COMMERCIAL STRAWBERRY FIELD PRODUCTION IN TEXAS

Texas A&M AgriLife Extension

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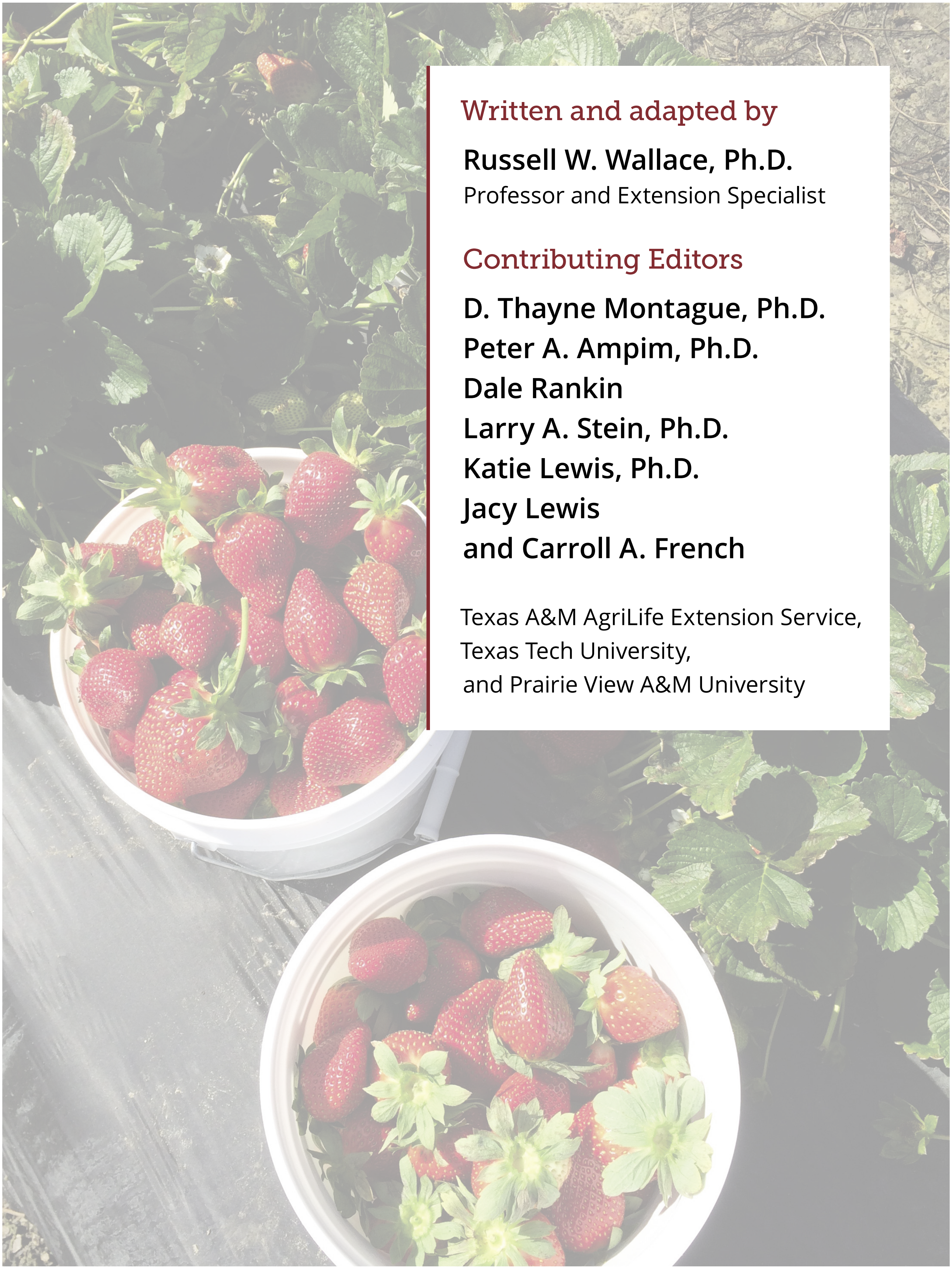

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Foreword

In the year 2024, strawberry production celebrates its sesquicentennial anniversary. For 150 years strawberries have been grown in the state by generations of growers who have supplied customers with locally grown, deliciously sweet, healthy fruit. While there have been many challenges due to regional diversity in soils and climates, Texas growers have always met the challenges. Over the past century, recommendations for Texas strawberry production have changed significantly, even in the past 10 years. This guide's goal is to provide updated information for current and future strawberry growers to meet the challenges of strawberry production statewide.

In 1884, Mr. Harrison Tone, President of the North Texas Horticulture Society, delivered an address to the society which stated in part the following:

> *The first setting of plants [in Texas] … was made in [1874]. It was an insignificant affair; only one acre in extent, and the experimenters were laughed at as engaged in a chimerical scheme. It was a tradition as old as the oldest inhabitant, that strawberries would not grow in this climate. The rain was too wet, and the air was too dry; the sun was too hot, and the northers were too cold.*
>
> *In short, there were a hundred reasons why the experiment was bound to be a failure, for strawberries just wouldn't grow. But the experimenters went on, and from the results reached by them, others were induced to enter the field, and now Denison strawberries are known from the gulf to the mountains.*

Published in *The Sunday Gazetteer, Vol. 2, No. 4, Ed. 1, Sunday, May 18, 1884, Page 2*.

For Texas Strawberry Growers

About This Guide

This new guide is updated in part from the Texas A&M AgriLife Extension 2014 Publication EHT-047 titled *Production Guide for Texas-Grown Strawberries*, 41 pages. The 2014 guide had multiple chapter authors. This guide includes new research and recommendations gathered since 2014. This information comes from trials funded by the United States Department of Agriculture Sustainable Agriculture Research and Education program (2016 to 2018) and three Texas Department of Agriculture Specialty Crops Block Program Grants (2018 to 2024). Collaboration on this project involved specialists and faculty with Texas A&M AgriLife Extension Service (2014 to 2024), Texas Tech University (2018 to 2024), Prairie View A&M University (2014 to 2024), and the University of Arkansas (2015 to 2018), as well as Texas A&M AgriLife Extension Service county agents. Multiple Texas growers also collaborated on this project.

Pesticides and other products mentioned herein do not indicate a recommendation but are used solely as references. Always read and follow pesticide labels.

Special thanks to the Texas Department of Agriculture and the Specialty Crops Block Program for funding the publication of this guide.

Photo credits: Russell Wallace, unless otherwise identified

For more information about growing strawberries, contact your local county Texas A&M AgriLife Extension Service office.

Introduction

Fresh strawberries are very popular with Texas consumers and throughout the United States (US). In 2021, fresh strawberries in the US were harvested from 43,400 acres (National Agricultural Statistics Service [NASS], 2021). According to a Texas 2017 NASS census, there were 122 farms growing strawberries on 126 acres in 45 counties (NASS, 2021). In that census, 15.5 percent of growers withheld their information to avoid disclosing individual data for their farm, or as is common in Texas, they produced strawberries on less than 1 acre. Today, the main strawberry-growing region is in Atascosa County with between 40 to 45 growers (Poteet Strawberry Growers Association). Texas A&M AgriLife Extension estimates that between 350 to 400 acres of strawberries are grown in the state today.

Strawberries are a healthy alternative to most snacks. One cup of strawberries equals 3 grams of fiber but contains only 45 to 55 calories, making them popular with health-conscious consumers. Since 2000, annual US strawberry consumption increased from 4.9 pounds to 8.5 pounds per capita. Increased consumption reflects the growing popularity of strawberries, suggesting a significant and viable market for Texas-grown berries.

Before spending significant money growing strawberries, especially for first-time growers, it is critical to understand the details of production, including reading this guide and discussing production with local county agents and specialists. There is a wide range of soils and climates in Texas that may be either conducive or detrimental to strawberry production—it is critical to understand this.

When strawberry production is managed correctly and efficiently, growers have the potential for high annual profits. Based on the author's experience, strawberries can be difficult to grow in regions where soil and climate are challenging, for instance, in the High Plains, West Texas, or Lower Rio Grande Valley. However, with careful attention, it is possible and can be done profitably. It is important for new growers to understand that strawberry production requires high labor demands, especially during planting and harvesting. Other challenges in production that impact profitability include controlling economically damaging pests.

This guide was written for Texas growers as a reference to help increase the potential for success in strawberry production. Due to the lack of funding and other priorities, strawberry research in Texas was limited between the 1970s and 2010. However, with renewed interest and funding, Texas A&M AgriLife Extension specialists, county agents, researchers, and collaborating growers have conducted trials across the state, and thus, new information is included in this guide.

Topics in this guide include strawberry biology, plasticulture, variety selection, pest and weed management, irrigation, soil salinity and pH, fertilization management, plant stress, organic production, harvesting and storage, and marketing strategies.

Collaborators for this guide include research and Extension specialists from institutions of Texas A&M AgriLife Extension and Research, Prairie View A&M University, and Texas Tech University. The information provided is the result of over a decade of research from funding provided by the United States Department of Agriculture (USDA; 2010 to 2013), the University of Arkansas National Strawberry Sustainability Initiative (2013 to 2014), the Sustainable Agriculture Research and Education (SARE) program (2016 to 2018), and three Texas Department of Agriculture (TDA) Specialty Crops Block Grants (2018 to 2024).

Growing Strawberries

The consumption of fresh strawberries continues to increase. Strawberries are popular and grown on many small farms, primarily for fresh market retail or U-pick sales. They can be very profitable when grown near urban centers and can be an excellent lead-in crop for summer vegetable sales. However, production costs are higher than many crops, ranging in Texas from $5,000 to $40,000 per acre. With the average number of plants at 17,000 per acre and current retail sales at $3.50 per pound, high profits are achievable. However, in Texas, average berry yields range between 0.5 to 1.5 pounds per plant, but higher yields can be reached. Yields higher than 1 pound are considered profitable.

As of 2024, Texas strawberry production is estimated at 350 to 400 acres, with the highest concentration of growers located in Atascosa County. This is up approximately 300 percent from 2010. California and Florida lead the country with an estimated 40,000 and 9,000 acres, respectively. While Texas will never compete for a national market, local retail sales are important to Texas consumers and local economies. Locally grown strawberries are considered to taste superior to imported products.

Interested growers should do considerable research prior to their first planting. Investing in land and equipment can be expensive, especially for first-time strawberry growers. Before investing large amounts of time and money, growers should contact Texas A&M AgriLife Extension Specialists, county agents, and other growers and discuss options with Risk Management Specialists to determine their options and regional market potential.

Questions For Growers Considering Commercial Strawberry Production

What production options are there for strawberries?

Options include producing field-grown strawberries on plastic mulch or bare ground, using conventional or organic production, open-field or low- or high-tunnel production, and greenhouse and/or hydroponic production. In Texas, most strawberries are grown as annual crops.

What type of equipment is needed?

Equipment needed for specific production systems can be expensive and should be researched thoroughly before purchasing. Considerations should include equipment for bed shaping, laying plastic mulch, and sprayers to control pests. Wildlife can be a severe problem in strawberries as animals can feed on the leaves, flowers, and fruits and defecate in fields. If deer, raccoons, and rodents are in nearby fields, growers should prepare a wildlife control plan before planting.

What about the soil and climate in my region?

Strawberries prefer cooler seasonal temperatures for optimal growth. High winds, saline and high-pH soils, and hot springtime temperatures may limit strawberry production; however, their effects can be reduced with some effort. Plasticulture, row covers, and shading can reduce the effects of freezing and hot temperatures, which damage the crop.

What about water and fertilization?

Strawberry production requires an ample supply of high-quality water, and the crop may need irrigation several times weekly during harvesting and hot temperatures. It is always best to have your water sampled for salts and pH before planting. Water may need to be treated if it is unsuitable for strawberry production. Some strawberry cultivars require more nitrogen than others. It is best to supply nutrients through drip irrigation. Fertilizer needs are typically managed through weekly applications.

What about farm labor?

Strawberries require higher labor requirements than many other crops, even with U-pick operations. High labor requirements are needed specifically at planting and during harvest, especially at peak production. In some cases, strawberries may need to be harvested several times weekly. The number of laborers needed depends on the size of the production field and the time of season.

What about insects, disease, and weed control?

Depending on the farm location, pest pressure can vary. For example, Botrytis gray mold fruit rot infections will likely be higher in locations with higher humidity levels or increased rainfall. Insects and weeds can vary depending on seasonal climates and their presence in previous crops. Be prepared to spend time scouting weekly for pests and determining the most effective and efficient method to control them.

Should I sell my berries wholesale, retail, or U-pick?

The marketing strategy chosen depends on the farm management and location (distance from

customers and their willingness to drive to the farm), access to labor at critical harvest times, and advertising methods (roadside, Instagram, Facebook, etc.). Other considerations include having enough local consumers to purchase strawberries and potential competition from other growers. Setting a selling price that increases profitability is essential.

Evaluating New Technology on Strawberry Farms

The information provided in this guide comes from over a decade of Texas A&M AgriLife Extension research. This guide discusses current and some new technologies for Texas growers. New technologies should warrant further investigation by each grower before expanding to the entire farm. There will always be new technology introduced into the strawberry industry, whether it is new pesticides, fertilizers, harvesting mechanisms, production methods, cultivars, etc. It is critical that growers conduct on-farm trials to determine whether the new technology has value. When evaluating new products, including fertilizers, biostimulants, pesticides, etc., always include a non-treated control. Non-treated controls allow for a comparison of the new technology to the standard practice and help determine whether there is a benefit. When doing so, always keep accurate records of the results for future use.

Texas Strawberry Production

Texas strawberry acreage has fluctuated since the first acre was planted in 1874. From 1874 to the 1890s, most Texas acreage was in the north. Beginning around 1900 to 1930 and with the help of migrant workers, strawberry production moved south to Galveston, Smith, Brazoria, Harris, and Atascosa counties. Most strawberries were shipped by rail to the Midwest and Northeast. Statewide, strawberries were popular and grew in most small family gardens. Industrialization after World War II shifted larger acreage to California and Florida, resulting in decreased Texas production. Even so, in 1948, strawberries were the most important berry crop produced in Texas.

In Texas, the average strawberry acreage from 1937 to 1946 was 1,360 acres. Smith and Wood counties (East Texas) and along the coastal area below Houston and the Wintergarden region had the highest production. By 1958, Texas acreage was down to 600 acres and represented less than 1 percent of the nation's strawberry production, as it does today.

The USDA reported in 1960 that Texas was one of three states growing early spring production, with commercial strawberries still shipped from Hidalgo, Atascosa, and Wood counties. By the 1990s, strawberry wholesale and fresh market production blossomed in the Poteet area (south of San Antonio). In 2004, competition from increased imports by California, Florida, and Mexico reduced Texas acreage to less than 150 acres. This accounted for less than 0.02 percent of national production. Today, with increased local consumer demand and interested growers, production has increased to over 400 acres. Most Texas strawberry growers produce strawberries on less than 3 acres, though some production is as high as 12 to 15 acres.

Current Texas Production Regions

Approximately 35 percent of the Texas land area has mean air temperatures above the critical level for strawberries, which are a cool-season crop. The other 65 percent has low temperatures reaching 0 degrees Fahrenheit (F) to 10 degrees F, which could reduce strawberry growth by injuring leaves, flowers, unprotected buds, and crowns. The diverse growing regions make large-scale strawberry production possible but more complex. Growing regions range from hot, windy, and semi-arid in the Trans-Pecos, High Plains, and Panhandle areas to humid and subtropical in East and Central Texas, the Wintergarden area, and Lower Rio Grande Valley.

In the southern and eastern regions, untimely freezes, rapid rises in day and nighttime temperatures, and heavy rains at critical flowering and harvest times can reduce fruit development and promote diseases. For example, during the February 2021 winter, extreme and extended low temperatures injured strawberry leaves and crowns of most plants statewide, thus decreasing overall yield. In contrast, in 2022, early spring freezes followed by a quick rise to high temperatures reduced the strawberry harvest season statewide.

In the High Plains and North Texas, strawberries are susceptible to cold winters, high winds, blowing dust, hailstorms, and heavy rains. However, the dry climate of the High Plains reduces the need for costly disease control. However difficult, with proper preparation and background knowledge, it is possible to grow strawberries profitably on the High Plains. Research has shown that protective covers, such as freeze cloth or plastic-covered low and high tunnels, significantly improve production by reducing crop injury. Growers should not produce strawberries on the High Plains without protection.

Soil quality is critical to strawberry production; sandy or sandy loam soils are best. Texas regions differ in soil characteristics. Soils in North Texas (Dallas and Fort Worth) and southern regions of San Antonio to Houston can be higher in iron compared to the High Plains. Soil pH can vary but is generally between 6.0 and 7.0. In the High Plains and other western regions, soil pH ranges from 7.4 to 8.3, which is high for neutral to acid-loving strawberries. High Plains soils are typically higher in potassium, magnesium, and calcium.

Arid soils and irrigation water may also have high salinity levels, which can limit strawberry production. For example, irrigation water on the High Plains typically has a pH of 7.4 or higher. Soils become more alkaline and saline farther west and south of San Antonio and Austin, past Midland to El Paso, and even north to the Panhandle. Before planting strawberries, it is important to consider the soil and environmental conditions carefully.

Field Selection

As mentioned previously, soil quality is critical to strawberry production. Strawberries are expensive to produce and should be planted in locations suited for maximum production. Strawberries prefer sunny locations. While they tolerate cold temperatures, in Texas, they grow best where winter temperatures are rarely below 20 degrees F. Sandy or sandy loam soils are best suited for production. High sandy soils that drain excessively may require increased irrigation. For strawberries produced on clay or

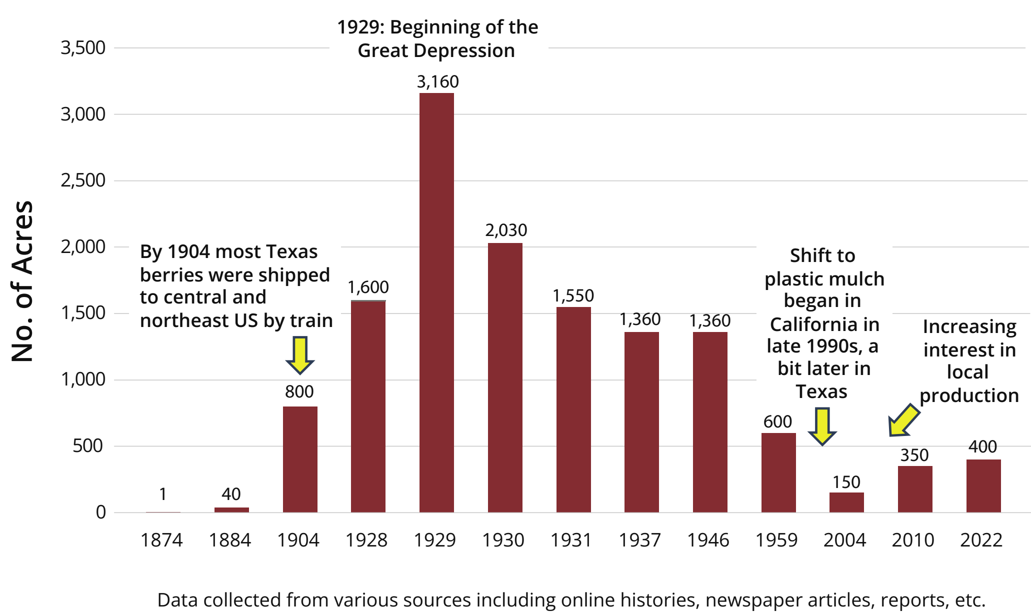


Figure 1. A bar graph of estimated strawberry acreage in Texas from 1874 to 2022. Acreage started at 1 acre in 1874 and increased to 3,160 acres in 1929. It has since decreased, ranging from 1,360 to 1,550 acres for most of the 1930s and 40s, then dropping to below 600 acres from 1959 to the present.

clay loam soils, water movement through the soil profile may be reduced, resulting in higher root disease potential. Management under these soils is more crucial and should be carefully considered.

For optimal production, avoid poorly drained soils (heavy clays, etc.) or low areas prone to flooding. Slightly elevated sites with some slope can be beneficial. Poor soil drainage where water stands for extended periods can increase root, crown, and berry diseases. During growth and development, strawberries prefer uniform soil moisture—not too wet or too dry. Nonuniform irrigation, especially during berry development, can lead to plant stress resulting in poor-quality, misshapen berries.

