21**
Leafhopper adult
(J. Dill)

**Photo 8-22**
Spittlebug mass and nymphs
(R. Williams)

**Photo 8-23**
Spittlebug adult
(NYSAES)

**Photo 8-24**
Cutworms
(J. Dill)

**Photo 8-25**
Strawberry rootworm adult
(J. Dill)

**Photo 8-26**
Root weevil adult
(D. Handley)

**Photo 8-27**
Root weevil larva
(M. Pritts)

**Photo 8-28**
Root weevil damage to planting
(M. Pritts)

**Photo 8-29**
Japanese beetle adult
(NYSAES)

**Photo 8-30**
Rose chafer adult
(NYSAES)

**Photo 8-31**
June beetle adult and larva
(J. Dill)

**Photo 9-1**
Sunscald on fruit
(D. Handley)

**Photo 9-2**
Later stage of gray mold on fruit
(M. Pritts)

**Photo 9-3**
Early stage of gray mold on fruit
(M. Pritts)

**Photo 9-4**
Leather rot
(W. Wilcox)

**Photo 9-5**
Fruit anthracnose
(M. Ellis)

**Photo 9-6**
Green petal MLO
(D. Handley)

**Photo 9-7**
Angular leaf spot on bottom of leaf
(M. Ellis)

**Photo 9-8**
Translucent leaf spots from top of leaf
(J. Maas)

**Photo 9-9**
Calyx affected with angular leaf spot
(M. Ellis)

**Photo 9-10**
Leaf spot
(M. Pritts)

**Photo 9-11**
Leaf scorch
(M. Ellis)

**Photo 9-12**
Leaf blight
(M. Ellis)

**Photo 9-13**
Powdery mildew
(M. Pritts)

**Photo 9-14**
Varietal differences in susceptibility to red stele
(M. Pritts)

**Photo 9-15**
Root showing red stele symptoms
(D. Handley)

**Photo 9-16**
Field infested with black root rot
(K. Wing)

**Photo 9-17**
Root showing black root rot lesions
(K. Wing)

**Photo 9-18**
*Verticillium* wilt
(M. Ellis)

**Photo 9-19**
Root lesion nematode
(J. Potter)

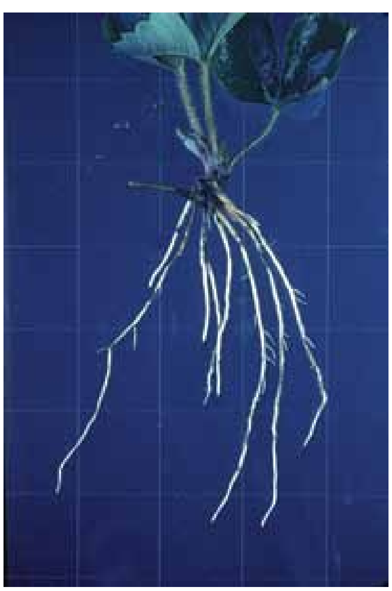


**Photo 9-20**
Root showing lesions
(J. Potter)

**Photo 10-1**
Flex-tine cultivator in a new strawberry planting
(M. Pritts)

**Photo 10-2**
Finger weeder
(D. Handley)

**Photo 10-3**
Injury from terbacil (Sinbar)
(M. Pritts)

**Photo 10-4**
Injury from glyphosate (Roundup)
(M. Pritts)

**Photo 10-5**
Ribbon row in killed sod
(M. Pritts)

**Photo 10-6**
Interplanted sudan grass in a matted row planting
(M. Pritts)

**Photo 12-1**
Clear polystyrene clamshell containers
(M. Pritts)

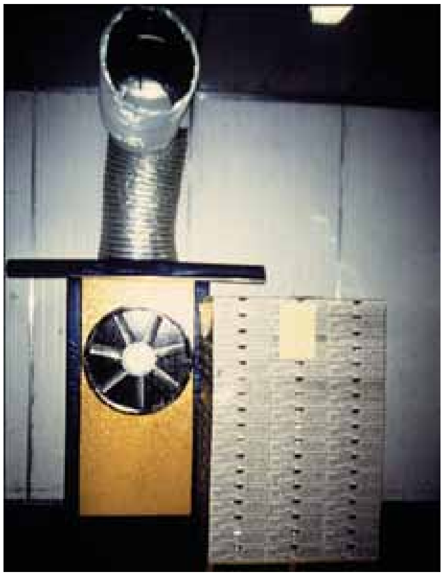


**Photo 12-2**
Forced air cooling unit
(C. Watkins)

**Photo 13-1**
Pick-your-own strawberry operation
(M. Pritts)


**Photo 13-2**
Rural farm market
(M. Pritts)

# Glossary

**Achene** — the hard, dry seed on the surface of a strawberry fruit

**Adventitious Roots** — roots that arise from the crown and serve as primary roots

**Annual** — a plant that completes its life cycle (vegetative growth, flower, and seed) in only one year

**Anthesis** — the time at which a flower is at full bloom and the pollen is shed

**Auxins** — one of several classes of plant hormones that regulate plant growth, particularly through cell enlargement

**Axil** — the point at which a leaf or branch is attached to the main stem

**Axillary Bud** — a bud that develops in the axil of a plant

**Bract** — a modified, reduced leaf associated with the flower

**Branch Crown** — a crown that arises in the axil of an older crown

**Buffering Capacity** — the ability of a substance to remain stable and resist change

**Calyx** — the lowermost whorl of a flower, usually consisting of modified, reduced leaves

**Chelate** — an organic molecule that forms an association with a metal ion

**Chlorosis** — a yellow color that develops in a green leaf

**Cross Pollination** — pollination of the flower of one variety with the pollen of a different variety

**Crown** — the short stem of a strawberry plant from which the leaves and roots originate

**Cull** — an unmarketable fruit that is usually discarded or used