Soil drainage and root development are improved by planting strawberries on raised beds that are 6 to 12 inches high and covered with plastic mulch (film). A raised strawberry bed removes excess moisture quickly and reduces over-irrigation. Adequate soil moisture is needed to prepare beds for shaping. Adding compost or other organic materials before bed shaping in sandier soils may improve water holding capacity. Fields should be free from rocks, clods, and dried plant debris to allow for easier laying of plastic mulch, with a firm, smooth bed.

Strawberries grow best in soils within a pH range of 5.5 to 7.0. It is essential that the soil be tested at least 3 months before planting,

especially when planting into new fields. Field soil should be analyzed every few years. Soils with higher pH levels (greater than 7.0) may still be productive, but fertility management may be more challenging than those with a lower pH. Higher-pH soils may be deficient in available iron and zinc which can result in leaf yellowing, stunted plants, and reduced yields.

For small-acreage growers, soil pH may be temporarily lowered with organic materials like compost, peat moss, pine needles, humic acid, or sulfur, but this may not be feasible on a large scale. Fertilizers, including urea, ammonium sulfate, or ammonium nitrate, can temporarily lower soil pH, especially if carefully applied directly to the roots through drip systems. Water additives (e.g., sulfuric acid) can also lower pH but may burn crop roots if not used carefully.

Research indicates that some strawberry cultivars are injured by high winds and blowing dust. Excessive wind can damage plant leaves and stems as well as developing fruit. Fields with natural windbreaks (trees, buildings, etc.) or using high tunnels will reduce the effect of wind on plants.

Rotating strawberry fields every 2 to 3 years with other crops is a good practice and will help suppress disease and insect populations. Strawberries may be rotated with cover crops like rye, barley, wheat, or legumes. Leguminous crops can increase nitrogen levels in the soil. Rotating with a vegetable crop may improve future weed control when cultivation or herbicides are used. It is important to provide enough time for crop residues to break down in the soil prior to bed shaping and planting. Otherwise, the crop stubble can make it difficult to shape the beds and lay the plastic mulch evenly. Clods and stubble can poke holes in the plastic, resulting in weed emergence.

The orientation of strawberry rows in the field can improve production. North-south orientation allows more even sunlight throughout the day, enhancing plant uniformity and berry ripening. Where fields are sloped and uneven, planting rows to prevent erosion is important. Where fields are mostly flat or slightly sloped, use row orientation to improve soil drainage in case of heavy rainfall.

Water quality and quantity is important. The field location should be close to a reliable source of clean irrigation water. Strawberries are susceptible to high salts, and alkaline water could prevent optimal plant growth. Prior to planting, irrigation water should be analyzed for pH and salts, preferably several months in advance. If the analysis indicates high pH or salt levels, adjustments to the water may be needed.

If irrigation water is supplied from ponds, a filter will be needed. Do not draw water from ponds where livestock can freely enter and contaminate the water source. Foodborne illnesses can occur as a result, especially if used during harvest season.

Land Preparation

It is best to plant strawberries in fields that have been rotated with other crops. This will reduce the potential for damaging pests. Rotations out of strawberries for at least 3 years is ideal. Strawberries are best produced when planted into well-drained soils where plant roots can easily expand throughout the soil profile. This also allows roots to take up moisture and nutrients more efficiently.

Soil should be of a good quality to allow for making smooth bed surfaces. Do not work the soil when it is wet as this will create large soil clods. A smooth surface covered with tight plastic mulch increases overall yield and berry quality. A smooth surface also allows excess rainwater to run off the top of the bed, reducing disease potential with waterlogged roots, crowns, and berries. Raised beds should be firm and uniform, and plastic mulch should be laid tightly over the bed to keep it from tearing during high winds. Loose plastic can damage plants, and it takes time and effort to replace it. Sufficient soil should cover enough of the plastic mulch on the sides of the bed to prevent winds from tearing the plastic.

Sandy and sandy loam soils are best for strawberry production. However, regardless of soil type, the field should be free of large crop residues and clods that may tear the plastic mulch or cause the bed surface to be uneven. If cover crops were grown in the field prior to strawberries, cultivating or rototilling the field several weeks in advance and then again just prior to planting will improve bed shaping. This will allow more time for crop residues to break down.

In fields where soil clods are common, several passes with a rototiller will make the soil more uniform, allowing for smoother beds. In some cases, overhead irrigation or rainfall prior to rototilling will help reduce soil clods.

Based on preplant soil analyses, fertilizers can be adjusted to meet the needs of the strawberries and can be applied before bed-shaping (if desired). When shaping the beds for planting, the soil should be moist enough to hold the bed shape when laying plastic. If the soil is too dry, the beds may fall apart and lose their edges when the plastic is pulled.

Finally, it is critical to have the field prepared with beds before the plants arrive. If fields are not ready, delayed planting may affect plant growth and development, especially with bare roots, and this may potentially reduce yields.

Equipment and Supplies

Strawberries grow best on raised beds, and thus, growers need the appropriate equipment to create 6-inch to 12-inch-tall beds. Raised beds improve drainage away from strawberry roots and reduce berries touching the soil.

For first-time growers, bed-shaping equipment can be an expensive investment. Growers should consider the cost of specialized equipment when developing a strawberry production plan. Factors to consider include the acreage to be cultivated and whether current tractors are sufficient to pull equipment, including a bed-shaper, a plastic mulch/drip tape layer, and transplanting equipment (if desired). Other equipment around the farm can be adapted for strawberry production.

Bed shaper/mulch layers can be expensive to purchase; therefore, it may be ideal for new growers to initially lease equipment or hire a local contractor. When investing in new or used equipment, be prepared to spend $5,000 to $15,000 or more.

Weed control between strawberry beds is critical. Growers can use standard cultivators, but these may need to be adapted to decrease the risk of tearing or pulling the plastic mulch edges. The wheel spacing on tractors may also need adjusting to match row spacing. The area between the beds to be cultivated may vary. The surface of the strawberry beds may range from 1.5 to 4 feet wide, though the standard is approximately 1.5 to 2.5 feet.

Although not essential, overhead sprinkler systems help bare-root or plug establishment during the first several weeks even when plastic mulch is used. Overhead watering can cool the crop during high temperatures, especially those planted on black plastic. However, it is most often used during crop establishment. Using overhead sprinklers may help keep flowers from aborting during heat and offer some protection for flowers during freezing temperatures. Low-impact sprinklers are preferable, but new or used overhead systems can be costly. Before purchasing an irrigation system, it is critical to know the pumping capacity of your water source.

A few Texas producers still use furrow irrigation for bare-ground strawberries. However, this may result in higher weed pressure compared to those grown on plastic and require more labor for hand-weeding, especially if herbicides are not used. In plasticulture, drip tape is the most common and must be placed below the plastic mulch, either on or several inches below the soil surface. Drip tape emitters can be purchased at different spacings; however, 12-inch emitters work best for strawberries. Expect to pay around $250 or more for 6,000- to 9,000-foot rolls of drip tape. Check with your local supplier or online for more details.

Most strawberry growers still transplant plugs or bare roots by hand, though transplanting equipment has become more popular for growers with large acreages. Single- or two-row transplanters are available that can punch holes through plastic mulch. With trained labor, an acre of strawberries can be planted quickly.

▼ Figure 2. Most strawberries in Texas are planted by hand using bare roots (left). Though some growers transplant plugs mostly by hand, some are transplanted by machine (right).

When using transplanters, it is critical to place the plants in the soil at the correct depth. It is easier to transplant plugs compared to bare roots. Bare-root plants often have roots that can be 6 to 8 inches long. The roots can be cut to shorter lengths to improve planting efficiency.

Other supplies that may be needed depend on the farm location. For example, deer fencing and/or bird netting may be required. Tractor sprayers, hand-held sprayers, picking baskets or containers for harvesting, and crates are also essential. Hand-pulled wagons or carts and 4-wheelers to carry berries from the field to on-site refrigerated coolers or vehicles for transporting and small coolers to remove field heat from the berries are important if storage is needed. Additional supplies may be required depending on the type of marketing used. Table 1 includes the costs of potential equipment and supplies needed to produce 1 acre of strawberries in Texas.

The overall cost of producing strawberries, based on 17,000 plants, can range from $1.63 per plant up to $3.05 (with plugs and low tunnels) or $27,710 to $51,850 per acre. Therefore, it is critical not only to maximize yield but also the price of strawberries to ensure profitability. Ensuring the highest yield per plant will increase strawberry production profitability.

Transplant Quality

Successful and profitable strawberry production increases when purchasing healthy, vigorous plants. Depending on the cultivars selected, multiple sources may be needed.

Table 1. Estimated variables and costs of production for 1 acre (17,000 plants) of commercial strawberries in Texas (2022)

Potential Variables Needed	Estimated Cost ($/A)
Preplant	
Preplant soil nutrient analysis	30
Irrigation water analysis	75
Plastic mulch (embossed)	900
Drip tape	1,200
Irrigation supplies	1,550
Tractor labor	950
Total	***4,705***
Transplanting	
Bare root	3,200
Plugs	7,000
Transplanting tools	100
Transplanting labor	2,040
Total	***5,340 – 9,140***
Maintenance	
Fertilizer	2,000
Pest control (chemical)	500
Pest control (organic)	1,000
Hand-weeding for season (organic)	5,600
Pesticide application labor	900
Total	***3,400 – 9,500***
Other options	
Low tunnel option	7,500
Row cover hoops	2,300
Row cover hand pegs	3,500
Pull low tunnel plastic labor	765
Total	***14,065***
Harvesting	
Berry flats	4,400
Berry fiber cups (pint)	2,000
Harvest labor (season)	8,000
Total	***14,400***
Estimated total	***27,845 – 37,745***
Estimated total with low tunnels	***41,910 – 51,810***

Most plants produced in the US are grown from tips produced in Canada and then sold to plug or bare-root propagators. When purchasing from local nurseries, be sure the plants originated from reliable propagators. Plants purchased from retail nurseries or from online sources are shipped from wholesale propagators. When visiting a nursery, always select healthy-looking plants with excellent roots.

Large quantities of plants can be shipped from nurseries directly to growers. However, increasing numbers of nurseries will only sell a minimum order of 30,000 plants. When plants arrive and before transplanting, it is important to inspect them for foliar and root diseases, viruses, or visible weeds and insects. Plants grown at the nursery may also have runners (daughter plantlets) upon arrival, and while not essential, transplanting efficiency can be increased by having them removed. Runners will continue to grow after transplanting and can also reduce nutrients needed for optimal growth.

Transplants should have plenty of healthy, moist roots. If roots appear brown or dry, check to see if they are still viable by sliding two fingers down several roots to pull off the outer sheath. If the root underneath the sheath is white, the roots are still alive and healthy. If the roots or the crown are brown and dried or if they are slimy in appearance and to the touch, they could be infected with diseases. If you find diseased plants, send samples to the Texas Plant Disease Diagnostic Lab or contact your local county agent for diagnosis.

It is important to understand that not all bare roots or plugs shipped will be the same size, though plugs are generally more uniform. Some plants may have more roots and leaves than others. Growers may be concerned about whether transplant size affects overall plant yield. Table 2 shows the results from a 2022 Texas AgriLife Extension trial evaluating transplant size. The results indicate that the bare root size has little negative influence on yield. It is more critical to ensure that all plants, regardless of size and roots, are transplanted correctly and at the proper depth. When planting bare-root plants, be careful not to break any new developing leaves or stems emerging from the crown area.

Table 2. Total yields for Fronteras and Merced from different bare-root-sized transplants at Lubbock

Size at transplanting		Fronteras	Merced
Bare roots	Avg. plant weight (oz)	Harvested berry weight (lb/plant)	
Large	1.00	0.59	0.61
Medium	0.50	0.82	0.61
Small	0.25	0.66	0.67
Mixed	—	0.48	0.68

Yield data collected in spring 2022 from Texas A&M AgriLife Research and Extension Center field trials

Bare-root plants can be chilled at the nursery prior to purchase. The chilled plants generally establish more quickly than those produced in warmer climates. They are available earlier (in September) than those fresh-dug plants available in October. Some bare-root plants are dug and frozen in cold storage until the following fall. Such plants show exceptional growth but may have excessive runners when planted.

When ordering plants, it is best to discuss the cultivars with the nursery. To get the cultivars desired, order early—it is best to order as early as February to April in the spring before fall planting. It is critical to know which cultivars perform best in each region. Descriptions of recommended cultivars for Texas are found in the *Cultivars* section of this guide.

Plugs Versus Bare Roots

In Texas, it is best to transplant both bare roots and plugs in the fall. Spring planting will result in poor production due to rising temperatures.

When planting for a perennial system, nurseries can produce replacement plants as needed each year. Regardless of the type of transplants, when placed in the soil, each plant must have good soil-root contact to increase survivability and growth. Past research suggests that plugs may initially grow faster than bare roots, but overall winter growth appears similar.

Bare Roots

Fresh-dug bare roots are generally available from September to November. They are packed in boxes and shipped to the grower's locations. Boxes average from 1,000 to 1,500 plants per box, depending on the supplier. Upon their arrival at the farm, if not immediately transplanted, they should be refrigerated and the roots inspected frequently. Do not allow roots to dry out, but they should be kept moist, especially during transport and handling to the field.

It is critical to plant bare roots within several days after their arrival. Quick transplanting of bare roots translates into higher plant survivability, improved plant stands, and higher yields. Growers should have production fields, strawberry beds, and irrigation prepared at least 1 week before transplanting. Bare-root plants can have roots from 2 to 8 inches long, which are more difficult to transplant than plugs. The roots can be clipped to a standard 4 inches for ease of transplanting, but soaking plants in fungicide dip solution before going to the field will reduce root infections. See appropriate fungicide labels for application uses.

During transplanting, do not bury the growing point (or top of the crown), but push the plants deep enough so roots are not exposed. If exposed, the plants will not mature properly in the spring and will produce little to no fruit. Growers may plant bare roots using a transplanter, but it can be difficult to achieve good establishment, and plants may need to be pushed deeper into the soil. Most bare-root plants in Texas are transplanted by hand.

Plugs

Plug plants are propagated at nurseries by placing imported runner tips (usually from Canada) into plug trays containing soilless growing media. After several months of growth, when the tips are well rooted in the media and crowns and leaves are actively growing, they can be shipped directly to the grower. Plugs are typically shipped in 50-cell trays with five trays per box for 250 plants per box. Plug plants usually cost twice as much as bare roots.

For Texas growers, plugs are usually grown in nurseries from the Midwest or Midsouth states. They are available a few weeks earlier than bare roots. Plugs are more uniform in size, and transplanting by machine is easier than bare roots. Transplanting plugs correctly is just as critical as transplanting bare roots. Plugs are more suitable for mechanical transplanting with a water wheel or mulch transplanter than bare-root plants. Plugs also require care before, during, and after transplanting. Plug plants grow rapidly and, after several weeks, may be further along than bare roots.

Figure 3. Strawberry bare-root plants before (left) and after (right) transplanting in the field.

◀ **Figure 4. Strawberry plugs before (left) and after (right) transplanting in the field.**

Transplanting

Proper transplanting for both bare roots and plugs is essential for high-yielding and high-quality strawberry production (Fig. 5a). Poor transplanting, especially when using untrained workers and volunteers, can result in lower yields. Care should be taken to hire and train quality workers for transplanting. When transplants are not planted correctly, either too deep or too shallow, plants become unproductive and may even die (Fig. 5b and 5c).

In both types of plants, the crown should be set deep enough in the soil to protect it from early freezes, but do not cover the first set of emerging leaves. Figure 5d shows the incorrect setting of plug transplants in the bed. Workers should return and push plugs deeper into the soil or crowns could dry out, freeze, or be otherwise damaged.

To increase plant survival at transplanting, the soil should be moist but not wet. Following transplanting, plants should be irrigated to keep roots moist to initiate new growth and development. In bare-ground fields, where plastic mulch is not used, overhead sprinklers or furrow irrigation will keep the soil moist. Overhead sprinkling can also decrease air temperatures around the plants to reduce early heat stress, but splashing could also spread potential diseases.

Plant Spacing

The correct plant spacing improves strawberry productivity, yield, and grower profitability. Research at Texas A&M AgriLife (Table 3) shows the effect of different plant spacings on overall strawberry yield. While 12-inch plant spacing is recommended and is considered the standard, higher yield (10 percent) was observed when strawberries were planted at 9 inches. However, the cost of higher-density plantings (5,000 more plants per acre) plus the additional labor cost for transplanting may outweigh the yield advantages. Cultivar performance may differ between plant spacings as well.

▼ **Figure 5. From left to right (a, b, c, d): (a) using a transplanting tool to correctly push bare-root plants into the soil; (b) an improperly planted bare root that should be replanted; (c) photo taken in May of poorly planted bare root showing very little growth and no flowers or fruit; (d) poorly planted strawberry plugs needing to be pushed further into the soil.**

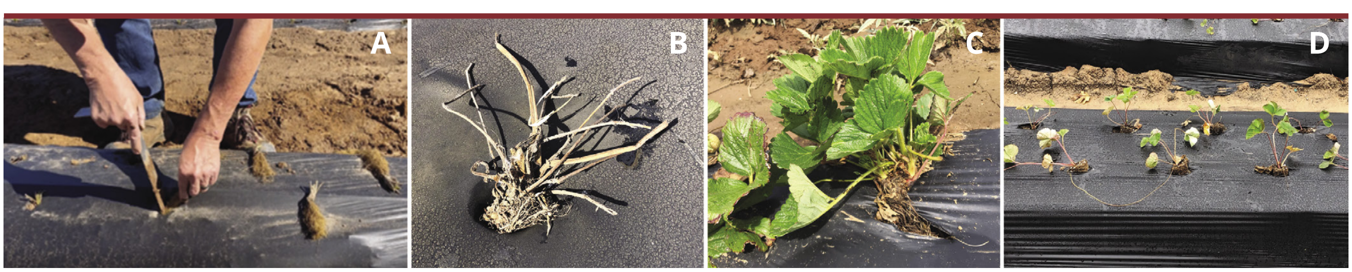


Table 3. The effect of plant spacing on strawberry yield in Texas			
Plant spacing (Inches between plants)	No. plants (Acre)	Yield (lb/Plant)	Yield (Acre)
9	22,651	0.47	10,646
12	17,424	0.55	9,583
15	13,939	0.58	8,085

Planting Times

In Texas, it is best to transplant strawberries from late September to early November. Earlier plantings will result in higher spring yields with larger, better-quality fruit. Spring planting in Texas is not recommended. Research indicates when strawberries are transplanted in the spring, the higher temperatures result in smaller plants with fewer crowns. The increasing day length also triggers early flowering with fewer buds and smaller fruit. It is important that following transplanting, plants experience cold temperatures for an extended period to develop future crowns and flower buds for bountiful springtime harvest.

The correct fall planting time is critical. Any delay in planting by several weeks usually results in yield losses. When ordering transplants, coordinate with the nursery for the best available times for arrival at the farm. It is important to have the land prepared and the field ready for immediate transplanting upon their arrival. It is critical to transplant them as quickly as possible. If plants are not ready for transplanting, they should be stored in a cooler for no more than a few days. Transplants held for too long will have new shoots emerging which can break off during transplanting. Note: Research trials conducted at Texas A&M AgriLife indicated that for each day fall transplanting is delayed, springtime yield losses could average 1.5 percent daily or a revenue loss of $500 per acre per day.

When planting in South Texas during September, high air and soil temperatures may cause plant stress or even death. Fields planted in early September should be overhead irrigated to keep plants cool until they are fully established, usually for several weeks. In North Texas and the High Plains, when transplanted during October or November, freezes may occur, and thus, floating row covers or low tunnels should be used to protect the tender, new leaves that are emerging.

Production Systems

There are several popular production methods for growing strawberries in Texas. While states in northern climates produce berries on perennial matted row systems, strawberries in Texas should be grown annually on beds covered with plastic mulch or on furrow-irrigated beds. Most strawberries in Texas are grown in open-field production. The following sections describe the strawberry production systems currently used.

Matted Rows

Strawberry systems using matted or space-matted rows as perennial crops do not use plastic mulch and are not common in Texas. This is due to high summer temperatures, which cause death to strawberry plants. Therefore, perennial systems are not recommended in Texas.

The matted-row system involves planting mother plants and letting them spread by runners over the entire bed. Using bare-root plants is considerably cheaper and preferred for perennial systems. The runners are evenly spaced by hand to achieve a more uniform system. Strawberries can be planted on hills spaced at 12 to 15 inches in the row on 36 to 48 inches beds. After several seasons, the matted row plants may cover the entire area.

Everbearing and day-neutral varieties grow best on the hill system if left as perennials. Transplant bare-root plants with 12 to 15 inches in-row spacing in double or triple rows per bed. Beds are generally wider than plastic mulch and should have 18 to 24 inches between beds to allow workers and customers to harvest berries. Open-field single-row plantings were common in the past (Fig. 6).