for processing

**Cultivar** — scientific term for a *cultivated variety*

**Cuticle** — the waxy layer on the surface of a leaf or fruit

**Dayneutral** — a plant that does not respond developmentally to the length of the day

**Desiccation** — the process of drying or losing water

**Dewpoint** — the temperature at which water condenses from the atmosphere, usually in the form of dew

**Diffusion** — the movement of nutrients from an area of high concentration outside the roots to an area of lower concentration inside the roots

**Dioecious** — describes plants that exist separately as males and females

**Endosperm** — embryonic tissue in the seed that serves as a food source for the embryo

**Epidermis** — the outside covering or skin of a leaf or fruit

**Evaporative Cooling** — the drop in temperature experienced when water evaporates from an object

**Exchange Site** — a site on a soil particle where positively charged ions can attach themselves and replace each other

**Fertigation** — the delivery of nutrients using an irrigation system

**Frass** — plant residues or fecal material that remains after insect feeding

**Guttation** — the process by which water is exuded from pores in leaves under moist soil conditions

**Hybrid** — a plant having parents of different species

**Hydrometer** — a device that measures the specific gravity (density) of a liquid

**Hydroponics** — growing plants in a water medium rather than a soil-based medium

**Inflorescence** — a flower cluster

**Instar** — a stage in the development of an insect between molts

**Lateral Roots** — roots that originate from the primary roots

**Mass Flow** — the movement of dissolved nutrients into roots through water uptake

**Micronutrient** — an essential plant nutrient that is required only in small quantities

**Necrosis** — the death of plant cells

**Nitrogen Drag** — the temporary unavailability of nitrogen that results from increased biological activity in the soil

**Node** — the point of branching of a stem

**Peduncle** — a flower stalk

**Perennial** — a plant that flowers and fruits in consecutive years

**Petiole** — the stalk of a leaf

**Phytotoxicity** — the process of plant death caused by an externally applied material

**Pick-Your-Own (PYO)** — description of a marketing strategy in which customers harvest their own fruit

**Pistil** — the female reproductive organ of a flower

**Plasticulture** — the process of growing strawberries on top of a plastic mulch

**Protected Cultivation** — the process of growing strawberries under plastic, glass, or other protective covering

**Receptacle** — the portion of the flower to which the flower parts attach

**Riparian Rights** — legal criterion for determining who has access to a flowing body of water

**Salt Index** — a relative measure of the ability of a chemical substance to disassociate at the molecular level and behave as a salt

**Sepal** — the outermost parts of a flower that enclose the bud

**Setae** — bristle-like parts or organs of an insect

**Stamen** — the pollen-producing part of a flower

**Stigma** — the female portion of a flower upon which the pollen germinates

**Stolon** — an aerial stem or runner

**Stomata** — the specialized structures on leaves through which carbon dioxide enters and water vapor exits

**Tensiometer** — a device used to measure the dryness of a particular soil

**Threshold** — a predetermined level below which no response occurs

**Tissue Culture** — the propagation of whole plants from single cells or growing points, usually under laboratory conditions

# *Table of Conversions*

| | To Convert This: | To This: | Multiply by This: |
|---|---|---|---|
| **Weight/Volume** | quarts (fruit) | pounds | 1.5 |
| | pints (fruit) | quarts | 0.5 |
| | pints (fruit) | pounds | 0.75 |
| | pounds | kilograms | 0.454 |
| | ounces | grams | 28.35 |
| | quarts | liters | 0.946 |
| | gallons | liters | 3.78 |
| | gallons (water) | pounds | 8.34 |
| | pounds (water) | gallons | 0.12 |
| | tons (English) | pounds | 2,000 |
| | tons (English) | tons (metric) | 0.907 |
| **Area** | acres | hectares | 0.405 |
| | acres | square feet | 43,560 |
| | acres | square yards | 4,840 |
| | square miles | acres | 640 |
| **Length** | inches | centimeters | 2.54 |
| | feet | meters | 0.305 |
| | yards | meters | 0.915 |
| | miles | kilometers | 1.6 |
| **Pressure** | pounds per square inch (psi) | bar | 0.069 |
| | pounds per square inch (psi) | kilopascal (KPa) | 6.895 |
| **Rate** | pounds per acre | kilograms per hectare | 1.12 |
| | miles per hour (mph) | feet per second | 1.47 |
| | miles per hour (mph) | kilometers per hour | 1.6 |

**Temperature** ˚C = 5⁄9 (˚F – 32)

# Suggested Readings

## Publications from NRAES

### *About NRAES*

NRAES, the Northeast Regional Agricultural Engineering Service, is a program focused on delivering engineering-related educational materials and training opportunities in support of northeast cooperative extension. All NRAES activities are guided by faculty members from northeast land grant universities. NRAES began in 1974 through an agreement among the cooperative extension programs in the Northeast. The program is guided by the NRAES Committee, which consists of a representative from each northeast state and the District of Columbia as well as the NRAES director and an administrative liaison appointed by the Northeast Cooperative Extension Directors Committee. NRAES is housed in the Department of Agricultural and Biological Engineering at Cornell University. Office hours are Monday through Thursday, 8:00 A.M. to 5:00 P.M., and Friday, 8:00 A.M. to 2:30 P.M., eastern time.

### *Ordering Information*

Publications can be ordered from NRAES. Before ordering, please contact NRAES for current prices and exact shipping and handling charges. NRAES has many other publications that are not listed here; call for a free copy of our publications catalog.

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Phone: (607) 255-7654
Fax: (607) 254-8770
E-mail: NRAES@CORNELL.EDU
Web site: WWW.NRAES.ORG

### *General Agriculture Publications*

*Farm Machinery Days for Small and Part-Time Farmers,* NRAES–45
Small farmers are often at an economic disadvantage when it comes to machinery. A number of options are available to those who wish to overcome competitive disadvantages such as small cash flows and production levels. This publication discusses these options and outlines methods to help reduce machinery costs. Ten papers are included. Published in 1990. *55 pages*

*Farming Alternatives: A Guide to Evaluating the Feasibility of New Farm-Based Enterprises,* NRAES–32
This book assists rural and farm residents who are considering alternative enterprises. The case study and workbook format helps in evaluating personal and family considerations, resources, market potential, production feasibility, profitability, cash flow, and all factors combined. Each chapter includes exercises, self-tests, checklists, and worksheets that allow the reader to analyze an enterprise idea. Published in 1988. *88 pages*

*Farming Alternatives: Innovation on Northeast Farms,* NRAES–28 (VIDEO)
Alternative farm-based enterprises such as deer farms, bed and breakfast inns, and herb gardens are explored in this VHS color video. Produced in 1988. *14 minutes*

*Used Farm Equipment: Assessing Quality, Safety, and Economics,* NRAES–25
This handbook shows the buyer how to inspect machinery for the reliability of its components and the quality of its safety features. The economics of owning and operating used machinery are covered, and methods of acquiring equipment are discussed. Published in 1987. *34 pages*

## Agrichemical Handling Publications

*Designing Facilities for Pesticide and Fertilizer Containment,* MWPS–37
This handbook compiles the best available information on storing, handling, and using agricultural pesticides and fertilizers. Chapters cover topics such as laws, site selection, functional system design, worker safety, storage, secondary containment, emergency response planning, rinsate management and waste disposal, and facility maintenance. Published in 1991. *113 pages*