▼ Figure 6. Typical strawberry production before plasticulture in Texas.

Annual Plasticulture Systems

Strawberry production using polyethylene plastic mulch (also called film) is the most common system in Texas. Plastic mulch systems can be used in open fields, high tunnels, or in fields where low tunnels are used. More than 95 percent of Texas strawberries are grown on plastic mulch.

The benefits of plastic mulch include warming soils in the root zone, controlling weeds, reducing soil moisture evaporation, and preventing berries from touching the soil. Plastic mulch allows the use of more efficient drip irrigation systems. Polyethylene mulches come in a variety of colors; however, black mulch and white on black are most common. Occasionally, red mulch is used (Fig. 7).

Depending on the mulch-laying equipment and bed size, plastic mulches range from 48 to 60 inches wide. When beds are formed, drip tape is placed just beneath the soil surface on beds that are typically 2.5 to 3 feet wide. Wider beds will likely need wider plastic and an increased number of drip lines. Strawberries are then transplanted in 2 to 4 lines per bed. Twelve-inch spacing is the most common. When beds are prepared, holes are punched into the plastic and plants are transplanted.

High Tunnels

High-tunnel strawberry production is like those in the open field, but the plants are grown in protected frames covered with greenhouse plastic or a similar type of plastic. Unless grown in hydroponic systems, the crops are grown in the soil on plastic mulched beds and drip irrigation, like open-field production. Fertilization, irrigation, and pest management are also like open-field production.

While the environment inside high tunnels is favorable for improved crop growth, it is also favorable for increasing certain pest populations. For example, two-spotted spider mites and aphids have been found in the winter

Figure 7. Although black plastic mulch (middle) is most used in Texas strawberry production, other colors, including white on black (left) and red (right), can also be found.

Table 4. Environmental effects on root and foliar diseases in two production systems at the Texas A&M AgriLife Research and Extension Center in Lubbock (2017)

Production system	% *Rhizoctonia*-infected plants	% Loss due to *Botrytis* gray mold	Marketable yield (lb/plant)	% Marketable yield loss due to disease
Open field	3.7	7.0	0.53	18
High tunnel	9.3	1.2	0.72	13

▲ **Figure 8. High tunnels may be used in regions of adverse weather (extreme cold and high winds, etc.) to protect plants from damage, extend the growing season, and increase yield and quality.**

on strawberries produced inside high tunnels grown on the High Plains. Increased pesticide use may be needed to keep diseases and insects under control. Research with Texas A&M AgriLife Extension has shown high-tunnel production to be very successful, especially in regions where high winds and extreme cold temperatures are common.

In high tunnels, strawberry yields of up to 2.0 pounds per plant have been recorded. Earlier berry yields have also been recorded with harvesting starting in late November from an October planting. One consideration that growers must understand is that strawberry production is best with crop rotation, especially in high tunnels. Research shows that after 3 to 4 years, strawberry yields in high tunnels decreased significantly (Table 5). A minimum rotation of 1 year out of production is needed.

For more information on high-tunnel production, visit the AgriLife Learn website and download *High Tunnels for Crop Production in Texas [HORT-PU-022]* and *Specialty Crops for High Tunnel Production in Texas [HORT-PU-037].*

Low Tunnels

Like high tunnels, low tunnels can be used to protect strawberry plants from adverse weather, including freezing temperatures, resulting in increased crop growth and yield and earlier harvests. Low tunnels are a critical component for northern climates in the Texas Panhandle. On a square-foot basis, low tunnels are cheaper than high tunnels, though the field labor involved may dissuade some growers from using them. In addition to setup, the need to uncover and recover the beds during high and low temperatures can increase labor costs. However, low tunnels have an advantage by being portable from field to field during crop rotation, whereas high tunnels are limited to the ground they are built upon.

Low tunnels are usually constructed after transplanting by placing wire hoops over the top of strawberry beds, usually 5 to 10 feet apart down the row. In windy regions, placing hoops 5 feet apart is recommended. Covers are then secured by placing hand pegs through the plastic edges or by placing weights on

Table 5. Strawberry yields in a 7-year, non-rotated, high-tunnel production system compared to new open-field production during 2019

Production system	Yield (lb)/plant	No. harvests
High tunnel (7 years, no rotation)	0.48	23
Open field low tunnel (new field production)	0.93	9

Figure 9. The use of low tunnels has increased in recent years to protect strawberries from adverse weather. From left to right: Newly laid low tunnels covering plants in the fall; low tunnels during a winter storm; and a view of protected plants inside a low tunnel.

the plastic. Securing the plastic covers with additional weight is essential to prevent them from flying off in windy areas. On the High Plains, strawberries will be injured during the winter and in high winds without protection (low tunnels). Past Texas A&M AgriLife research has shown that plants grown under low tunnels have yields equivalent to those grown in high tunnels and are superior to those grown uncovered.

Row Covers

With the changing climate patterns in Texas during recent years, row covers, or floating row covers, have become an important production tool for growers. Row covers are important for protecting flowers and developing fruit, primarily in the early spring. Row covers are made of spun-bonded polypropylene fabric placed over the top of the plants in the field. Depending on cloth thickness, they will offer protection down to 28 to 30 degrees F using the lightest cloth or to 24 to 26 degrees F with the heaviest cloth. Light transmission ranges from 85 percent down to 50 percent using heavy cloth. For strawberries, it is recommended to use heavy cloth for the best protection of the flowers and fruit.

It is best to have row covers on the farm before freezing temperatures are forecast. It may be difficult to purchase and receive them when ordered late or near an upcoming freeze. Row covers may cause some undesirable damage to the leaves and flowers when covering the field, and some growers find using small hoops (hoop loops) to support the row covers to be less damaging to the plants. Row cover hoops are spaced about 10 feet apart with support string running along both sides to keep the covers from touching the plants.

Figure 10. Row cover cloth placed over strawberry plants to protect the flowers and developing fruit (left). Row covers can also be used in high tunnels (right) for added protection.

Row covers can be purchased in multiple sizes ranging from 10 to 50 feet wide and between 500 and 1,500 feet long. While row covers are initially expensive, they will pay for themselves—even within one season—and will increase profits by protecting plant growth and flower production. When kept in good condition, row covers can last for several years or longer.

Hydroponic or Soilless-based Systems

Few Texas growers currently produce strawberry crops in hydroponic systems either in the open field, in high tunnels, or using controlled environmental agriculture (CEA), like greenhouses. CEA protects high-value crops by growing them in soilless media either in gutters, hydrostackers, or buckets. Though there is significant interest, hydroponic strawberry production in Texas is very limited.

Advantages of hydroponics include reduced space needed while increasing production, reduced water use, better control of nutrients, and no soil erosion or weeds to control. Disadvantages of hydroponic CEA include high setup costs and a high learning curve for production. Also, there is the potential for equipment failure and loss of electricity, resulting in the loss of the entire crop. The Department of Horticultural Sciences recently hired faculty and staff at the Texas A&M AgriLife Research & Extension Center at Dallas to evaluate CEA and hydroponic systems. There is potential to evaluate hydroponic CEA strawberry production in the future.

Figure 11. Two types of hydroponic systems used for strawberry production include the gutter system (left) and a hydrostacker system (right). Other systems are available.

Strawberry Growth and Development

Plant Biology

Strawberries (*Fragaria x ananassa*) are small evergreen plants and are included in the rose family. They are low-growing, with tri-lobed leaves and shallow-growing fibrous roots. Roots and leaves arise from thick, semi-woody structures called crowns. Crowns are perennial structures, and there are usually multiple crowns on each plant.

With each season of growth, new leaves and roots emerge from the higher positions on the crown. Plants seemingly grow out of the ground. The crowns will initiate stolons (or creeping stems), known as runners, that extend from the original crown to form new daughter plants or plantlets. If allowed to grow close together and for enough time, the runners will proliferate and form dense fruit-bearing mats.

▲ **Figure 12. During the growing season, runners may emerge from the crown region, diverting nutrient resources away from the development of new flowers and fruit.**

The first cultivated strawberries were initially bred in France in the 1750s. This breeding crossed a native North American species (*Fragaria virginiana*) and a South American species from Chile (*Fragaria chiloensis*).

Strawberry growth develops in phases. Dormant crowns form new roots and leaves, then flower and bear fruit. Plants will then stop flowering and form runners and daughter plants in that sequence. Soil and air temperatures affect the timing and duration of the different phases. Though strawberries generally grow and develop best at 70 to 75 degrees F, strawberry breeders have produced varieties that grow and bear fruit in somewhat cooler or warmer climates.

Strawberries are fibrous-rooted plants that do not root deep into the soil. Depending on soil conditions and mulch and irrigation practices, most roots penetrate only in the top 6 to 12 inches. Strawberry roots need good soil moisture but must also have good aeration. Well-drained soils are essential to root health, plant growth, and bearing fruit. Plants standing in water for even brief periods may become unthrifty or die.

Figure 13. A cluster (left) of strawberry flowers after recently opening, and a closeup (right) of a flower showing the male and female structures that contribute to fruit development.

Strawberry flowers have male and female structures and are self-pollinating. Pollination occurs naturally with the wind and movement of the flowers. However, bees and other beneficial insects can increase the pollination rate and improve berry yield and quality. The flower pistils become receptive in successive rings starting at what forms the fruit base. The progression of pistil maturity takes 4 to 7 days, during which time the wind and bee visits help a well-formed fruit to develop.

Although the strawberry fruit resembles a conical berry, it is correctly identified as an accessory fruit or pseudo fruit. It is formed from an enlarged flower receptacle embedded with many tiny ovaries or achenes. Achenes resemble tiny seeds on the outside of the berry. New cultivars of strawberries come from controlled pollination and the planting of selected seeds, whereas genetically identical plants arise from the runners of the mother plant. The plants sold by nurseries are genetically identical, having arisen from a single mother plant.

Cultivars

Strawberry cultivars (or varieties) are categorized according to their flowering response to day length. Three general categories are used to describe flowering performance: short-day (also called "June-bearing" or "spring-bearing"), long-day (also called "everbearing"), and day-neutral (cultivars not sensitive to day length). They are described in the following sections.

June-bearing (Short-day)

Short-day cultivars are commonly called "June-bearing" or "spring-bearing" in much of the US. June is typically the time for peak production. In Texas commercial field production, short-day strawberries are planted in the fall and harvested in the spring. The flower buds develop during the autumn months when day length is 10 hours or less. Flowering is suppressed by cold mid-winter temperatures and begins when temperatures get warmer. Harvesting could be as early as January or February in South Texas or in April in the north.

Figure 14. The strawberry flower (left) develops into what resembles a conical berry, or an accessory fruit or pseudo fruit. It is formed by an enlarged flower receptacle that is embedded with many tiny ovaries or achenes (right), which resemble tiny seeds on the outside of the berry.

In the past, the most successful commercial strawberry crops in Texas were short-day cultivars. June-bearing strawberries produce one main crop and typically yield the highest amount of fruit during a 2- to 3-week window. They switch to the runner production phase once day length and temperatures increase. Different June-bearing cultivars may have slightly earlier or later flowering and ripening dates. Growers wanting to extend their harvest season should consider planting a mix of cultivars for early, mid-season, or late harvests. June-bearing varieties produce many runners and daughter plants, making them suited to matted-row or annual hill systems.

Everbearing (Long-day)

Long-day or everbearing cultivars initiate flowers when day length is 12 hours but struggle to flower consistently when temperatures reach 90 degrees F or above. Since these conditions are common in Texas during the summer months, everbearing cultivars are generally not suited for open-field production in the state. They can be suitable for commercial production when grown in climate-controlled greenhouses. In temperature-controlled environments, day-neutral cultivars are a better choice as they bear more steadily in optimal conditions. Everbearing cultivars do produce fewer runners than June-bearing types.

Day-neutral

Day-neutral cultivars are insensitive to day length. They are an improvement over everbearing cultivars as they can flower and bear fruit over a range of light periods. Like everbearing cultivars, day-neutrals are affected by air temperature. They will flower and form runners between 35 to 80 degrees F, though flower bud formation declines above 70 degrees F. Temperatures of 90 degrees F and above reduce flower production and runner formation. With a few exceptions (e.g., 'Albion'), these cultivars generally produce fewer runners than June-bearing types. In many regions of Texas, temperatures may exceed the threshold for forming fruit buds in day-neutral cultivars as early as April.

Texas Cultivar Evaluations

The following list of cultivars are those that have been evaluated for at least 1 to 2 years or more by Texas A&M AgriLife Extension and by growers across the state in sponsored trials. Growers looking to plant specific cultivars should first evaluate them on a small scale before committing to large-scale production. While this list of cultivars may be helpful, cultivar and yield responses may differ depending on farm location, field, soil type, climate, and production practices.

Note: Not all cultivars listed may be currently available. Check with nurseries to determine accessibility to cultivars. It is important that growers evaluate cultivars (both old and new) annually to determine yields and potential profitability. Most general cultivar descriptions can also be found online.

Day-neutral Cultivars

'Albion' is still considered the Texas standard in terms of flavor and production. Albion is resistant to *Verticillium* wilt and *Phytophthora* crown rot and relatively resistant to anthracnose crown rot. While reports indicate tolerance to two-spotted spider mites, without treatment in Texas, it is typically one of the hardest-hit cultivars and should be monitored regularly. The berries are typically long, conical, firm, dark red, and very symmetrical with excellent taste. Although yields in Texas were lower, Brix (total amount of soluble solids or sugars in berries) levels were good at 10.2. The berries are good for storage and shipping. By comparison, it typically produces 25 percent lower yields than Camino Real. Applying too much nitrogen early often results in increased runner production.

'Beauty' is a new Florida cultivar that has been evaluated for 2 years at the Texas A&M AgriLife Research and Extension Center in Lubbock. It is excellent for early plantings with fruit onset having little to no chill requirement. In the second year, it was slow to emerge from bare roots compared to other cultivars. It has uniform, bright red, glossy fruit with a good shelf life. It has a high percentage of large, marketable fruit set on a compact plant structure. It had good Brix levels at 10.3 in Texas trials. It is moderately susceptible to several root diseases. It responds well to higher nitrogen rates early in the season.

'Cabrillo' is a moderately strong flowering cultivar (everbearing type). Fruit size and firmness are comparable to Albion, and it offers outstanding flavor. It has produced beautiful berries in Texas and was the second highest-yielding cultivar in the 2023 trial. Not quite as sweet as other cultivars, with a Brix value of 8.4 in Texas trials. It is resistant to powdery mildew, *Verticillium* wilt, *Phytophthora* crown rot, and common leaf spot but is susceptible to anthracnose crown rot. With proper treatment it is also tolerant to two-spotted spider mites.

'Monterey' is a moderate day-neutral cultivar, and it flowers somewhat stronger than Albion. Like Albion, it has a vigorous plant structure and thus may require more planting space (12 to 15 inches). The berries are slightly larger than Albion but not as firm. Monterey has a distinct sweet aftertaste. It had a good Brix level of 10.7 in Texas trials. It is resistant to several diseases but is susceptible to powdery mildew. It appears to do well in organic applications, including trials with Texas A&M AgriLife Extension.

'Rikas' is a new cultivar developed in Spain. The plants are upright and open, with a vigorous structure that facilitates harvesting. Berries are medium in size, with a long conical shape and light red, glossy, firm fruit with a 10.6 Brix value in Texas trials. It is good for storage as it resists bruising and has an excellent taste and appearance. However, it does produce a moderate number of runners. It is moderately resistant to powdery mildew, *Verticillium* wilt, and *Phytophthora* crown rot. It is somewhat tolerant to aphids and spider mites. It continued to produce fruit through mid to late June in research trials on the High Plains and was the highest-yielding cultivar in 2023.

'Royal Royce' is a new day-neutral cultivar from the University of California (UC) Davis breeding program. It typically produces higher yields over the entire season, but in 2023 Texas trials, it ranked in the lower third for yield. In California trials, Royal Royce produced significantly higher yields compared to San Andreas. Rikas produces fewer runners than many other cultivars. Plants were rated as being strong and wind resistant in Texas. The berries are firm and large with low acidity and had a 9.8 Brix in Texas trials. It also has good disease resistance.

'San Andreas' is a moderate day-neutral like Albion with excellent season-long plant growth and vigor. It generally produces fewer runners than Albion. The fruit is excellent in appearance, especially in the early season, which makes it a good candidate for South Texas. The berry color is somewhat lighter than Albion and it has good fruit flavor with a Brix of 10.4 in Texas trials. San Andreas has good disease resistance and has performed very well in high-tunnel trials.

'Seascape' produces a vigorous plant with dark foliage and large fruit but is not as high yielding as Albion. The plants are virus resistant and grow well in a wide range of growing conditions. The berries are bright red, firm, and conical-shaped with a glossy finish and have an excellent flavor. Trials in Texas indicated it had average yields unless planted inside high tunnels where it performed well.

'Sweet Ann' is a vigorous plant but more compact in size. In Texas trials, it was productive while producing few runners. Sweet Ann has attractive large berries that are long and conical-shaped. The berries are not as firm as other cultivars, but they have a good acid-sugar balance and are very sweet (Brix 10.1). The berries seem to mature more slowly in Texas; however, when mature, they are glossy red in color inside and out. It is resistant to most diseases except *Fusarium* wilt. It is also a good choice for organic systems and high tunnels.

'Valiant' is a new generation day-neutral cultivar released by the UC Davis breeding program. It produced medium-sized vigorous plants in Texas trials. It has a high potential for large early season production and high yields. Berries are uniformly medium to large, low in acidity—with Brix levels averaging 9.8—and very firm. Valiant also has good disease tolerance.

June-bearing (Short-day) Cultivars

'Benicia' was evaluated for 2 years in Texas and performed well inside high tunnels. The plant size is medium. Benicia is a spring-bearing (short-day) cultivar that can produce fruit over extended weeks when planted in arid, sub-tropical environments. It has a somewhat mild flavor and excellent shape. In the Texas trials, it produced consistently large fruit early in the spring but did not seem very heat tolerant. It has good disease tolerance except for *Verticillium* wilt. However, it has not recently appeared on nursery lists of cultivars, and its availability is uncertain.

'Brilliance' is named for its glossy and conically shaped, firm, excellent-tasting fruit. The berries have an excellent shelf life with a juicy texture. It produces earlier yields than many other short-day cultivars and produces fewer runners. Its open plant structure with long stems is also conducive to easier harvesting. Brilliance does not require as much early season nitrogen as other cultivars. It has moderate to high resistance to most diseases but is susceptible to crown rots caused by *Phytophthora cactorum*. A preplant fungicide would help reduce crown rot. In Texas trials, plants were small and open, but berry numbers were high and yields were outstanding. The fruit Brix averaged 9.3.

'Camarosa' is an early short-day variety. It is popular with many growers in Texas as it is adapted to many growing regions. With its earlier flowering, it is recommended to use row covers for protection during freezes or substantial losses may occur, which has occurred in trials statewide. Camarosa is like Chandler in plant structure but has larger, firmer fruit that is flat and conical. The fruit interior color is a brilliant red, though uniformity is not as good as other cultivars. The berries are sweet, with Brix levels typically averaging 10.6. It has a high yield potential and good disease resistance, including resistance to *Phytophthora* crown rot. It does well in open-field and high-tunnel production.

'Camino Real' is like Camarosa in all aspects, including its production pattern, though it is a bit later to initiate fruiting. It will also need row cover protection during early season freezes. It has been the Texas A&M AgriLife recommended June-bearing cultivar for the past 10 years due to its consistent yield performance in both open-field and high-tunnel production. It is generally one of the highest-yielding cultivars. Yields tend to increase with higher nitrogen rates. The external and internal fruit color is dark red with a good flavor. The fruit is excellent for both fresh market sales and processing. It is, however, susceptible to common leaf spot and sensitive to powdery mildew in humid climates. It is resistant to *Verticillium* wilt, *Phytophthora* crown rot, and somewhat resistant to anthracnose crown rot. It has shown some tolerance to two-spotted spider mites.

'Chandler' is a popular, consumer favorite, June-bearing cultivar that produces vigorous, productive plants with large- to medium-sized fruit. It performs well in high tunnels. Chandler flowers early and row cover protection may be needed. The berries are conical- to wedge-shaped with a medium, red, glossy finish but are not very uniform. The fruit quality is excellent and produces high yields with excellent-tasting berries, though the berries are softer than most other cultivars and should be sold immediately. Chandler is a good cultivar for U-pick farms but not for storage. Increasing numbers of growers are not planting Chandler. The fruit Brix average is 9.8. Chandler continues to flower late but with increasingly small flowers, and it is more difficult to find inside the canopy. On higher-pH soils, Chandler is susceptible to iron and zinc deficiencies, but foliar or soil treatments can reduce their effects.