*Fertilizer and Manure Application Equipment,* NRAES–57
This publication discusses fertilizer and manure nutrient values and provides guidance on equipment selection. Procedures for calibrating fertilizer and manure application equipment are reviewed. Also included are over thirty illustrations, six tables, a plan for a fertilizer storage shed, and a glossary. Published in 1994. *22 pages*

*Hydraulic Nozzles for Boom Sprayers,* FS–38
This factsheet describes the seven commonly used nozzles on boom sprayers: regular flat fan, even flat fan, hollow cone, solid (full) cone, flooding fan, Turbo Floodjet™, and twin fan. Nozzle spacing, directed spraying, and band spraying are described, and a procedure for checking the spray pattern is included. Published in 1994. *6 pages*

*On-Farm Agrichemical Handling Facilities,* NRAES–78
This publication discussed considerations regarding agrichemical storage, principal parts of the facility, storage environmental requirements, safety requirements, and storage alternatives. Included are two appendixes: one is a plan for a post-frame chemical storage building and another is a list of companies that distribute equipment for storage or containment of chemicals. Published in 1995. *22 pages*

*Orchard Spraying: Getting Results,* FS–37
This factsheet is a guide to calibrating air blast sprayers. It includes sections on precalibration checks, field calibration, travel speed, pressure checks, nozzle output, calculating application rates, correcting sprayer output, field checks, and application tips. The use of calibration equipment and procedures is illustrated, and equations necessary for calibration are included. Published in 1993. *4 pages*

*Pesticide Sprayers for Small Farms,* MD–317
This publication helps the small farmer make informed decisions about pesticide application equipment. Topics discussed include types of sprayers, sprayer parts, calibration, and cleaning and maintenance. Appendixes cover pesticide mixing, safety guidelines, and drift control. Published in 1987. *24 pages*

*Pesticides and Groundwater: A Guide for the Pesticide User,* NRAES–34
This publication is for pesticide users and rural residents concerned about protecting groundwater. Chapter titles are: Groundwater, Pesticides in the Environment, Applicator Practices, and Health Effects of Groundwater Contamination. This edition contains a 10-page table of U.S. Environmental Protection Agency (EPA) drinking water contaminants found in pesticide products. Revised in 1995. *26 pages*

## Fruit and Vegetable Production Publications

*Apple Harvesting, Handling, and Storage,* NRAES–112
This is the proceedings from a workshop held in August 1997 at Cornell University. Ten papers are included that discuss the following topics: management of Gala, Braeburn, and Fuji for quality; Retain™; current issues facing Washington State growers; calibration and use of penetrometers, refractometers, gas monitoring equipment, and thermometers; cooling needs for rapid CA storage; changing options for controlling postharvest decay; selling fruit for fresh or processing markets; calcium and DPA research; and fresh and minimally processed produce and food safety. Published in 1997. *84 pages*

*Bramble Production Guide,* NRAES–35
This guide provides detailed information about all aspects of bramble production for both potential and established growers. Topics discussed include site selection and preparation, plant selection, pruning and trellising, pest and disease management, spray technology, harvesting and handling, and marketing. The guide contains over 115 color photos, a glossary, and a disease diagnostic key. Published in 1989. *189 pages*

*The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks,* USDA–66
The goal of fruit, vegetable, and cut flower storage is to provide an environment that minimizes deterioration until the final steps in marketing. General topics such as quality, precooling, relative humidity, respiration rates, and supplements to refrigeration are covered in the first section of this book. Subsequent sections cover optimum storage conditions for specific commodities. Published in 1986. *130 pages*

*Facilities for Roadside Markets,* NRAES–52
This publication is for persons considering a roadside market or looking to improve or expand an existing one. Chapters cover site considerations (visibility and accessibility, utilities, drainage, zoning, and building ordinances); market layout (areas for sales, preparation, and shipping and receiving); and market structure and facilities (parking, lighting, fire protection, security, and more). Also included are twenty-six illustrations, four tables, and two sets of plans. Published in 1992. *32 pages*