'Festival' (Strawberry Festival) has been evaluated in Texas for more than a decade. It has performed well in both open-field and high-tunnel trials. Festival flowers early and produces yields of medium, firm, attractive, and very flavorful berries. The berries are mostly conical with an external color that is deep red and glossy, while the internal color is bright red with a Brix average of 9.8. In Texas 2023 trials, yields were low due to flower injury from early freezing, so row covers should be used to protect the flowers. Festival generally produces many runners which can take growth and yield from the crop. Applying less nitrogen to the crop may be useful. It has excellent disease resistance except for anthracnose (*Colletotrichum acutatum*).

'Flavorfest,' released by the USDA-ARS in Beltsville, Maryland, was evaluated for only 1 year in both South Texas and on the High Plains. While it may grow well in other states, it performed very poorly at both Texas locations. The plants were very stunted and produced only a few misshapen berries. Leaf analyses showed extremely high boron levels, and the plants showed extreme leaf toxicity symptoms. It is likely that Flavorfest is a luxury consumer of boron and perhaps other micronutrients. Before growing on a large scale, transplant a few plants as a trial to determine their performance level. However, it currently is not a recommended variety.

'Fronteras' is a cultivar that produces a large and vigorous plant, released in 2014 by the UC Davis strawberry breeding program. It has performed well in Texas A&M AgriLife Extension trials across the state for 5 years or more. Fronteras has produced good yield under a wide range of nitrogen rates, although it typically averages 15 percent less yield than Camino Real. Fruit quality and shape are excellent, and Brix averages 9.0. Fronteras produces a moderate number of runners. Research indicates it is resistant to *Phytophthora* crown rot.

'Keepsake' is a newer mid-season strawberry recently released by the USDA-ARS in Beltsville, Maryland. It is closely related in genetics to Flavorfest (see above), so boron uptake was also high and toxicity symptoms were recorded. Thus, nutrient management is essential. Like Flavorfest, growers may want to evaluate a few plants of Keepsake prior to large-scale planting. However, it is not recommended for growing in Texas as it produced very low yields, with moderate runner production. The berries were misshapen and non-uniform in size. A few berries harvested were large, juicy, and had excellent flavor. The berries were very sweet with an average Brix of 11.9, the highest in the Texas trials.

'Medallion' is a recent release from the University of Florida breeding program. It has consistent conical-shaped berries with uniform size. The berries are nice looking, a medium red color, glossy, and very firm, making it a good cultivar for short-term storage. In Texas trials, berry size was in the medium range, yields were average, and Brix was 9.2. It is a more compact but upright plant, allowing for an easier harvest. However, plant growth will increase with higher fertilization rates needed to achieve optimum yield. It produces fewer runners and shows resistance to *Phytophthora* crown rot.

'Merced' is a cultivar that has been around for a while. While many growers in Texas have grown Merced, it is more difficult to find at nurseries. When grown under optimum conditions, the plants are large and vigorous, though somewhat smaller than Camarosa. The berries are lighter in color with good flavor. In Texas trials, it was evaluated for at least 5 years and did well under a wide range of nitrogen rates. Its yields are almost equal to Camino Real.

'Florida Radiance' is a cultivar that performs better in high tunnels than in open fields in Texas. In the open fields, plants are susceptible to damage in high-wind regions. The plant canopy is more open and throws its fruit out for easy harvesting. It produces beautiful, uniform, large conical berries. In high tunnels, it can produce early in the fall and even during the winter months. The fruit is smooth and glossy, bright to dark red, and is easier to harvest than many cultivars. The fruit is juicy, with a nice calyx and the flavor is acceptable. However, Brix only averaged 7.6; therefore, it is not as sweet as other cultivars. It is moderately resistant to anthracnose crown and fruit rots, but it is highly susceptible to *Phytophthora* spp. crown rot.

'Pearl' is a new cultivar from the University of Florida breeding program. It is an early, short-day cultivar characterized by berries with white flesh both inside and outside. It is a somewhat compact plant but with excellent yields. The fruit is medium-sized and conical-shaped. Pearl is very resistant to most diseases and other pests. For growers that are looking for a white strawberry, it is likely a good choice.

'Ruby June' is a strong short-day cultivar and a grower favorite. Plantings of Ruby June continue to expand throughout Texas. It does well in the southern regions of Texas. It has performed well in Texas A&M AgriLife and grower trials as well as high-tunnel trials on the High Plains. Ruby June produces very sweet, dark, flavorful berries on medium to large plants. The plants are somewhat compact. While overall yields are not the highest, the berries typically rank high in taste and are a favorite with consumers. The berries are medium to large and have one of the darkest exterior and interior red colors, medium firmness, and an average Brix was 10.5 in Texas trials. Ruby June is resistant to many diseases.

'Sweet Charlie' is a popular cultivar still grown in Florida and southern states and is one of the first to flower. It has performed well in Texas and does very well in high tunnels. It grows best in lower-pH soils. The plants are medium to large and easier to harvest. The berries are also medium to large but medium in firmness. They are great for fresh market and U-pick sales. The plants are prolific in flowering, with large fruit in the first few weeks followed by much smaller fruit beyond that. Fruit ripening can be somewhat variable, but flavor is excellent. Sweet Charlie is resistant to crown and fruit rot, powdery mildew, and two-spotted spider mites. It is highly resistant to anthracnose fruit rot caused by *Colletotrichum acutatum* and is somewhat susceptible to *Phomopsis* leaf blight and fruit rot and *Botrytis* gray mold fruit rot.

'Sweet Sensation' was released in 2013 by the University of Florida breeding program and is an earlier-maturing short-day cultivar. It is good for early plantings and flowers early. It may need row covers for early spring freezes. It was evaluated for 1 year in Lubbock trials with mixed results. It is well adapted to plasticulture and grows well in open fields and high tunnels. In Texas, the plant was compact but robust, making harvesting easy. Overall yields were average. The fruit has been described as uniform, medium to large, medium to bright red in color, and glossy. Sweet Sensation is resistant to anthracnose fruit rot but may be more susceptible to *Botrytis* fruit rot and *Phytophthora* crown rot compared to other cultivars. Careful nitrogen and irrigation monitoring improves yield and quality.

'Sierra' is a relatively new cultivar released by the Lassen Canyon Nursery breeding program. The plants are moderately vigorous. The berries ripen in the early to medium season and are conical, very attractive, medium firm, with good disease tolerance. The fruit has a light red exterior and should look appealing at farmers' markets. The fruit ripens nearly up to the calyx and there is no unripe shoulder. Although not a high-yielding cultivar in Lubbock trials, the berries were very sweet, measuring 11.2 in Brix.

'Victor' is a new cultivar released from the UC Davis breeding program. In California, the plants are considered compact, but they were the largest in the 2023 Texas trials. Overall plant growth may be a factor in the total nitrogen applied. Flowering occurs during mid to late season, making it a good choice to plant with early cultivars. The later flowering is good for reducing loss due to freezing temperatures. Research in Texas indicates Victor produces medium yields, though it has only been evaluated for 1 year. The berries are medium to large, exceptionally firm, and nice in appearance. Brix averaged 9.3, so they are not as sweet as other cultivars. Victor does have good resistance to *Fusarium* and *Phytophthora*.

Weather Monitoring

The climate is both a friend and an enemy to sensitive crops like strawberries. Observing the current or near future potentially damaging weather patterns is essential for all strawberry producers. Preparedness can be the difference in profitability. Pre-irrigating fields before bed shaping during dry weather can improve strawberry beds. After planting, it may only take one light freeze to kill developing flowers and buds and significantly set back the season.

It is best to download a local weather app and receive alerts for excessive cold or hot temperatures and plan accordingly. Getting weather alerts will help make the many critical decisions needed to protect the strawberry plants, flowers, and berries from adverse weather. Adverse weather includes drought, freezes, hail, wind, and heavy rains. While it may not be possible to protect the plants from all types of adverse weather, being prepared for damaging conditions is critical.

Weather apps can also provide information on relative humidity and rainfall. Under high humidity, berries are more susceptible to fungal and bacterial diseases, which may impact pest control (spray applications) and harvesting decisions.

Purchasing protective covers ahead of the season can help in areas where freezing temperatures occur, including South Texas. Even if covers are not needed for the current season, being prepared for future events is an important tool. Growers must decide whether covering the plants with row covers or low-tunnel plastic on the High Plains or closing high tunnels, overhead irrigating to protect flowers, or irrigating during drought conditions and shading during hot temperatures is critical to their sustainability. Each decision is based on grower preference, labor availability, and farm income. However, in most cases, protective measures, whatever they are, usually pay for themselves when employed.

For more details on protective covers, including high/low tunnels, see the *Production Systems* section.

Pollination

Pollination is the act of transferring pollen (male genetics) grains produced by the anther, or male part, of a strawberry flower to the stigma, or female part. Many plants have either female or male flowers, while some have both. Some plants have flowers with both male and female structures. The pollen is transferred by pollinators (bees, flies, and other insects) or by wind to produce seed for reproduction.

Strawberry flowers are self-pollinating and have both male and female structures. The flowers produce both pollen and nectar that is attractive to pollinators. To produce fully formed berries, each flower must be pollinated evenly, either by wind, insects, or both. Cross-pollination produces more fruit than self-pollination and leads to fewer deformed berries. Self-pollination by wind is enough to produce good yields, but pollination from wild bees, honeybees, or bumblebees (including those that can be purchased) may increase yields by 20 percent.

Poorly pollinated flowers lead to misshapen berries and lower marketable yields. Full pollination can require as many as 10 to 20 pollinator visits to a flower. Depending on bee activity and the weather, full pollination can take 3 to 7 days. Bee-pollinated fruit may be heavier and may be redder, firmer, and have a lower sugar-to-acid ratio.

Bumblebees are considered better pollinators than honeybees because they visit more flowers daily. Bees are most active during the morning and early afternoons when temperatures are

Figure 15. Honeybees (left) and bumblebees (right) are excellent pollinators and should be protected from pesticides and other harmful products. They can improve the quality of the fruit and increase yield.

between 50 and 85 degrees F. When hives are placed inside high tunnels, avoid overheating the hives by raising the side ventilation systems when it is hot. Honeybees use sunlight for navigation and do not work as efficiently inside high tunnels or greenhouses.

Bee activity also depends on flowering patterns. When the strawberry crop does not have enough flowers, bees will go elsewhere in search of pollen and nectar. This may reduce their efficiency when strawberries are in full bloom. To reduce this influence, mow nearby weeds regularly to keep flowering to a minimum, thereby reducing competition with the strawberry crop.

Bees are active throughout most of the day and are easily killed by insecticides. Therefore, use insecticides cautiously. Read and follow the label instructions for each insecticide as some may have residual for several days. Labels also have instructions regarding how to reduce injury or death to pollinators. It is best not to spray certain insecticides directly onto the crop during peak bee activity.

Fertilization

Nutrient Management

To grow strawberries successfully and profitably, the developing crop must have available the appropriate nutrients from transplanting throughout the harvest season. Understanding each farm's soil plant-available nutrient levels and the plant's fertilizer needs can be challenging. However, these are critical to maximize yield. A lack or excess of one essential nutrient can result in yield and quality losses.

Nutrient deficiencies in plants reduce plant growth and yields by interfering with physiological processes, such as photosynthesis, cell reproduction, etc., and prevent the plant from optimal performance. Conversely, over-fertilizing strawberries may result in excessive levels that can also interfere with physiological processes and cause plant cell death, leaf burn, or plant stunting.

Whether fertilizing with organic or conventional products, strawberry roots take up nutrients in the same chemical form. Nitrogen from compost, manure, or processed fertilizer is absorbed by the roots as ammonium and nitrate. Therefore, the source of fertilizer is not as critical as the right amount. This section describes the importance of optimizing strawberry fertilization.

Nutrient needs for strawberries across the season can differ between locations in Texas. For example, nitrogen uptake during the winter months will be less compared to early spring and summer. Following transplanting, nutrient uptake may be quicker in South Texas compared to North Texas or the High Plains due to temperature differences. Based on soil tests, macronutrients like nitrogen, phosphorus, and potassium are generally applied before bed shaping. Rates may differ based on soil tests. Deficient micronutrients can be easily applied through drip systems.

Soil Testing

It is very important to collect a soil sample for testing before preparing the land and shaping strawberry beds. Soil sampling is critical prior to planning strawberry planting and nutrient management, especially when rotating crop production fields. Collect samples approximately 3 months before planting to determine the amount of nutrients (deficiency or excess) in the soil and soil pH and provide recommended amounts needed to correct deficiencies. It is best to resolve nutrient deficiencies prior to planting rather than risking deficiencies during the growing season as plant injury may occur with yields reduced before symptoms are visual.

Figure 16. Collecting soil samples (left) before and during the strawberry season helps correct plant nutrient deficiencies before significant problems occur. Though not as common, tissue or leaf samples (right) can also be collected regularly during the season.

It is best to collect random soil samples from the field at 6- and 12-inch depths. Samples from the same field can be combined and thoroughly mixed, from which a sub-sample from each depth can be submitted for testing. Soil testing labs may be available locally or samples can be sent to labs in other states. Texas A&M AgriLife Extension offers soil testing services, and *sample forms* can be found on their website. Since strawberries are sensitive to many essential nutrients, it is best to get the soil analyzed for pH levels and all macro and micronutrients.

It is also important to know that even fields within a farm or county can have very different textures and available nutrients. Table 6 includes differences in soil pH and available nutrients from 19 strawberry farms sampled across Texas. As seen, soils from the strawberry fields in the diverse regions can have significantly different levels of soil pH and nutrients. For this reason, making specific recommendations for strawberry production in Texas can be difficult and must be made on a farm-by-farm basis. However, some generalizations are important.

For optimal growth, strawberries do best in acidic to slightly acidic soils with pH levels between 5.5 and 7.0. This pH range is optimal for plant nutrient availability in soils. A higher (more alkaline) or lower (more acidic) soil pH may result in some nutrients becoming less available for root uptake.

If soil is too acidic (below 5.5), the addition of limestone can help raise the pH, but avoid raising it too high. Strawberries can grow in slightly alkaline soils, even those with pH levels greater than 7.5. Soil amendments like elemental sulfur and ammonium sulfate may be used to lower the pH, but this depends on soil type. In certain soils, such as those in South Texas, acidifying materials may have a limited effect due to the high buffering capacity of calcareous soils containing high levels of calcium and magnesium carbonate.

Tissue Sampling

Tissue sampling is a method for determining plant nutrient concentrations during the crop season, indicating potential deficiencies due to low uptake and limited availability. Tissue samples, such as from leaves and petioles,

Figure 17. Petiole and leaf samples should be collected from random plants with the same level of maturity. Avoid older leaves as well as newly emerged leaves.

indicate what the current nutrient levels are in the plant at that specific time. Leaf sampling can detect nutrient deficiency and toxicity levels, but it may take several weeks to get results, thereby delaying quick corrective actions.

Tissue sampling demonstrates the effectiveness of a soil nutrient management program. Leaf nutrients are measured by analyzing the "suggested sufficiency levels" of essential nutrients. This is based on previous research in California and other states. Suggested sufficiency levels are the minimum levels of selected nutrients required for plants to achieve maximum yield. As mentioned previously, when one of the nutrients is either below or above the sufficiency level, yield loss may occur.

For tissue analyses, leaf samples (the petiole plus the three leaflets) should be collected from the same location and leaf maturity on multiple plants at the same time. Avoid older yellowing leaves and newly emerging leaves. New fully expanded leaves are best. Each cultivar should be sampled independently as there may be differences in specific nutrient requirements. Follow the mailing instructions for the lab selected for analysis.

Table 6. Differences in preplant soil nutrient analyses reported from samples collected at 17 grower's fields from selected regions across Texas in 2022

Farm location	pH	% OM	NO_3	P	K	S	Zn	Fe	Mn	B
South Texas										
A	6.5	2.4	14	**49**	**340**	12	*1.8*	**15**	15	*0.3*
B	6.1	1.0	**33**	**91**	**235**	**23**	*0.7*	**32**	16	*0.2*
C	6.9	1.4	*6*	**119**	**256**	9	3.3	**24**	*8*	*0.4*
D	6.7	2.4	**35**	**47**	**402**	6	*0.7*	7	21	*0.3*
E	**7.4**	2.2	**22**	**50**	**512**	**73**	*1.5*	6	16	*0.1*
F	6.3	1.2	*9*	**54**	86	*5*	*2.3*	**48**	*7*	*0.4*
G	**7.2**	3.3	*4*	**96**	**250**	**18**	**3.7**	**14**	*9*	*0.1*
Central Texas										
H	6.9	1.1	**20**	**60**	**300**	*2*	*0.7*	**10**	19	*0.5*
I	**7.6**	3.3	*8*	**32**	**700**	*7*	*1.7*	8	**24**	*0.3*
J	6.9	3.4	*6*	*16*	**341**	*7*	3.0	7	16	*0.5*
East Texas										
K	5.6	1.3	*6*	**46**	**108**	*4*	*2.0*	**99**	12	0.4
North Texas										
L	5.5	2.2	**24**	**58**	126	11	*0.7*	**99**	**36**	0.7
M	6.2	1.6	55	26	123	14	**2.4**	**22**	**20**	0.1
High Plains										
N	**7.3**	1.9	21	**43**	**579**	**51**	*0.9*	*5*	*8*	*0.5*
O	**8.0**	1.8	10	**34**	**543**	**18**	*0.7*	6	*9*	*0.2*
P	6.8	1.1	*6*	**88**	**507**	**49**	*1.9*	*5*	17	*0.5*
Q	**7.7**	1.8	*7*	**28**	**675**	*3*	*0.7*	6	15	*0.4*

*Font styles and colors for nutrient values based on whether the levels are low (red, italicized), medium (black, no style), or high (**blue**, bold) in the grower's soil. Samples were sent to the Texas A&M AgriLife Extension Service Soil, Water and Forage Testing Laboratory in College Station, Texas.*

Assessing Tissue (Leaf) Nutrient Analyses

Table 7 depicts the leaf nutrient (N, P, K, Ca, Zn, Fe, and B) levels of three cultivars (Albion, Camino Real, and Fronteras) sampled from three locations with different soil pH levels in Texas. Each location was fertilized at a rate of 120 pounds of nitrogen per acre. The table also shows the California recommended suggested sufficiency levels for those nutrients.

The leaf analyses indicate the nutrient levels for Albion, Camino Real, and Fronteras. In some cases, the average nutrient levels differ by cultivar and location. In South Central Texas and the High Plains, depending on the cultivar, nitrogen (N) levels were at or below recommended levels, while in the north, all cultivars were within the sufficiency range. Nitrogen is very mobile in the soil and is usually the most limiting nutrient. Adjustments to nitrogen fertilizer programs may help depending on the strawberry cultivar.

Table 7 also shows phosphorus (P) levels in leaves from the South Central and North Texas crops which were within the recommended sufficiency range. However, strawberry leaves from the High Plains crop fell below the recommended sufficiency levels. This suggests that even when soil samples analyzed from the same location have elevated phosphorus levels, plant uptake may not be sufficient to fall within the recommended sufficiency level.

The results demonstrate that while soil tests may indicate appropriate or even high nutrient levels, the availability of that nutrient to plants grown under high pH levels may be limited. Lower-leaf phosphorus levels in strawberries may also be a result of the interaction of high iron (Fe) levels, which for plants on the High Plains were three to four times higher in the leaves of all cultivars compared to the recommended sufficiency range.

Potassium (K) levels in leaves sampled were within the sufficiency range on the High Plains but were above sufficiency levels for Albion

Table 7. The levels of selected nutrients sampled from the leaves of Albion (AL), Camino Real (CR), and Fronteras (FR) grown with a seasonal fertilizer rate of 120 pounds N/A in South Central, North, and the High Plains during 2020

Macronutrients	South Central *Soil pH 6.5* Sandy loam			North Texas *Soil pH 7.0* Sandy loam			High Plains *Soil pH 7.6* Clay loam			Suggested sufficiency levels (CA*)
	AL	CR	FR	AL	CR	FR	AL	CR	FR	
N (%)	3.1	*2.7*	*2.8*	3.1	3.2	3.5	*2.9*	*3.0*	*3.0*	3.1 – 3.8
P (%)	0.7	0.6	0.5	0.6	0.7	0.7	*0.3*	*0.4*	*0.3*	0.5 – 0.9
K (%)	**2.6**	1.9	**2.6**	2.0	1.9	**2.5**	1.8	1.8	2.2	1.8 – 2.2
Ca (%)	1.0	0.9	0.8	1.1	1.3	0.9	1.2	1.2	1.2	0.6 – 1.3
Micronutrients										
Zn (ppm)	22	22	19	26	26	**29**	14	14	14	13 – 28
Fe (ppm)	96	111	97	99	101	**549**	**442**	**347**	**409**	70 – 140
B (ppm)	43	39	41	**48**	**51**	**55**	**57**	45	**67**	31 – 46

** From The University of California Agriculture and Natural Resources website. Nutrient values highlighted in **red and italicized** indicate levels below the average range for suggested sufficiency levels. Nutrient values highlighted in **blue** and bolded indicate levels above the average range.*

and Fronteras in South Central Texas and for Fronteras in North Texas. These results occurred even though potassium levels in soils tested at all three locations were somewhat high and found to be excessive in the High Plains (Table 6). Calcium (Ca) levels for leaves sampled at all locations were within the sufficiency range levels for all cultivars and, therefore, were not a limiting factor.

In North Texas, Fronteras had higher than the suggested sufficiency levels for zinc (Zn), iron, and boron (B). On the High Plains, the leaves of Fronteras had very high levels of iron and boron. Interestingly, boron levels found in the leaves of the cultivar Flavorfest (data not shown) had toxic levels at all three locations, which significantly reduced its growth. As a result, Flavorfest is not recommended for Texas.

Leaf analyses for zinc showed that all cultivars sampled were within or close to the sufficiency levels. Zinc deficiency symptoms were also temporarily observed in leaves on the High Plains and are likely a result of the interaction between zinc and high phosphorus in alkaline soils.

Iron levels in leaves sampled from all cultivars on the High Plains and from Fronteras in North Texas ranged 250 to 490 percent greater than the suggested sufficiency level. In the High Plains alkaline soils, iron uptake through the roots—even with high soil levels—can be limited due to its interaction with phosphorus. As a result, iron chlorosis or deficiency can sometimes be expressed. If deficiency symptoms are observed, a soluble chelated form of iron should be sprayed on the foliage or applied through drip irrigation to the roots to help overcome the deficiency.

Boron is an important micronutrient in strawberry production. Low boron levels may reduce crop growth, while high levels may result in plant toxicity. In South Central Texas, boron levels in sampled leaves were within the sufficiency range for the three cultivars. In North Texas and the High Plains, boron levels were in the upper sufficiency range or higher in all cultivars. However, with the exception of Flavorfest, this did not appear to affect yields.

High-pH Soils

Texas soils are widely diverse in both texture and pH. A 2022 survey of strawberry fields showed that soil pH ranged from 4.6 to 8.0. With this diversity, recommending nutrient programs for growers is challenging. Strawberries grow best in soils with a pH range of 5.5 to 7.0, which is optimal for nutrient availability and root uptake. When soil pH is more alkaline and above 7.5, essential nutrients are less available, possibly increasing nutrient deficiencies.

Depending on soil properties, a temporary change in the soil pH can benefit strawberry production. Attempts to lower the soil pH should occur only for the strawberry bed, not for the entire field. The idea is to lower the pH around the roots of the plants rather than in the entire field. Concentrating on the strawberry bed will decrease costs and be more efficient. Be sure to follow the product application instructions carefully.

On the High Plains, elemental sulfur—either applied preplant or through drip irrigation during the season—can help lower the pH. However, adding sulfur to some soils in South Texas may not effectively change the pH because of high amounts of calcium and magnesium carbonate buffering the pH and making it more difficult to acidify the soil. Ammonium sulfate (21-0-0-24) granules can be applied during land preparation or during the crop season as a soluble formulation through drip irrigation systems. During the microbially mediated nitrification process of ammonium nitrogen to nitrate nitrogen, acidity is generated and the pH of the soil is lowered. Growers wishing to lower the soil pH should put out a test plot to determine whether elemental sulfur or other products are effective.

Fertilizer Applications

While strawberries are considered low-growing and small plants, they require high and consistent amounts of nutrients available throughout the season for optimal growth and yields. Over 95 percent of annually produced strawberries are fertilized through drip lines placed beneath the plastic mulch and between the two rows of plants. Fertilizers are best applied following planting through drip irrigation systems. Drip systems target the strawberry roots and fertilizer rates can be controlled efficiently. Growers should have fertilizer systems that are efficient at nutrient delivery. Fertilizer systems should be checked and cleaned before the first application and regularly during the crop system to avoid misapplications.

Granular fertilizer is often applied preplant to the soil during land preparation or bed shaping. Many growers apply one-third to one-half of the total nitrogen needs at that time. This helps the plant roots move deep into the soil to search for nutrients during the fall when new growth and development occurs. Once plants begin to flower in the spring, fertilizer applications should be made weekly until at least 2 to 3 weeks before the final harvest.

Granular and Controlled-release Fertilizers

Preplant soil-applied products include granular and controlled-release fertilizers (CRF). Granular fertilizers should be applied at the appropriate rates based on previous soil tests and knowledge of soil type (sandy versus clay loam, etc.). Fertilizer applied in sandier soils will leach out quicker than in clay or clay loam soils. If recommended, it is beneficial to apply preplant fertilizers using a balanced (N, P, K) product so plants will have sufficient macronutrients for root uptake during the first few months. Most soils contain enough micronutrients, though a soil test will indicate whether any are needed to be applied preplant. If micronutrients are deficient, applying fertilizers with those will be beneficial. If not, micronutrients can be applied through drip systems during the growing season or applied as a foliar spray.

Nitrogen is the most limited nutrient for most crops, including strawberries, and it is essential for all preplant applications. Nitrogen is very mobile in the soil, and therefore, it is critical to not over-irrigate the beds and leach it out following preplant applications. It is also important to not apply excessive amounts of readily available nitrogen, as excessive amounts will burn roots and hinder growth.

Though fertilizer costs continue to rise, granular fertilizers are generally available and easy to apply during land preparation. The most efficient approach to applying granular fertilizers is with a spreader on a tractor. When using a spreader, be sure to calibrate it for applying the correct amount. Application uniformity across the field is important. Over- or under-applications can create uneven plant growth and delay maturity and yield.

CRFs are manufactured as coated pellets and are increasingly more popular in strawberry production. They are used widely in California and Florida. Advantages of CRF products include ease of use, reduced fertilizer application costs, and potentially reduced environmental impacts. The disadvantages include a lack of flexibility once applied and a nutrient rate that is "locked-in" once applied. However, growers can still supply nutrients using fertigation to supplement nutrients as needed.

CRFs slowly release nutrients into the soil around the root zone based on soil temperature and moisture. Special formulations can release nutrients for up to 9 months or longer during the strawberry season. Other benefits of CRFs are that when based on farm soil tests, the nutrients can be individually designed and manufactured for specific strawberry needs.

CRF products are applied preplant to the bed in the soil several inches below the plastic mulch surface. They can also be applied on the soil surface between it and the plastic film. If needed, CRFs can also be broadcast over the entire field before bed shaping. When beds are shaped, the product will be concentrated in the strawberry beds and will be available for the roots as they expand in the soil throughout the growing season.

Soluble Fertilizers, Biostimulants, and Other Soil Amendments

Many types of soluble fertilizers, biostimulants, and soil amendments are available for agricultural crops. They are generally sold as liquids or soluble granules, which readily dissolve in water. They can also be applied either as a drench, in-furrow, to the foliage, or through the drip system. Many of these products contain the micronutrients required for plant growth, and some are manufactured with beneficial organisms (fungi and bacteria) or plant extracts.

Soluble fertilizers and amendments for strawberries are best injected through the drip irrigation system (fertigation) and applied directly to strawberry roots. Applications through the drip system generally improve nutrient uptake better than foliar sprays. As the crop grows, especially when flowering, weekly fertigation will keep the strawberry roots supplied with essential nutrients, ensuring the plants remain in optimal health.

Following transplanting, an application of a "pop-up fertilizer" or a biostimulant that is quickly available for root uptake will provide a quick start and improve plant growth. Increasing crop growth during early growth is important, especially as the plants prepare for overwintering. Most preplant fertilizers do not last the entire 9-month crop season (except for CRFs), so weekly applications are needed. Weekly fertigation will provide the crop's nutrient needs, which may change during the season when flowering increases and berry growth occurs.

▲ **Figure 18. Weekly applications of fertilizers are essential to keeping an adequate supply of nutrients in the strawberry root zone.**

Foliar-applied Fertilizers

It is best to supply plant nutrients to the soil for root uptake. However, under certain conditions, some nutrients are deficient. Deficiencies can be corrected using foliar applications by spraying products onto the leaves. Care should be taken to follow label instructions to avoid potential flower and leaf injury.

Common nutrient deficiencies in Texas-grown strawberries include the macronutrients of nitrogen, phosphorus, potassium, calcium, and sulfur. These are generally applied to the roots for uptake. Micronutrients like zinc, iron, boron, manganese, and copper products are commonly manufactured as foliar fertilizers. Foliar sprays are easy applications. Micronutrient plant deficiencies can be temporarily corrected using these foliar-applied fertilizers. The products are chelated formulations, which means they are more readily available for uptake in leaves. While foliar applications are good, some chelated micronutrients like iron, zinc, and boron can be applied to the roots through the drip system.

Application timing is critical. It is best to spray foliar treatments at the first sign of deficiency. Foliar sprays may not correct severe deficiencies. However, their use has been reported to increase fruit firmness, sugar content and flavor, fruit set, and yields. Strawberry research with foliar-applied fertilizers has not been conducted in Texas; therefore, recommendations are not provided. Application of foliar fertilizers should be based on the specific label instructions of each product.

Common Nutrient Deficiencies and Symptoms

Nitrogen is a major component of plant growth and chlorophyll production in leaves. It assists with converting sunlight energy into sugars using carbon dioxide (CO_2) and water via photosynthesis. It is one of the most common deficiencies in plants statewide due to greater plant requirements and loss potential from the soil. Deficiency symptoms include stunted plant growth and overall leaf chlorosis. Symptoms first begin on the older leaves. With nitrogen deficiency, overall strawberry plant growth and flower and fruit size are reduced, and marketable yields will be reduced.

▼ **Figure 19. Nitrogen deficiency is identified by symptoms including stunted plant growth and general leaf chlorosis. Symptoms first begin on the older leaves.**

Phosphorus works by converting nutrients into the basic building blocks for overall plant growth. Phosphorus stimulates root growth, stem strength, flower formation, and berry quality and improves plant resistance to diseases. Phosphorus deficiency symptoms begin on older leaves that become excessively dark green with possibly a purplish-reddish tint, especially on the underside of the leaves. The purpling brightens as the leaf ages with continued deficiency. The fruit, flowers, and leaves are generally reduced in size.

▼ **Figure 20. Phosphorus deficiency symptoms begin on older leaves that become excessively dark green with possibly a purplish-reddish tint, especially on the underside of the leaves.**
Photo source: Yara International.

Potassium is used for energy (sugar) transport in the plant for improved growth and enzyme production. Potassium is important in the control of leaf stomata for CO2 uptake, photosynthesis, leaf respiration, etc. Like phosphorus, potassium increases plant resistance to diseases. Potassium deficiency symptoms are found on the older leaves as purplish-black regions with possible dry (necrotic) margins that progress inward between leaf veins, giving them an appearance of being scorched. There may be no symptoms on younger leaves.

▲ **Figure 21. Potassium deficiency can be found on older leaves as purplish-black regions with possible dry (necrotic) margins that progress inward between leaf veins, giving them an appearance of being scorched.**

Calcium is a major nutrient in the building of plant cell walls, as it improves plant structure, berry firmness, and berry shelf life. Calcium also helps increase plant cold tolerance and disease resistance. Calcium deficiency symptoms include deformed and/or necrotic leaf tips, unusually hard berries with higher seed density, and small fruits that are densely covered with seeds.

▼ **Figure 22. Early signs of calcium deficiency in strawberries include deformed and necrotic leaf tips, often on the newer leaves.**

Iron is required in plants for the synthesis of leaf chlorophyll and is used in photosynthesis. Iron is also needed for energy production and overall plant growth. Iron deficiency symptoms include the appearance of bright yellow younger leaves with green veins. Under severe deficiency, leaves may be bleached with brown areas developing between veins. Newly formed leaves become progressively smaller. Iron deficiency is more common in high-pH soils.

▲ **Figure 23. Iron deficiency symptoms appear on younger leaves, causing them to be bright yellow with green veins. Severely deficient leaves are bleached with brown areas developing between veins, and newly formed leaves become progressively smaller.**

Zinc is needed for synthesis of plant hormones like auxins used in plant growth and development as well as for the activation of certain plant enzymes. Deficiency symptoms include yellowing of younger leaves with green veins and leaf margins. Leaves may become narrower and reddish in color as they mature. Berry size and number are reduced. Zinc deficiency is more common in high-pH soils, though symptoms often disappear as the plants mature and roots move deeper into the soil profile.

▲ **Figure 24. Zinc deficiency symptoms include yellowing of younger leaves with green veins and leaf margins. Leaves may become narrower and reddish in color as they mature.**

Boron is used in the formation of plant cell walls, plant metabolism, and sugar transport within the plant. Deficiency symptoms include younger leaves that are crinkly in appearance, yellowing and burned leaf tips, fruit size reduction and deformity, and stubby roots. Boron toxicity symptoms include necrotic lower leaves with spotting and marginal leaf necrosis that eventually covers the entire plant. Plants are stunted and growth is excessively compact. Certain cultivars seem more sensitive to boron toxicity than others.

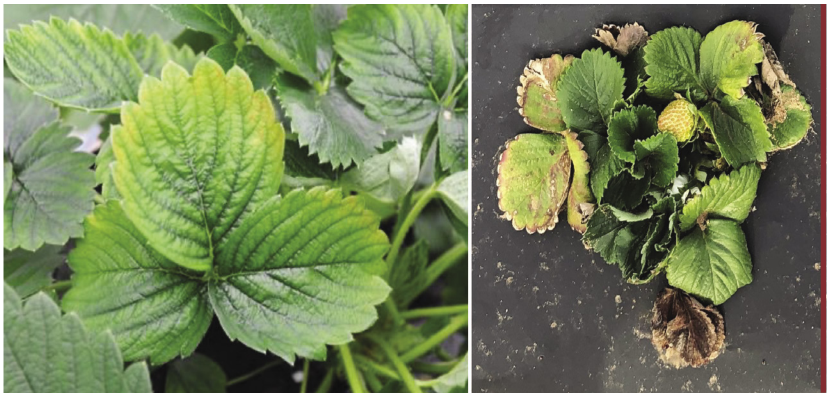


Figure 25. Boron deficiency (left) is identified with younger leaves that are crinkly, yellowing, and have burned tips. Boron toxicity symptoms (right) include necrotic lower leaves with spotting and marginal leaf necrosis that eventually covers the entire plant. Plants are stunted and growth is excessively compact.

Photo source (Boron deficiency): Yara International.

Cultivar Responses to Fertilizer Rates

Strawberry cultivars may differ in growth and yield response to increasing fertilizer rates. Because it simplifies labor and time, most growers apply equal amounts of fertilizer to all cultivars. However, doing so could result in economic yield loss, increased runner production, or unnecessary fertilizer costs. In Tables 8 and 9, Texas A&M AgriLife Extension trials demonstrate the yield responses of Albion and Camino Real cultivars when increasing nitrogen rates are applied.

Research in a recent field study (Table 8) demonstrated that as nitrogen rates increased from 60 to 180 pounds nitrogen per acre, Albion yields **decreased** 26 percent. In contrast, as nitrogen rates increased to 180 pounds per acre, Camino Real yields **increased** 24 percent. These results suggest that over- or under-fertilizing some strawberry cultivars may influence crop yield. For example, at higher nitrogen levels, Albion produces excessive amounts of runners, resulting in lower berry yields. Other cultivars—especially day-neutrals—may respond similarly.

In Table 9, average yields of five cultivars are shown averaged by cultivar and across three fertilizer rates. When averaged across fertilizer rates, Fronteras and Camino Real had significantly higher yields compared to Chandler, Albion, and Flavorfest. However, when cultivars were averaged across each fertilizer rate, there was no "significant" difference in yield.

The results in Table 9 suggest that cultivar selection is not only important for achieving high yields, but with each cultivar, increasing or decreasing fertilizer rates can significantly influence overall production. Less fertilizer applied to cultivars requiring lower nutrient

Table 8. Comparison of Albion and Camino Real yields at increasing rates of nitrogen fertilizer (Lubbock)

Fertilizer rate (lb N/A)	Yield (lb/A)	
	Albion	Camino Real
60	8,122	10,935
120	7,215	11,310
180	6,001	14,480

Table 9. Comparison of strawberry yields when averaged across variety or fertilizer rate at Lubbock (2020)

Variety	Yield (lb/A)	Fertilizer rate (lb N/A)	Yield (lb/A)
Fronteras	15,028 a	60	10,563
Camino Real	14,266 a	120	9,257
Chandler	12,197 b	180	11,108
Albion	8,494 c		
Flavorfest	1,416 d		

Yield averages within columns followed by the same letter are not significantly different from each other at the 0.05 significance level.

▼ **Figure 26. The effect of increasing rates of nitrogen at 60 pounds N/A (left), 120 pounds N/A (middle), and 180 pounds N/A (right) for the season on strawberry plant growth.**

levels saves production costs and reduces potential leaching of excess nutrients into groundwater and allows for optimal yield potential.

It is important to understand that fertilizer application rate should be seriously considered when selecting future cultivars. With the high number of cultivars available, additional research is needed to determine optimal fertilizer rates for cultivars grown in Texas. This is true especially when considering the wide range of soil types, newly released cultivars, and production methods across Texas.

It is also critical for growers to evaluate new cultivars with selected fertilizer rates to optimize production. Determining the correct rate is critical for maximizing overall cultivar yield. Determining the appropriate fertilizer rate comes with experience. Production nurseries may have information on specific cultivars.

Soil Salinity

Strawberries are salt-sensitive plants. Growing strawberries in soils with moderate to high salt concentrations often results in reduced yield and berry quality. Symptoms of salt injury include brittle leaves with marginal leaf burning or browning, plant stunting, and dead roots. In severe cases, plant death may occur.

High soil salt levels interfere with root growth from the strawberry crown, reducing root development, moisture uptake, and overall crop yield. Excessive fertilizer or compost applications and foliar sprays can result in salt toxicity symptoms. Salt injury can be confused with root and foliar diseases or herbicide injury; therefore, a correct diagnosis from injured plants is needed before corrective treatments can occur. Strawberry plant response to salinity may depend on plant growth stage, soil type, cultivar, and growing environment.

Like the fertilizer requirements mentioned above, strawberry cultivars may differ in tolerance to soil salinity levels. To improve growth in moderate- to high-saline soils, it is important to understand what soil salinity is. Salinity is a measurement of the concentration of dissolved mineral salts in their ionic forms, including sodium (Na^+), magnesium (Mg^{2+}), chloride (Cl^-), calcium (Ca^{2+}), sulfate (SO_4^{2-}), and bicarbonate (HCO^{3-}) in water or soil. The amount of each of these salt ions in water and soil varies widely by region and individual fields

Overall salinity is best described as the concentration of total dissolved solids (TDS) in water. It is measured by the electrical conductivity (EC) of irrigation water or by a soil sample. Salts will often accumulate in soils or fields that are highly fertilized (e.g., strawberries) or irrigated with water high in mineral concentrations. Soil types with higher salt concentrations are more prevalent in arid and semiarid regions of Texas where rainfall is low and evapotranspiration is high but may also occur during temporary drought conditions.

For new growers with little experience, it is recommended to get soil and irrigation water analyzed for salinity prior to planting strawberries. Where soil analyses indicate high salinity levels, growers should consider either not planting strawberries or planting potentially salt-tolerant cultivars. This may reduce salt effects on yield and berry quality. As with other production practices, conducting small cultivar trials in fields with potentially high salinity levels is important before planting on a large-scale production.

Higher salt levels can potentially be found in fields with low spots or where soil drainage is poor. Salts can accumulate in high-tunnel strawberry production, where fertilizers and irrigation water are applied through drip systems, where drainage may be limited by plastic mulch and covers, and where no rainfall can leach salts from the upper soil levels

Unfortunately, no field salinity research has been conducted in Texas on strawberries. However, Texas A&M AgriLife Extension greenhouse trials (Sun et al., 2015) demonstrated that strawberry cultivar response varied to low, medium, and high salinity levels. For example, Albion, Camarosa, and San Andreas were more salt tolerant, while Benicia, Camino Real, Chandler, and Radiance showed less tolerance. Other university research confirms varying responses of strawberry cultivars to increasing salt levels. In Texas, this indicates the importance of cultivar selection in regions with medium- to high-saline soils or where there are high salinity levels in irrigation water.