*Highbush Blueberry Production Guide,* NRAES–55
This book is the first comprehensive resource for blueberry growers and their advisors. It covers all aspects of blueberry production, including site selection and preparation, plant selection, blueberry growth and development, maintenance, pest management, harvesting, and marketing. Topics that other fruit-production guides rarely address, such as nuisance wildlife management, water management, spray technology, and budgeting, are discussed as well. The guide features 168 full-color photos, 27 tables, 24 figures and charts, and a key to problems. Published in 1992. *200 pages*

*Implementing Pheromone Technology in the Northeast,* NRAES–83
The importance of pheromones for pest surveying and management has grown stronger over the years. This publication includes nine papers that contain benchmark information about the use of pheromones. Current pheromone technology is discussed, including the types of pheromone traps and lures, pheromone-mediated mating disruption, and commercial applications. Also discussed is how pheromones are used in the many crops and commodities of the Northeast. Published in 1996. *65 pages*

*Mid-Atlantic Orchard Monitoring Guide,* NRAES–75
This comprehensive, regional guide provides the background and instruction necessary for an effective orchard monitoring program. The guide will help fruit growers, consultants, chemical field representatives, and extension personnel manage the complex agroecosystem of an orchard. Early sections provide background information on the production components for which monitoring is essential. Later sections focus on developing a monitoring plan and schedule. This user-friendly guide features 13 chapters, 18 appendixes, 322 full-color photos, 13 figures, 26 tables, and a glossary. Published in 1995. *361 pages*

*Produce Handling for Direct Marketing,* NRAES–51
This publication is valuable for growers who sell seasonal produce at local farmers' markets or roadside markets. It describes postharvest physiology, food safety, produce handling from harvest to storage, refrigerated storage, produce displays, and specific handling and display recommendations for over 40 types of fruits and vegetables. Published in 1992. *26 pages*

*Refrigeration and Controlled Atmosphere Storage for Horticultural Crops,* NRAES–22
General construction procedures for storage facilities are discussed in this handbook, such as site selection, structural considerations, thermal insulation, vapor barriers, and attic ventilation. Different refrigeration systems are explained, including operating procedures. Storage construction, testing, and operation are also discussed, especially in relation to apple storage. Published in 1990. *44 pages*

*Trickle Irrigation in the Eastern United States,* NRAES–4
While the eastern United States generally receives adequate rainfall, enough moisture may not be present at critical stages of plant growth. This handbook was developed for humid climates and is an excellent planning and installation guide for growers considering a trickle irrigation system. Information is provided on plant-soil-water relationships, system components, specific crop recommendations, and system planning. Two appendixes cover designing laterals and submains and preventing line clogging. Published in 1985. *24 pages*

## Greenhouse Publications

*Greenhouse Engineering,* NRAES–33
This manual contains current information needed to plan, construct, and control the commercial greenhouse. Major sections describe various structures, methods of materials handling, the greenhouse environment, and energy conservation. Other topics include plans for noncommercial greenhouses, access for the handicapped, and remodeling existing greenhouses. A large appendix includes conversion tables, worksheets for performing calculations, and sources of greenhouse construction materials and contractors. Published in 1994. *212 pages*

*Water and Nutrient Management for Greenhouses,* NRAES–56
This publication will help greenhouse managers learn skills essential to managing a greenhouse for zero runoff. The book begins with discussions on general crop needs, balancing nutrient applications with crop demand, and units used in measuring fertilizer quantities. Subsequent chapters go into more detail about specific components of the root zone: water, fertilizer, substrate, temperature, and the biotic environment. How to use a fertilizer proportioner and the features of a well-designed water and nutrient delivery system are also discussed. Published in 1996. *110 pages*

## Other Publications of Interest

*Home*A*Syst: An Environmental Risk-Assessment Guide for the Home,* NRAES–87
This publication is designed to help homeowners in rural and suburban areas assess their homes and properties for pollution and health risks. The eleven chapters cover site assessment, stormwater management, drinking water well management, household wastewater, hazardous household products, lead sources and management, yard and garden care, liquid fuels management, indoor air quality, heating and cooling systems, and household waste management. Each chapter provides tables of assessment questions to help readers evaluate their own situations and management practices. Published in 1997. *122 pages*

*On-Farm Composting Handbook,* NRAES–54
This handbook presents a thorough overview of farm-scale composting and explains how to produce, use, and market compost. Topics covered include benefits and drawbacks of composting, the composting process, raw materials, methods, operations, management, site and environmental considerations, using compost, marketing compost, economics, and other options for waste management. Also included are 55 figures, 32 tables, calculations, and a glossary. Published in 1992. *186 pages*

*Private Water Systems Handbook,* MWPS–14
Topics covered in this book include water system design, correcting problems in existing systems, water quality and quantity, water sources, pumps, pressure tanks, piping, and water treatment. Published in 1979. *72 pages*

## Publications from Cornell Cooperative Extension

### *Ordering Information*

The publications listed here are available from the Cornell University Resource Center. Before ordering, contact the resource center for current prices and shipping and handling costs. A complete publications catalog is available.