Strawberry plants are very sensitive to increasing chloride levels. Care should be taken when using chlorinated city water to grow strawberries. Where chloride levels are high, mixing city water with filtered water or captured rainwater on small fields can help. Chloride toxicity symptoms include leaf yellowing followed by progressive death from the leaf margin inward.

Sodium sulfate and sodium bicarbonate do not cause immediate toxicity symptoms in strawberries. However, moderate to high levels of sodium chloride or potassium chloride may cause immediate damage. Bicarbonate can make salinity issues worse as it can tie up calcium-forming calcium carbonate, which essentially removes calcium from the water solution.

Reducing salinity and its effects is critical. Certain cultural practices may help. Preplant strawberry bed preparation may help reduce salinity. The effects of salinity can be reduced by leaching (rainfall is best), deep chiseling, or plowing and overturning the soil. Growing strawberries on raised beds helps increase drainage and leach salts away from the root zone. In general, the higher the strawberry bed, the better the leaching of salts from the root zone.

Deep plowing the soil mixes the salts in the upper layer, reducing their concentration (diluting the salts within the soil profile) and subsequent impact on strawberry roots. This can easily be achieved in annual strawberry production but is more difficult in perennial systems. Care should be taken not to plow the soil excessively, or hardpan layers may form below the surface, reducing drainage and increasing root zone salt levels.

Adding soil amendments to the field can help with drainage and leaching of salts. However, it is not recommended to apply significant amounts of composted materials or fresh manure within 12 months of strawberry production. These organic materials, while beneficial overall, may also contain high salt levels that can increase the damaging effects on strawberry roots. Green manures and cover crops should be incorporated well ahead of bed shaping and planting to allow for decomposition.

Soil Amendments

As mentioned previously, in Texas, site selection is critical for optimal strawberry production and yield. Strawberries should be produced on the most favorable and productive soil on the farm. Soils in Texas are variable, even on a single farm, and some fields may not be ideal for strawberry growth. To improve soils, amendments can be applied, which may enhance strawberry growth by decreasing soil pH and improving water drainage or water retention in the soil. Soil tests are recommended before adding any amendments.

Lime and Sulfur

Lime is a soil amendment made from ground limestone rock. It contains natural calcium carbonate and magnesium carbonate, which increases soil pH. For soils in Texas that have a pH less than 5.0, applying lime may benefit the crop. It is estimated that 1.2 tons of agricultural lime per acre on loam soil raises the pH by 1 point. For sandy soils, only half the amount is needed, while for clay soils, twice the amount may be required.

In some alkaline (pH > 7.0) soils, elemental sulfur can be applied to temporarily lower soil pH to a range suitable for strawberry growth. For example, this has worked in soils on the High Plains. As mentioned previously, the ideal pH for optimal strawberry growth is between 5.5 and 6.5. Lowering the pH allows most micronutrients like iron and zinc to become more available for root uptake. However, in some South Texas soils, especially those with a high buffer capacity, applying elemental sulfur may not result in a significant pH change.

Sand and Bark

Water drainage could be a problem in fields where clay content is high, even when strawberries are planted on raised beds. Strawberries do not grow well in soils with poor drainage. Sand or pine bark can be added to improve aeration and drainage. However, this can be expensive on a large scale and growers should determine whether applications of sand and bark are cost-effective.

Crop Residues and Cover Crops

Crop residues and cover crops can improve a soil's physical properties and increase nutrient availability. When strawberries are rotated with vegetables and other row crops or with cover crops, plant residues should be incorporated into the soil before bed shaping. Depending on climate, it takes about 3 to 4 weeks for incorporated residues to decompose and even longer under drier, less humid conditions. High residue levels, especially those lying on the soil surface, can interfere with bed shaping and laying of plastic mulch. A uniform, well-shaped, firm, and smooth strawberry bed is needed for optimal production. All weed residues should also be buried and decomposed prior to bed shaping. Rototilling the soil several times before bed shaping helps to decrease crop residue size and increases the rate of decomposition. In addition, a reverse mulcher could be purchased, which does an excellent job of burying debris.

Applying Compost

Composted products are manufactured from plants and manure-based organic materials. Composts can be made from animal manures and crop residues, including vegetables, grains, agronomic row crops (cottonseed and peanut hulls), pecan shells, tree bark, hardwood chips, and even shredded paper. When considering compost, it is critical that the product is a stable, relatively uniform organic material created by the decomposition of the organic materials mentioned above. If the compost has a foul odor, it is likely not ready for field application.

Amending soils with compost can significantly increase the soil's organic matter content and potential fertility. It can also improve the soil's physical, chemical, and biological properties. Compost should be spread evenly on the surface and incorporated uniformly into the soil. The nitrogen content in compost is generally low (1 to 3 percent by weight) and is not enough to meet the demands of strawberry growth; therefore, an additional source of nitrogen will be required.

Manure-based compost may contain high amounts of phosphorus. Repeated applications of manure-based composts may increase phosphorous accumulation. Excess phosphorous can compete with the plants' uptake of other essential nutrients.

Manure must be completely decomposed prior to planting strawberries. Applying fresh manure should be avoided sooner than 4 months before planting and should never be applied during the crop season. Manure can contain bacteria that cause foodborne illnesses, which could injure customers and field workers and possibly result in a lawsuit.

Finally, as mentioned, composted manures may contain high salt levels, which can significantly affect strawberry roots, foliage, and nutrient uptake. Therefore, caution is advised when applying composted manure.

Biochar

Biochar is a relatively new biological product for agriculture. It is a charcoal-like substance made by burning agricultural and forestry organic waste through a process called pyrolysis. During pyrolysis, organic materials are burned in containers with little oxygen and converted into biochar, a stable form of carbon. Biochar looks like common charcoal but is generally smaller in size.

The benefits of biochar applications include improved soil water retention and decreased leaching of natural and soil-applied nutrients. Biochar may benefit the soil atmosphere, potentially increasing microbiological activity.

University research evaluating biochar in strawberry is limited and has produced mixed results. Currently there is no research or recommendations for its use in Texas. Biochar applications can be expensive, and a thorough understanding of its properties and uses should be taken before considering applying it to strawberry fields.

Irrigation

Water management is crucial to maximizing strawberry growth and optimum yields. Proper irrigation should consist of uniform watering so soil is always moist but not too dry or too wet. Strawberry plants generally use only 55 percent of the volume applied. However, intermittent periods of water stress from the time of transplanting and early crop development to flowering and berry development can negatively affect yield potential. The effects of water stress hurt the plant's overall production prior to seeing plant symptoms.

▲ **Figure 27. Using drip irrigation systems are critical to strawberry production. Mainline layflat hoses attached to drip lines below the plastic mulch are most common. Water can be applied uniformly and as needed.**

Water stress during early crop development reduces overall plant growth and root structure, limiting subsequent production. Water stress during fruit development reduces fruit size and berry quality. Conversely, overwatering strawberries is detrimental as it increases the risk of root diseases, slows root growth, increases iron chlorosis (particularly in high-pH soils), and leaches nitrogen, sulfur, and boron out of the root zone. Overwatering the crop during harvest also leads to poor-tasting fruit.

Overwatering increases irrigation costs and leaching of expensive fertilizers. Uniform soil water supplied throughout the entire strawberry season is important for successful establishment, plant growth and development, and possibly freeze protection. In warmer climates, strawberries are typically irrigated more frequently during the growing season. Significant water volumes can be lost to leaching, evaporation, inefficient applications, and an inadequate ability to assess the daily water requirements of the plants.

Recent Texas research showed that higher soil moisture levels can result in lower total nitrogen levels (Table 10). Higher moisture levels also corresponded to a reduction in total plant yield. In that trial, a 22 percent reduction in soil moisture resulted in a 26 percent yield

Table 10. Effect of irrigation level on total nitrogen and strawberry plant (Camino Real) yield in a clay loam soil in Lubbock, Texas (2021)				
Avg. % soil moisture	Nitrate nitrogen	Ammonium nitrogen	Total nitrogen	Total yield (lb/plant)
8.5	8.98	1.59	10.57	0.50
7.8	10.22	1.05	11.27	0.58
5.8	9.45	2.06	11.51	0.69
6.6	10.32	2.25	12.57	0.68

increase. While encouraging, soil moisture and total nitrogen levels may also be dependent on rainfall during crop production. Care should be taken to understand the strawberry field's soil type. For example, strawberry plants grown in sandy soils may not respond to the same irrigation levels as those grown in clay loam soils.

Overhead Irrigation

In commercial strawberry farms, overhead sprinkler irrigation can be used for establishing the plants. After establishment, the crop can be followed by standard drip irrigation. Establishing strawberry plants can account for up to one-third of total seasonal water use in strawberries. In other states, growers may use high-impact sprinkler systems (4 to 5 gal/min/head) to irrigate bare-root plants. Irrigation may occur continuously for about 8 hours daily for the first 10 to 14 days after transplanting. Although plug plants cost twice as much as bare roots, planting plugs may reduce irrigation needs during the establishment period and enhance early growth and flowering. Overhead irrigation may be required for South Texas plantings, especially during high temperatures.

Drip Irrigation

In annual plasticulture systems, growers should place one or multiple drip lines in 24- to 45-inch-wide beds approximately 2 to 4 inches below the soil line or on the soil surface just under the plastic mulch. Installing subsurface drip irrigation systems can be costly but may be extremely useful for strawberries and will increase water use efficiency. Disposable surface drip systems for annual production allow for easier rotations with other crops.

Advantages of drip irrigation include the precise application of lower water volumes, reduced soil erosion, better management and timing of irrigation, application of fertilizers through irrigation (fertigation), lower pumping needs, and better automation. Drip irrigation increases the adaptability to different field shapes. It also improves the cleanliness of harvested berries. With drip irrigation, berries are less exposed to excess moisture, reducing fruit diseases. In addition, drip systems combined with plasticulture reduce weed issues.

Drip tape is manufactured at different thicknesses, emitter spacing, and emitter volume. Thicker drip tape is generally used for subsurface irrigation, while thinner tape (5/8 to 7/8 thickness) is used for annual production and is usually removed after production is complete. Emitter spacings range from 8 inches up to 30 inches apart. Since strawberries are best planted at 12-inch spacings, using drip tape with 12-inch emitters spaced between the plants works best. This spacing increases root zone soil moisture uniformity and allows for quicker watering.

Depending on the manufacturer, drip tape flow rates may range from 0.07 to 0.36 gallons per hour (gph) or greater when pressured between 8 to 10 pounds per square inch (psi). Therefore, actual irrigation volume per acre depends on the emitter spacing, flow rate, and psi. For example, on an area basis, the volume of water from 8-inch emitter spacing will be three times greater than emitters spaced at 24 inches given that the gph flow rates are equal. Additionally, a 0.07-gph emitter will put out five times less in 1 hour compared to a 0.36-gph emitter. To determine the actual water volume applied, it is a good idea to capture irrigation water from multiple emitters during irrigation to determine the applied flow rate and water volume. Drip tape specialists and salespeople may help identify the appropriate drip system for your farm.

The goal of a well-managed irrigation program is to maintain uniform soil moisture, generally between field capacity—the amount of water held in soil after the excess has leached out—and the point of allowable depletion, or the point where plants begin to experience drought stress. For strawberries, the point of allowable depletion is about 50 percent of the total available water in the soil. Therefore, water should be applied when approximately half of the available water has been depleted.

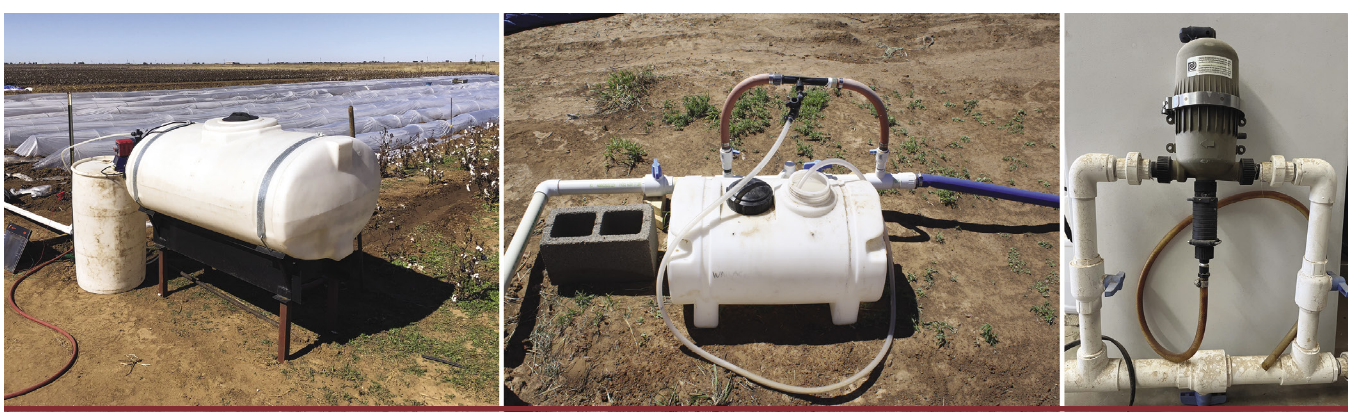
Fertigation

Fertigation is the process of applying fertilizers through the drip irrigation system. It is an excellent way to apply nutrients to the roots quickly and easily. Soluble fertilizers in readily available forms can easily be applied through drip systems to keep a consistent level of nutrients near the plant roots. Many soluble fertilizers also contain essential micronutrients that aid in keeping plant growth optimal. Gravity-fed systems or using a Mazzei® Venturi-type system or Dosatron®/Dosamatic® injectors work very well.

Furrow Irrigation

Since strawberries were first grown in Texas in 1874, furrow irrigating on bare-ground raised beds was the most common method of delivering water to the plants. Today, very few acres are grown using furrow irrigation. However, one benefit of furrow irrigation is the ability to water deeply and supply moisture into the root zone quickly.

Furrow irrigation can be less efficient than other irrigation practices. Disadvantages of furrow irrigation include soil displacement (erosion) and increased leaching of soil nutrients, herbicides, and soil-applied pesticides. Although preplant herbicides may be used, in-row weeds are still prevalent in bare-ground furrow irrigated fields. Thus, furrow-irrigated fields require more hand-weeding and labor than crops grown on drip irrigation and plastic mulch. Growers who have furrow-irrigated fields often water every other row to allow field workers to control weeds and harvest berries without disruption.



▲ Figure 28. Fertigation systems, including gravity-fed tanks (left), Mazzei® Venturi-type systems (middle), or injector systems (right), are important for adding fertilizers or other products like biostimulants into the soil root zone beneath the plastic mulch.

Rainfall

As most growers know, rainfall is both a blessing and a curse, especially in strawberry production. Timely rainfall benefits early strawberry plant growth and development, but heavy rainfall can erode soil and leach fertilizers, herbicides, and soil-applied pesticides from the root zone. Rainfall during flowering can lead to foliar diseases, including *Botrytis* gray mold, anthracnose, *Cercospora* leaf spot, and root or crown diseases like *Rhizoctonia*, *Verticillium*, and *Phytophthora*, among others.

Rainfall during the crop season does not mean strawberry beds do not require irrigation. On annual plasticulture fields, most of the rain washes off the beds into the area between the rows. Therefore, the immediate area below the plastic and around the roots could still be dry. Soil moisture beneath the plastic mulch should be monitored, even after rainfall.

Soil Types and Irrigation

The soil type in the field where strawberries are planted greatly influences available soil moisture. It is critical to understand the soil's water holding capacity (the ability of soil to retain moisture) within the root zone effectively. Sandy and sandy loam soils have less water holding capacity than clay or clay loam soils. However, strawberries generally respond better when grown in sandy and sandy loam soils. Growing strawberries in clay or clay loam soils is possible, but more challenging.

Again, a soil's water holding capacity is defined as the volume of free water readily available to plant roots and depends on soil characteristics. Before planting or when moving to different fields, growers should visit the *NRCS Soil Survey* website to determine the soil types and potential water holding capacities of each field.

Maintaining even amounts of readily available soil moisture for the strawberry roots requires close monitoring of both irrigation, rainfall, and the soil's water content. This also includes tracking water losses through evapotranspiration (ET). ET is the process by which water is transferred from the soil to the atmosphere by evaporation from the soil surface and by transpiration from the plant. Estimates of ET losses are based on climate data from local weather stations, including air temperature, light intensity, relative humidity, and wind speed. This information can usually be found online from local weather stations.

To calculate ET in the field, it is important to understand certain relationships. Reference evapotranspiration (ETo) refers to the expected water use from a uniform green cover crop surface. In most cases, a grass crop is used as the reference crop. The actual crop use (ETc) is generally less than the ETo. ETc can be determined by multiplying ETo by a correction factor or crop coefficient (K) that is specific to plant growth at various stages of plant development. The equation is as follows: $ETc = ETo \times K$. Unfortunately, there is not a reference value yet determined specifically for strawberries.

Strawberry plants are not deeply rooted; therefore, maintaining adequate, uniform moisture in the upper 6 to 12 inches of soil is critical. This is especially critical during fruit development and harvesting and when temperatures are hotter than normal. It is best to regularly monitor the moisture within the strawberry beds. Though sensors may be expensive, soil moisture can be monitored by purchasing and using devices such as tensiometers, electrical resistance blocks, or dielectric soil moisture sensors. However, for smaller farm operations, sensors may not be worth the expense.

Regardless of the irrigation method used, maintaining enough soil moisture throughout the crop's life cycle is critical to achieving high-quality strawberry yields. Soil moisture levels should be monitored regularly to ensure the strawberry crop receives adequate and timely moisture. Historical experience with the field's soil and the soil's ability to hold moisture is just as important.

Figure 29. Irrigation and heat stress can affect strawberry plants, even though there are no symptoms. The plants on the left received only 40 percent total irrigation. The photo on the right shows non-stressed berries (top) and heat-stressed berries (bottom). Heat-stressed berries have lost their luster and turgidity.

Abiotic Plant Stress

Cold Stress and Freeze Damage

Weather in Texas is unpredictable and includes wide temperature extremes in short periods of time. While strawberries are cold-tolerant plants, extreme low temperatures (less than 25 degrees F) can cause leaf, flower, and fruit injury if plants are not adequately protected. This is especially true when cold temperatures immediately follow warm weather conditions when new tender leaf and flower growth has occurred. Severe cold and extended low temperatures below 10 degrees F during the winter months can cause significant injury to strawberry crowns, roots, buds, and leaves, causing lower yields or even plant death.

Growers in northern Texas regions should always be prepared for extreme cold temperatures. In those areas, row covers (for light to moderate freezes) or high and low tunnels can be used for added cold protection. At the minimum, severe cold temperatures that delay flowering or kill existing flowers may result in 3 weeks loss of harvesting and overall production.

Freeze damage may occur even when plants are protected by freeze cloth or when covered with low tunnels. Most freeze cloth will not protect flowers below 28 degrees F for an extended period. Figure 30 shows damaged leaves (left) when temperatures dipped below 0 degrees F on the High Plains and at 19 degrees F in South Central Texas (Poteet). Light freezes below 28 degrees F may not damage strawberry leaves but will kill flowers (right) and, thus, future berries may be damaged or harvesting delayed.

Following severe or extended freezing temperatures, it is important to check a few strawberry crowns by doing the following: (1) dig up a few random plants from the

Figure 30. Freeze damage on strawberry leaves (left) showing necrotic damage from the leaf margin towards main veins. Flowers damaged by freezing temperatures are black (right) where the flower structures have been killed and will not produce fruit.

strawberry bed; (2) immediately wash soil from the roots; (3) with a razor or sharp knife, slice the crown down the center longitudinally; (4) inspect the crown immediately to determine damage. If the crown has a white, creamy appearance, it does not likely have injury. If the crown is slightly brown near the top, the crown is slightly injured, but if the crown is brown throughout, it is severely injured. While strawberry crowns may have mild to moderate injury, they can still recover fully or partially but will likely have some bud loss. After crowns are cut, within the next few minutes, all the regions will eventually turn darker. This color change is normal, even with non-injured crowns.

Following freezing temperatures, foliar sprays of boron and zinc have been shown to aid the recovery of strawberry buds. Bud damage occurs when the vascular connections have been damaged, and auxin (a plant hormone) is needed to repair the connections. Boron and zinc play a major role in auxin synthesis. Thus, it is important to ensure there is an adequate amount of boron and zinc in the plant's leaves. Additional boron and zinc will aid the plant in synthesizing auxin and help with recovery. Applying boron and zinc is not a guarantee that the crowns will recover from severe cold, but it may help those crowns with viable buds.

When applying boron or zinc it is important to follow the label instructions or plant injury may occur. Boron can be purchased as Solubor® and applied foliarly to the leaves at a rate of 1.0 pound of actual boron per acre. Chelated zinc can be applied as an EDTA formulation (see label for instructions and use). Local nurseries or retail stores may have these products on hand, or they can be purchased online.

Heat Stress

After fall transplanting, air and soil temperatures begin to cool, causing carbohydrate translocation to shift from the leaves to the roots. This is beneficial after transplanting and during early crop establishment and plant growth. Increased root growth in the fall produces larger plants in the spring. It is important to check soil and air temperatures to determine the best time for transplanting strawberries in warmer regions of Texas. Avoid transplanting during extremely high temperatures, especially when planting on black plastic mulch. As previously discussed, daily overhead irrigation during hot temperature establishment can cool air and soil temperatures around plants.

Strawberry harvests generally begin to decline when air temperatures are high, generally above 85 degrees F. Hot temperatures in the early spring can lower yields by reducing flowering, fruit size, and quality, especially during the reproductive process. During high temperatures, berries may have a darker flesh color, while leaves become lighter green and increasingly dull. Higher temperatures have been shown to decrease fruit quality, including soluble solids, and may alter berry flavor.

Some strawberry cultivars have been shown to perform better in higher temperatures than others. However, soil types and pH may also influence cultivar development in hot climates. When evaluating new cultivars for heat tolerance, it is best to plant a small cultivar trial to evaluate the yield and quality potential prior to planting unfamiliar cultivars in a large area.

Hail and Heavy Rains

Hailstorms and heavy rains may occur during strawberry production without warning. Plant and berry loss can be significant, and growers can suffer severe economic losses when fields are hit at the wrong time, especially during peak harvests. Hail physically damages strawberry leaves, flowers, and developing fruit (Fig. 31).

While rainfall in Texas is always welcome, heavy rains during harvest usually lead to high rates of *Botrytis* and anthracnose fruit diseases as well as other crown and root rots. Due to damaged vascular tissue (xylem and phloem) within the plant, strawberries with mild to moderate hail injury will have delayed new growth and flowering.

▲ **Figure 31. Hail-damaged strawberry plants. Leaves are shredded and fruit is destroyed. Depending on the time of year, the plants may recover but yield loss may be significant.**

Similar to freeze damage, plant hormones, including auxin, will be needed to repair these connections within plant cells. Boron and zinc play a major role in auxin synthesis of plants. To help with auxin synthesis and plant recovery, it is important to ensure there is an adequate amount of boron and zinc in the strawberry plant leaves. Applying boron and zinc does not guarantee recovery but will help recovery if plants have viable buds.

Shading

To capture greater sales, most growers are interested in extending the harvest season. Since strawberries are a cool-season crop, extending harvests by lowering air temperatures surrounding the crop (plant microsphere) may be critical. Like low and high tunnels, which raise early season temperatures to improve crop growth, shading strawberry plants to lower air and leaf temperatures during hot periods may improve crop growth and increase yield. In Texas research projects, Aluminet shade cloth treatments were placed over low tunnel hoops with three shade levels: 0 percent shade (full sun), 30 percent shade, and 50 percent shade. Two strawberry cultivars, Albion (day-neutral) and Camino Real (June-bearing), were evaluated for growth and yield. Shade cloth treatments were left over the strawberries for either the full season or placed over the plants during the spring only.

Experimental results indicated shading reduced the surrounding air and leaf temperatures and improved overall plant growth compared to full sun. However, overall yield results were mixed. When covered with 30 percent Aluminet shade cloth, Camino Real had higher quality and greater yield compared to full sun and 50 percent shade plants. For Albion, yields were greatest when plants were covered with the 50 percent shade treatment. However, in each case, harvesting was extended between 10 and 14 days. Shade cloth can be expensive, and while the results show promise, using shade cloth may be cost-prohibitive. However, when cared for properly, shade cloth may be used for multiple years.

◀ **Figure 32. Black shade cloth supported on a frame in a grower's field (left). The grower can drive a tractor within the shade house to prepare the ground and transplant strawberries. Shade cloth supported by hoops covering a single bed of strawberries (right).**

Introduction to Pest Management

Strawberry pest management can be complex, but to prevent economic losses, it should be understood and planned before transplanting occurs. Many pests attack strawberries throughout the 9-month growing season. The best approach to pest control includes Integrated Pest Management (IPM) techniques. IPM combines the use of preventive, cultural, mechanical, chemical, and monitoring techniques to control pests both sustainably and economically.

Although it is easier and more tempting to create weekly chemical spray schedules, unnecessary sprays can be costly and potentially increase pest resistance, harm beneficial insects, increase costs, and potentially lower yields. Sprays can negatively affect photosynthesis. Unnecessary use or misuse of pesticides can negatively impact human health, strawberry fruit, and the environment. Using sustainable practices not only benefits the grower but reduces the concerns of customers.

Creating efficient strawberry IPM programs requires a knowledgeable background of the biology and ecology of the field soil, the strawberry crop, and key insects, weeds, and diseases. The economic pests described in the following sections are found in Texas strawberry fields.

Regularly scouting strawberry fields is critical to higher quality yields and lower production costs. Many strawberry pests are not visible without examining the underside of the leaves or looking deep into the crown region. A 10X hand lens should always be available when scouting fields.

Finally, determining whether the poor growth of a plant or entire crop is due to a pest or soil nutrient issue is critical to successful production and preventing economic losses and making poor management decisions. If unsure about an issue in the field, contact a county Extension agent or specialist for assistance.

▲ **Figure 33. Scouting strawberry fields regularly for insects, diseases, and weeds will help growers catch pest problems before they become economically damaging.**

Insect Pests

Introduction

Regardless of production systems, economically damaging insects must be controlled in strawberry fields. Not only can insects damage roots, leaves, stems, and fruit, but they can also infect strawberry plants acting as vectors (carriers) of pathogens and viruses. While strawberry plants can tolerate some insect damage without economic yield loss, it is important to control them, especially when they attack developing and mature fruit.

This section discusses the major insect strawberry pests in Texas. Before taking any control measure, especially when insecticides are applied, it is critical to correctly identify the pest. Not all insects are economic pests; some may be found on a plant without any intention of feeding on it. Correct identification aids in managing the decision process, potentially saving production costs.

To correctly identify insect pests, collect live samples from the field. If unable to identify, contact the local county Extension agent to assist with identification. If agents are also unable to identify the pests, they can contact the Texas A&M AgriLife Extension Department of Entomology for assistance.

When applying insecticides, it is important to understand their effects on beneficial insects, such as bees, and how insecticides affect their pollination and flight patterns. Most insecticide labels have information for applying when bees are active in production fields. Bees are important for strawberry pollination (see the *Pollination* section discussing bees) and spraying when they are present may reduce the population and damage the colony. Always read and follow insecticide label instructions for managing bee populations.

For a current list of insecticides, see Table 11 beginning on page 64.

Aphids

Aphids are sucking insects, and when left unchecked, populations will increase rapidly, especially during optimal growing temperatures. Aphids reproduce by bearing live young; thus, no eggs are produced. Aphids can be green, dark green, black, orange, or red. They have six legs, two antennae, and two cornicles—tube-like structures located on their posterior—present on their bodies. In high densities or under certain stresses, aphids may develop wings and fly to other berry plants or plant hosts.

Aphids directly damage healthy leaves and plants and indirectly reduce fruit quality by diverting nutrients and carbohydrates away from the berries. Aphids stunt plant growth, carry viruses, and secrete “honeydew,” a sticky excretion that sticks to leaves and encourages fungal pathogen growth. Honeydew can even be found on the berries, causing them to be sticky and unpleasant to harvest.

The presence of ants can also be a sign of aphid infestations as they "farm" aphids for their honeydew. High aphid populations can cause leaves to curl and dry out, and if left unchecked, may kill most if not the entire plant.

Aphids can be difficult to find. They are typically found on the underside of leaves or near major leaf veins on lower leaves and on new vegetative growth. Since aphids are born live, they molt their skin at least four times during their life cycle. Often the molted skins can be seen on lower leaves or on the plastic mulch below the plant. This can make scouting easier but is also an indication that the population is already high. Aphids should be monitored throughout the season, even during winter months.

▲ Figure 34. Aphids can be difficult to find. They are typically found on the underside of leaves or near major leaf veins on lower leaves and on new vegetative growth.

It is important to sample from 10 to 40 trifoliate leaves (depending on crop area) weekly. Be sure to look at the underside of the leaves when scouting. In Texas, begin scouting for aphids within several weeks after transplanting. In colder regions of the High Plains, aphids can be found on plants grown under low or high tunnels in January and February. While it is more difficult to scout under plastic covers, it is still critical for successful management.

Aphid populations should be managed when infestation rates reach at least 30 percent, less if aphids are causing damage to the fruit. Aphid populations usually begin on plants in small, isolated spots. If left uncontrolled, aphids spread rapidly to other areas of the crop. Yellow sticky cards can also be used to monitor winged aphids, though this is a sign of higher infestations or migration from plant to plant.

Prevention aids in aphid suppression. Keep fields and surrounding areas weed-free as weeds can act as alternate hosts. Although potentially costly, removing leaves from the field that are currently infested with aphids can help reduce future populations.

Natural enemies are important for controlling aphids. Natural predators include lady beetles, parasitic wasps, lacewing larvae, syrphid fly larvae, and ground beetles. Lady beetles and parasitoids can be purchased early in the season to suppress aphid populations. However, using natural predators may require significant management if chemical pesticides are used to control other pests. Some chemicals are detrimental to beneficial insects and parasitoids. Check labels prior to any pesticide applications.

Spider Mites

(Tetranychus urticae, Tetranychus cinnabarinus)

Spider mites are one of the most damaging pests to strawberries and can cause significant economic losses. Spider mites are more closely related to spiders than insects. They are found on the underside of leaves and best identified when using a 10X hand lens for magnification. Spider mites feed by sucking on strawberry leaves using their mouthparts to damage plant cells, consuming the contents or sap.

Symptoms of spider mite infestations include leaf stippling, plant discoloration, severe webbing, plant stunting, or, when under severe attack, plant death. Spider mites attack the leaves, stems, and flower calyx, causing indirect damage by reducing plant growth and yield. This damage reduces leaf transpiration and photosynthesis. Damaged cells turn gray or brown.

Female spider mites lay eggs, forming colonies. Under ideal conditions (high heat and low humidity), spider mites spread very quickly. After hatching, young spider mites move to nearby leaves, fruit, and stems and then onto other plants, and when mature, begin reproducing.

There are three species of spider mites in Texas that can cause economic damage. These include the two-spotted spider mite (*Tetranychus urticae*), the carmine spider mite (*Tetranychus cinnabarinus*), and the Banks grass mite (*Oligonychus pratensis*). Most populations observed in Texas strawberry fields have been the two-spotted spider mite, followed by the carmine spider mite.

Unless controlled, spider mites will begin colonizing strawberries when they are first planted and continue through the end of the season. Scouting is a season-long effort. Spider mites may even be found on transplants arriving from the nursery. To monitor mites throughout the season, select leaves to inspect each week, looking for hot spots on the underside of the leaves.

While scouting, look for webbing and brown leaves on the plants. Webbing indicates that populations are relatively high and likely economically damaging. It is best to inspect each cultivar since spider mites have been shown to have preferences. For example, Albion is one of the first to have spider mite populations and should be inspected earlier and more thoroughly than other cultivars.

Early detection of spider mites and control is essential to prevent economic outbreaks. Strawberry yield losses have been reported when at least one spider mite per leaflet is observed before fruit set. After fruit set, plants can generally tolerate more spider mites, even 15 to 20 per leaflet; however, damage to the fruit is still possible.

Figure 35. Spider mites can cause significant damage to strawberry leaves, resulting in lower yield and quality. A spider mite adult and eggs (left) found on the underside of a leaf and spider mite webbing (right) indicate the presence of significant populations.

Preventing spider mites from entering strawberry fields, high and low tunnels, or greenhouses is difficult. Spider mites arrive through the air on silken threads or may overwinter on nearby weeds and other plants. Keeping fields free of weeds will help reduce infestations. Texas research shows that spider mite populations can be greater in high tunnels compared to open-field production. This may be due to better growing environments for both the crop and spider mites and possibly fewer beneficial insects.

Biological control is available for spider mite control, but research is limited in Texas. Predators include the spider mite destroyer beetle (*Stethorus punctillum*), predatory spider mites (*Phytoseiulus persimilis* or non-plant feeders), minute pirate bugs (*Orius* spp.), and several species of thrips, including the six-spotted thrips (*Scolothrips sexmaculatus*).

To increase suppression, biocontrol applications should begin before the colonies expand, generally at the first sign of mites. To keep mite predator populations high, spraying chemicals should be limited. Avoid broad-spectrum insecticides like synthetic pyrethroids that kill or decrease beneficial or predatory insect populations. Read chemical labels for application timings to reduce damage to predators. Choose insecticides and miticides that are specific to the insect pest and do not harm beneficial species.

There are labeled insecticides and miticides for controlling spider mites. Some products take several days for control, while others have a residual lasting several weeks. Products are also available that kill spider mite eggs. Miticides should be applied when the populations are small but increasing.

Thrips

Thrips (plural and singular) are tiny insects with rasping mouthparts that damage plant cells, though they leave the tissue intact. To view them when scouting, it may be necessary to have a 10X hand lens. Thrips are tiny with yellow to brownish bodies. They are first attracted to developing strawberry flowers, and their feeding damages the stigmas and anthers. Research indicates this damage does not interfere with flower fertilization, though under high populations, thrips cause shoulder bronzing on the fruit. Several species of thrips are found in Texas, including western flower thrips (*Frankliniella occidentalis*), onion thrips (*Thrips tabaci*), and tobacco thrips (*Frankliniella fusca*).

Thrips are difficult to see on plants. The adult and immature stages look similar, but the adults have thin, feathery, whisker-like wings. Although extremely small, thrips can be monitored by shaking strawberry flowers above a white piece of paper and counting the thrips that fall off. There may be dust and debris on the paper, but thrips are the ones running around. California research suggests spraying for thrips when at least 10 thrips per flower are found, though economic damage may occur with fewer. Thrips are also monitored using yellow sticky traps, though this is for flying adults.

Figure 36. Thrips present on strawberry flowers (left) can cause significant damage to developing berries. When left uncontrolled, thrips can cause fruit bronzing (right) and result in low-quality harvests.

Thrips can live on many different hosts and usually move from one host to the other when the plants start to decline. They are more common in greenhouses and low and high tunnels than in open fields. In Texas, large numbers of thrips take flight in the spring when early season crops mature. They also move with the wind or on infected plants. Flights occur earlier in southern regions versus those in the north. Strawberry fields near or surrounded by grain crops are particularly susceptible to thrips invasion. With their mobility and very small size, exclusion is often ineffective in greenhouses and high and low tunnels.

Western flower thrips are predators of spider mite eggs and are beneficial in high tunnels if they remain below damaging levels. There are both chemical and biological products to control thrips. Green lacewings, minute pirate bugs, predatory mites, and parasitic wasps help suppress thrips populations. Avoid broad-spectrum insecticides like pyrethroids, which may kill beneficial insects and facilitate spider mite and aphid outbreaks. Chemical rotation is best to reduce potential resistance and improve control.

Lygus Bug/ Western Tarnished Plant Bug

Lygus bugs are widespread in Texas and are typically found in most strawberry fields. Lygus bugs cause damage using their slender, straw-like mouthparts to pierce individual seeds on developing fruit. The damage halts development of the flesh (receptacle) beneath the damaged seeds, resulting in an unmarketable cat-facing appearance.

Several species of lygus are found in Texas, including the tarnished plant bug (*Lygus lineolaris),* western tarnished plant bug (*Lygus hesperus*), and the pale legume bug (*Lygus elisus*). Adults are approximately 1/4 inch long and are tan to brown. Nymphs or juvenile bugs are smaller than the adults, usually greenish, and have wing pads, or underdeveloped wings.

Lygus adults and nymphs can be found on strawberry leaves, flowers, and fruit. They can reside underneath the leaves and inside the canopy, so monitoring is like that of thrips—placing a white piece of paper (or your hand) beneath the plants, beating them, and catching the insects. When using the beat method, the University of California recommends a threshold of one lygus bug nymph per 20 plants for most crops. The threshold in strawberries is significantly lower, as fewer Lygus are tolerated due to their destruction of the seeds in developing fruit.

There are many suitable hosts for lygus bugs. They often fly to other strawberry plants and crops when host plants decline. Alfalfa is a major host for lygus. Cutting alfalfa will cause lygus bugs to move on to new hosts, like strawberries. If lygus bug populations are found to be high in nearby alfalfa fields, it may be useful to spray those fields to reduce strawberry infestations.

Lygus bugs also feed on wild mustards, curly dock, poppy, and other weed species found

Figure 37. Lygus bugs (or western tarnished plant bugs) feeding on flowers can cause mishappen fruit and significantly lower quality and overall yield.

in Texas fields. Thus, keeping fields and surrounding areas weed-free is an important method of suppression.

Insecticides are more effective on nymphs than on adults, so once identified, chemical sprays should be considered immediately. Currently there are no reliable biological products for lygus control; however, the University of California research suggests that the parasitic wasp, *Anaphes iole*, may have potential.

Lepidopterous Pests

Lepidopterous pests like caterpillars attack strawberries by feeding (chewing) on leaves, stems, fruit, and even flowers. Lepidopteran larvae (juveniles) can cause significant damage by chewing on leaves and fruit, reducing yield and quality (Fig. 38). Adult moths lay their eggs on many plant parts and the hatched caterpillars begin feeding. Specific species can be identified by their eggs before hatching.

Lepidopteran caterpillar pests of Texas strawberries include but are not limited to the beet armyworm (*Spodoptera exigua*), fall armyworm (*Spodoptera frugiperda*), cabbage looper (*Trichoplusia ni*), corn earworm (*Helicoverpa zea*), cutworms, and saltmarsh caterpillar (*Estigmene acrea*). Adult lepidoptera are nocturnal. Larvae are often found during the day, but some are found only at night.

Some adult lepidopterous pests (moths) can be monitored using pheromone traps; however, these can be expensive, especially for small-acreage farmers. It is best to scout strawberry leaves for chewing damage or lepidopteran frass, which looks like small black pellets. If chewing is present, scout for caterpillars to identify the number and species. Timing is critical, as some caterpillars consume up to 98 percent of their foliage intake in the last three stages (instars) of their larval development.

To prevent or suppress lepidopterous larvae from feeding on strawberries, remove alternative hosts, including weeds, from the surrounding area. Caterpillars can be removed manually and discarded away from strawberry fields.

▲ Figure 38. Lepidopterous larvae feeding on the leaves (top) and fruit (bottom) of strawberries can cause lower yields and damage to the fruit, making it unmarketable.

Caterpillars can be controlled both organically and through chemical spraying. Often a combination of the two methods improves control. There are also many parasitic wasps and viruses used to control lepidopterans. Mating disruption can be used to manage certain lepidopteran pests.

Leafrollers

While leafroller caterpillars exist in Texas, no species have been identified on strawberries to date. They usually are not a significant economic pest in Texas.

Leafrollers are caterpillars found in the family Tortricidae. They chew on strawberry leaves and can bore inside the fruit. Leafrollers can be easily identified as they cause leaves to curl by applying thick white webbing on the inside of the leaf, which gives them their name.

Leafroller adults can be monitored using pheromone traps. However, it is easier to scout for their chewing damage, frass, and curled leaves. Opening the curled leaves and webbing usually results in finding larvae and insect frass.

Preventative control methods for leafrollers include removing alternative weed hosts from the field and surrounding area. If only a few are present, leafrollers can be removed by hand and discarded.

There are many naturally occurring parasitic wasps and viruses of leafrollers. Again, mating disruption can be used for managing some lepidopteran pests.

Weevils

Weevils are beetles that feed on strawberry leaves and roots. Weevils have three body segments and a long snout that resembles an anteater. Weevils can cause feeding damage both in the larvae and adult stages by chewing on the leaves.

Adult female weevils will lay eggs in the soil where the larvae are able to feed on the roots, causing plants to wilt and be stunted. Unfortunately, this symptom also mimics other insects or diseases, so digging up the plant to inspect it is needed. Under high populations, plants can be killed by larval feeding. Weevil larvae are typically white, thick, and legless with a curved shape around ¼ inch long.