Cornell University Resource Center
7 Business and Technology Park
Ithaca, New York 14850
Phone: (607) 255-2080
Fax: (607) 255-9946
E-mail: Dist_Center@cce.cornell.edu
Web site: www.cce.cornell.edu/publications

### *Publications*

*Dayneutral Strawberry Production Guide*
This publication will help serious hobbyists and commercial growers make the most of this recently developed cultivar. Plants flower and fruit continuously, yielding fresh strawberries throughout the summer and into October. Publication number 155IB215. Published in 1989. *9 pages*

*Integrated Pest Management in Strawberries* (VIDEO)
Weed, insect, and disease control practices are covered in this videocassette, with special emphasis on control strategies for tarnished plant bug, strawberry bud weevil, two-spotted spider mite, and *Botrytis* food rot. Produced in 1992 by the Minnesota Department of Agriculture. *17 minutes*

*Strawberry IPM Scouting Procedures: A Guide to Sampling for Common Pests*
This publication is useful anywhere strawberries are grown. The scouting methods can be applied anywhere to achieve IPM goals of reducing the use of chemical pesticides to the minimum level necessary to produce high-quality food and produce that will be competitive in the marketplace. Included are factsheets with color pictures of pests and other problems, including *Botrytis* fruit rot. Publication number 102IPM203. Published in 1993. *33 pages plus charts*

# An Invitation to Join

The North American Strawberry Growers Association (NASGA) was organized in 1977 by a group of progressive strawberry growers and leading small fruit researchers. Its purpose was to support U.S. Department of Agriculture and state research programs; develop educational seminars and publications; promote the development of equipment, varieties, and cultural methods; and ultimately improve the efficiency of the strawberry industry. This includes supporting grower-applied research and promoting beneficial legislation. In 1980, NASGA was incorporated as a not-for-profit corporation.

Today, NASGA represents members in forty states, ten Canadian provinces, and fifteen countries. NASGA continues to be a grower-based association strongly rooted in the original philosophy that ongoing research will provide knowledge to strengthen and improve strawberry production and marketing. To accomplish this mission, NASGA:

- commits 25% of dues to research. To date, NASGA has granted over $360,000 to research.
- publishes the annual journal *Advances in Strawberry Research,* a compilation of selected completed research projects. The journal is purchased by libraries worldwide.
- formed the NASGA Research Foundation in 1993 to generate increased funds for research. To date, the foundation has granted a total of more than $150,000. It is a C3E-class foundation that provides tax-deductible receipts for contributions.
- sponsors an educational winter annual meeting focusing on production and marketing information. This three-day conference is held in a different region of North America each year, usually in February.
- publishes an annual proceedings.
- publishes a newsletter five times per year that is focused on production and marketing information.
- supports issues critical to the well-being of strawberry growers through an active legislative committee.
- creates marketing aids, such as informational brochures, strawberry gift products for resale, a manual on conducting blossom tours, etc. These are popular with members who retail directly to consumers.
- published a strawberry cookbook that has national distribution through bookstores and is available to any strawberry grower who markets through a roadside market or pick-your-own.

Membership dues are:

- Full membership: $175 for farms, nurseries, suppliers, and consultants. This full membership includes our newsletter (published five times per year), the *Advances in Strawberry Research* journal, the proceedings from and attendance at our educational conference, and voting privileges at our annual meeting.
- Associate membership: $55 for professionals, students, and associate members. Associate members can be other people interested in strawberries who don't fit one of the categories described under the full membership or a grower who is interested in commercial strawberry production. Associate members receive our newsletter.

For more information, please contact NASGA at Box 923, Niagara Falls, New York 14302, or call Bob or Donna Cobbledick at (905) 945-9057 [fax (905) 945-8643]. Or visit their web site at <http://www.fvs.cornell.edu/GrowerOrganizations/NASGA/WELCOME.HTM>.

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