It is best to look for chewing insect damage and for the weevil adults. Pitfall traps can help monitor adult populations. If plants are experiencing wilting and dieback, the roots should be examined for weevil larvae. Weevil larvae can also be monitored by taking soil samples at the end of the harvest.

Barriers like screens can be used to exclude adult weevils in high and low tunnels. Aluminum flashings with a slippery Teflon coating around the plants may help, but they are not likely economical in strawberry fields.

There are commercially available parasitic nematodes, *Heterorhabditis bacteriophora* and *Heterorhabditis marelatus*, used to control weevils. However, these nematodes should be used early in the season when the soil is warm and moist.

Spotted-wing Drosophila

(Drosophila suzukii)

Spotted-wing drosophila (SWD) is an invasive vinegar fly accidentally introduced to North America in 2008 through ports in California. SWD will typically lay eggs inside ripening berries just before they are harvested. The larvae then eat the fruit on the inside. The infested fruit will soften quickly, followed by adult flies emerging after it is spoiled. Damage from SWD allow secondary pests, like fungi, to invade the fruit. It can appear that fungi were the primary pest.

SWD males have a spot on each wing at the tip of the second wing vein. The females have serrated ovipositors, which is a tubular organ through which females lay their eggs. SWD are not found abundantly in Texas; however, strawberry growers in similar climates report fruit damage.

Using yellow sticky traps can help monitor for SWD adults, especially near harvest time. Apple cider vinegar traps can also work, but they do not target SWD specifically. Sanitary conditions are critical to preventing SWD populations.

Remove and discard any fallen or rotting soft fruit from the field and surrounding fields.

If you detect an infestation, pick the fruit earlier to prevent SWD from laying eggs. This, however, may affect berry appearance, flavor, and customer preferences.

There are a few chemical insecticides labeled for SWD control as well as some organically acceptable products. Current research suggests that several parasitoids and fungi may be of benefit. Always read and follow label instructions.

Whiteflies

(Bemisia spp.)

Adult whiteflies are identified by their yellow bodies with whitish wings. Adults lay oval eggs, often found in circular patterns on leaves. The first-instar nymphs (immature or juvenile stages) emerge from the eggs and begin as “crawlers” similar to small scale-like insects. They are flat, ovular, and often remain still once they find a good spot to feed. Although still small, older nymphs are larger and easier to recognize. Pupae are yellowish and have two red eyes that are visible through the cuticle.

Whiteflies cause damage by sucking sap from the underside of the leaves, causing them to turn yellow and wilt. The leaves often have small yellow spots or appear dry under heavy infestations. A sticky, shiny residue called honeydew is secreted from whiteflies onto the strawberry leaves. Honeydew also acts as an inoculant for fungi (e.g., sooty mold). Whiteflies can also vector (carry) plant viruses and pathogens and infect plants while feeding on them. While not common, some virus-infected strawberries have been reported in Texas.

To monitor for whiteflies, inspect the underside of leaves for clusters of whitefly nymphs and flying adults as well as the sticky residue. You can scout for whiteflies at the same time as aphids and spider mites. Ants can be a sign of whiteflies because they farm for the honeydew they produce.

Yellow sticky traps can be placed on the edge of fields or in the crop area to detect whitefly migration. While sticky traps can indicate a level of infestation, the number of whiteflies on the sticky cards does not correlate to the number of nymphs on the plants. Many vegetables and citrus are host plants and should also be monitored closely. It is important to remove weeds and nearby host plants by hand-weeding or spraying herbicides. Whiteflies should also be controlled after the final harvest to reduce future populations.

Several biological control products are available for whitefly control, including lacewing larvae and parasitoids from the genera *Encarsia*, *Eretmocerus*, and *Prospaltella*. These are commercially available. Chemical pesticides and organic oils are also available. Always read and follow label instructions.

Grasshoppers

Grasshoppers are common pests that can easily destroy strawberry leaves through their voracious feeding habits. They feed on the leaves, stems, and flowers and, though rare, may feed on the fruit. Grasshoppers are easy to spot and are quick to move within the field.

Grasshoppers use mandibles to chew plant tissues. They prefer the leaves, but large populations can damage other parts of the plant. Caterpillars also have mandibles, and their damage can look similar. It is important to scout for both insects, though grasshoppers are more easily found.

Grasshopper leaf damage is easily identified as it usually begins on the outside edge and progresses inward. Caterpillars often begin in the middle of the leaves and leave evidence of frass. There is no need to identify the grasshopper species because damage and control practices are the same.

Mature female grasshoppers deposit their eggs in the soil. Immature grasshoppers (first instar) are small and difficult to detect but are usually found during scouting because they move when disturbed. The small nymphs do not cause significant damage but should be controlled before they become older nymphs or adults.

Minor to moderate leaf damage during early fall growth is often reported. However, unless significant damage occurs, most plants recover without the application of pesticides. Careful monitoring of the grasshoppers will aid in determining whether to apply a control measure or not. Grasshopper adults die during the winter in many cold locations but may overwinter in southern regions.

Exclusion by controlling or eliminating weeds inside and around strawberry fields or around high tunnels may prevent grasshopper infestations and will keep them from being attracted to the area.

There are no commercially available predators for grasshoppers, but blister beetles and robber flies do aid in their control. Broad-spectrum insecticides with quick knockdown are available but may kill other beneficials that control pests. Controls are best used when the grasshoppers are small as they are less effective on large grasshoppers.

Red Imported Fire Ants

Red imported fire ants (*Solenopsis invicta*) are medium-sized, red- and black-colored ants that build soft mounds of soil around and inside crop fields. In South Texas, they can be found in strawberry fields, including within beds covered with plastic mulch and in transplant holes where moisture is easily available. It is important to control fire ants as soon as they appear in the strawberry beds or before the harvesting season begins.

Fire ants can be very difficult to manage; however, it is essential that they are controlled to prevent stinging field workers and consumers in strawberry U-pick operations. About 1 percent of the population, especially those with compromised immune systems, can have severe to lethal reactions to fire ant bites and their venom. Healthy people may also experience severe reactions, including anaphylactic shock if they are stung multiple times. If severe reactions occur, get medical attention immediately.

Fire ant mounds are easily recognized. They are generally 18 inches or less in diameter with smaller mounds found in colder regions of Texas. If smaller, they may be more difficult to identify. When the mounds are disturbed, fire ants emerge aggressively. They start crawling up vertical surfaces and begin biting and stinging. Their sting is very painful and often leaves a white pustule on the skin.

Most fire ants are workers that vary in size from small (0.06 inch) to large (almost 0.25 inch). Most native ants have workers of a uniform size but can vary in body color. Interestingly, the nests of small- to medium-sized mound-building ants have central openings where the ants enter and leave. With fire ant mounds, there are no central openings.

Figure 39. While fire ants do not cause any real damage to strawberry plants, they can form colonies within the beds and around the field. When disturbed, they can bite and cause significant injury to U-pick customers and farm employees.

Fortunately, there are products available for controlling fire ants in fields. Always read and follow label instructions to avoid fruit or human contamination. For more information contact your local county Extension agent or visit the *Texas A&M Texas Imported Fire Ant Research and Management Project website*.

Red Harvester Ants

Red harvester ants (*Pogonomyrmex barbatus*) can be problematic in strawberry fields. They are found throughout Texas but have been declining in numbers, especially in East Texas. Interestingly, they are a major source of food for the threatened Texas horned lizard. Harvester ants' main food sources are seeds and dead insects. Their mouthparts are designed for chewing.

Though not considered a serious agricultural pest, harvester ants can be problematic. They have been reported to destroy strawberry plants near their nest. Harvester ants can also leave painful bites on the skin of unsuspecting people, which can be medically serious. Proper care should be taken upon being bitten.

Harvester ants are much larger (0.25 to 0.5 inch) than most other ant species, with somewhat square heads. They move from the nest to new areas with winged males and females that mate, often following rainstorms. The male then dies and females drop their wings and look for new nesting areas.

When harvester ant nests interfere with strawberry production, including harvesting, destroying their nest is the best option. In non-planted fields, regular cultivation and disking can destroy their nesting areas without the use of insecticides. However, in cases where that is not possible, there are insecticides labeled for the control harvester ants. Insecticide baits are a good choice, as the workers carry the product deep into the nest, killing the queen. For chemical control, always read and follow label instructions. For more information contact your Texas A&M AgriLife Extension county office.

▲ **Figure 40. Harvester ants can destroy strawberry plants near their nest. They can also leave painful bites on the skin of unsuspecting people, which can be medically serious.**

Crickets

Crickets (*Gryllus* spp.) can be occasional pests of strawberries. Young crickets are called nymphs and appear like miniature, wingless versions of the adults. Adult crickets have wings, which are used primarily for communication and not flying. Male crickets can often be heard in the evenings rubbing their wings together to attract females.

Crickets can be found in crop residue and often hide in the soil underneath plastic mulch. They are quick to hide and can easily jump into the transplant holes where developing plants are located, making their control difficult.

Crickets mostly damage the leaves of young strawberry plants following transplanting or later in the spring. Their leaf damage is identified as irregular and more rough-edged than the damage from grasshoppers. Their feeding usually occurs during the evening and nighttime. At times, crickets may feed on strawberry fruit, but this is rare and appears to occur more inside high and low tunnels than open-field production. Rarely will cricket damage significantly impact strawberry yield. There are no established thresholds for crickets.

Several foliar insecticides are labeled for controlling crickets; however, if feeding damage is less than moderate, control will likely not be necessary.

Table 11. Selected registered conventional insecticides for use in strawberries. Some active ingredients have multiple product names that may not be included in this table.

Product names	Active ingredients	Insecticide group	Application type	Insects controlled or suppressed	Comments
Acramite 50WS	Bifenazate	25	Foliar	Spider mites	Two applications per season. Minimum interval between applications is 21 days. 1-day PHI.
Actara	Thiamethoxam	4A	Foliar	Aphids, leafhoppers, lygus bugs (western tarnished plant bug), whiteflies, weevils	Ground applications only. Apply before pests reach damaging levels. 10-day minimum interval between applications. 3-day PHI.
Admire Pro	Imidacloprid	4A	Soil, foliar	Aphids, whiteflies, spittlebugs	Apply to root zone through drip system after plants are established or as a plant hole treatment prior to or at transplanting. Band application prior to mulch laying. 14-day PHI. Apply as a foliar spray with 5-day minimum interval. 7-day PHI. Do not apply within 10 days before bloom.
Agri-Mek 0.15EC	Abamectin	6	Foliar	Spider mites	First two applications 7 to 10 days apart when mites are first present. Wait 21 days until next application. Thorough coverage is needed. 3-day PHI.
Assail 30SG	Acetamiprid	4A	Foliar	Aphids, lygus bugs (western tarnished plant bug), western flower thrips, spittlebug, whiteflies	Begin applications when thresholds are reached. No more than two applications per season. No more than once every 7 days. 1-day PHI.
Agree	*Bacillus thuringiensis* ssp. *aizawai* strain GC-91	—	Foliar	Lepidopterous larvae	Begin applications with first sign of feeding larvae. 3- to 7-day spray intervals. Use higher rates under heavy pressure. Continue applications as needed for larval control.
Beleaf 50SG	Flonicamid	9C	Foliar	Aphids, lygus bugs (western tarnished plant bug)	Apply when insects first appear. Stops insects from feeding. Two sequential applications are best. No more than 3 applications per season. 0-day PHI.

Table 11. Selected registered conventional insecticides for use in strawberries. Some active ingredients have multiple product names that may not be included in this table.

Product names	Active ingredients	Insecticide group	Application type	Insects controlled or suppressed	Comments
Brigade WSB	Bifenthrin	3A	Foliar	Aphids, armyworms, flea beetles, lygus bugs (western tarnished plant bug), stink bugs, sap beetles, spider mites, weevils	Apply when pests reach damaging levels and repeat as needed every 7 to 14 days. Do not exceed three applications per season. 0-day PHI.
Danitol 2.4EC	Fenpropathrin	3	Foliar	Aphids, lygus bugs (western tarnished plant bug), lepidopterous larvae, sap beetles, spotted-wing drosophila, two-spotted spider mites, spittlebugs, stink bugs, weevils, whiteflies	Begin applications at first sign of insects. Alternate with other insecticides if retreatment is needed but no less than 14 days (spotted-wing drosophila) or 30 days (other pests). 2- to 3-day PHI depending on pest.
Deliver	*Bacillus thuringiensis* ssp. *kurstaki* strain SA-12	11A	Foliar	Lepidopterous larvae	Apply as needed to maintain control. 0-day PHI.
Dibrom 8EC	Naled	1B	Foliar	Aphids, leafrollers, lygus bugs (western tarnished plant bug), spider mites, spittlebugs, western flower thrips	Apply at first sign of insects. Do not apply more than five applications per season. Allow 7 days between applications. 1-day PHI.
Entrust SC Success Seduce (bait)	Spinosad	5	Foliar	Lepidopterous larvae, thrips, red imported fire ants	Apply when pests appear, targeting eggs or hatched larvae. For thrips, use a 3- to 4-day spray interval if population is high. Spray interval should be no less than 5 days apart. No more than three applications per season. 1-day PHI.

Table 11. Selected registered conventional insecticides for use in strawberries. Some active ingredients have multiple product names that may not be included in this table.					
Product names	Active ingredients	Insecticide group	Application type	Insects controlled or suppressed	Comments
Esteem 0.86EC	Pyriproxyfen	7C	Foliar	Whiteflies	Apply when pests reach threshold (three to five adults/leaf). Thorough spray coverage is needed. No more than two applications per season. 30-day interval between applications. 2-day PHI.
Fujimite SC	Fenpyroximate	21A	Foliar	Spider mites, whiteflies (suppression)	Apply by ground sprayer. Allow 14 days between applications. Avoid puddling of product on plastic film. 1-day PHI.
JMS Stylet-Oil	Paraffinic oil	—	Foliar	Aphids, spider mites	Begin sprays as soon as plants emerge. Spray weekly or twice weekly and continue through harvest. Spray at no less than 400 psi. Check compatibility with other products. 0-day PHI.
Intrepid 2F	Methoxyfenozide	18	Foliar	Armyworms, corn earworms, cutworms	Apply at first sign of pests. Do not make more than three applications per season with a minimum interval of 10 days. 3-day PHI.
Kanemite 15SC	Acequinocyl	20B	Foliar	Spider mites	Apply when mites are first present. Make only two applications per season with a 21-day interval between applications. 1-day PHI.
Malathion 8E	Malathion	1B	Foliar, drip	Aphids, crickets, cutworms, leafhoppers, leafrollers, lygus bugs (western tarnished plant bug), spittlebugs, thrips, whiteflies	Apply when pests are first found. Good coverage is essential. Only four applications are allowed with a 7-day retreatment interval. 3-day PHI. See label instructions for drip applications.
M-Pede	Potassium salts of fatty acids	—	Foliar	Aphids, mites, thrips, whiteflies	Apply to leaves until wet. Complete coverage is needed for control. Make applications at 7-day intervals. Only three sequential applications. 0-day PHI.

Table 11. Selected registered conventional insecticides for use in strawberries. Some active ingredients have multiple product names that may not be included in this table.					
Product names	Active ingredients	Insecticide group	Application type	Insects controlled or suppressed	Comments
Nealta	Cyflumetofen	25	Foliar	Spider mites	Apply at first sign of mites before populations increase. Apply at a minimum 14-day interval and only two applications per season. 1-day PHI.
Neemix 4.5, Azaguard, Asa-Direct	Azadirachtin	—	Foliar, soil drench	Aphids, spider mites, whiteflies, lygus bug nymphs, thrips, lepidopteran larvae	Spray when pests first appear. Complete coverage is needed. Make two to three applications at 7-day intervals. Early morning or evening sprays reduce potential crop injury. 0-day PHI.
Oberon 2SC	Spiromesifen	23	Foliar	Spider mites, whiteflies	Spray at first sign of pests. Allow a 7-day interval between applications. Only three applications per season. 3-day PHI.
Omni Supreme	Narrow-range oil Paraffin base	—	Foliar	Spider mites, whiteflies	Make the first application when pests are at a moderate level. Apply at 14-day intervals. Do not apply product during peak bloom or fruiting or during temperatures higher than 75°F for several days.
Pyganic 5.0	Pyrethrin	3A	Foliar	Aphids, beetles, caterpillars, crickets, grasshoppers, lygus bugs, mites, thrips, weevils	Spray to wet but not runoff. Direct sprays into canopy. Product must contact pest for control. No more than 10 applications per season. Do not apply within 3-day intervals. 0-day PHI.
Pyrenone	Pyrethrin/ piperonyl butoxide	3A	Foliar	Aphids, beetles, caterpillars, crickets, grasshoppers, lygus bugs, mites, thrips, weevils	Spray to wet but not runoff. Direct sprays into canopy. Product must contact pests for control. No more than 10 applications per season. Do not apply within 3-day intervals. 0-day PHI.
Radiant SC	Spinetoram	5	Foliar	Lepidopterous larvae, spotted-wing drosophila, thrips	Treat when pests first appear, targeting eggs at hatch or small larvae. 3- to 5-day interval for thrips; for all other pests, wait 5 to 7 days. Maximum of three applications per season. 1-day PHI.

Table 11. Selected registered conventional insecticides for use in strawberries. Some active ingredients have multiple product names that may not be included in this table.

Product names	Active ingredients	Insecticide group	Application type	Insects controlled or suppressed	Comments
Rimon 0.83SC	Novaluron	15	Foliar	Lepidopterous larvae, lygus bugs (western tarnished plant bug), thrips, sap beetles	Apply when majority of pests are at egg hatch to second instar. For lygus bugs, apply when adults are observed and prior to egg hatch. Begin when thrips are visible. Spray at 7-day intervals. 1-day PHI.
Savey 50DF	Hexythiazox	10A	Foliar	Two-spotted spider mites	Apply when mites and eggs are first noticed. Will control newly laid eggs. Do not make more than one application per season. 3-day PHI.
Sivanto Prime, Sivanto 200SL	Flupyradifurone	4D	Foliar, drip irrigation	Aphids, lygus bugs (western tarnished plant bug), chilli thrips	Can be applied as a foliar or through a drip irrigation system. Minimum interval for applications is 10 days. 0-day PHI.
Transform	Sulfoxaflor	4C	Foliar	Plant bugs, thrips (suppression)	Follow pollinator bee restrictions. Apply at the first sign of pests. No more than two consecutive applications per crop at a minimum of 7 days apart. 1-day PHI.
Trilogy	Neem oil	—	Foliar	Aphids, spider mites	Apply when mite and aphid levels are low. Thorough coverage is needed for control. Apply at 7- to 21-day intervals. Do not apply to newly planted crops. 0-day PHI.
XenTari	*Bacillus thuringiensis* ssp. *aizawai* strain ABTS-1857	—	Foliar	Lepidopterous larvae	First apply when larvae are young and actively feeding. Use higher rate under heavy pressure. Repeat spray intervals every 3 to 14 days depending on weather. 0-day PHI.
Zeal	Etoxazole	10B	Foliar	Spider mites	Apply at first sighting of mites; best when populations are low. Use during early life cycle. Only one application per season. 1-day PHI.

Non-Insect Pests

Pill Bugs

Pill bugs, also known as roly-polies or potato bugs, are not insects but are in the woodlice Armadillidiidae family. When they feel threatened or triggered by vibrations and pressure, they roll into a ball shape.

Pill bugs are nocturnal and require high humidity for survival. They are typically found in wet areas or waterlogged soils, under high-rainfall areas, or where flooding occurs. They prefer considerable amounts of soil organic matter and neutral to high soil pH. Although beneficial decomposers, they feed on many vegetable and strawberry leaves, stems, roots, and fruit. They can damage strawberry fruit by creating feeding holes, resulting in nonmarketable berries. These holes may lead to secondary pathogens attacking the fruit. They can be economically damaging in high numbers.

Preventative cultural practices are most common for pill bug control. Raised beds improve soil drainage, and the removal of crop debris or other items will decrease excess soil moisture. Low-lying areas, especially at the ends of fields where irrigation lines are placed, may increase soil moisture or standing water, thus increasing pill bug populations. Spreading diatomaceous earth around the beds or plants can help with control. Permethrin-based insecticides may offer some control; however, the population should be high enough to justify the cost of spraying.

Slugs and Snails

Snails and slugs are common pests in landscapes and fields. “Slug” is the common name for any shell-less terrestrial gastropod mollusk, while snails are similar in body but have a spiral-shaped shell on their backs. Both feed on decaying plants, crop residue, and fungi. Snails and slugs feed on strawberry leaves when other sources are not available. Evidence of their feeding is the rasping appearance of ragged holes in the leaves and damage to the fruit. They feed on ripening berries and produce rough holes or channels, causing unmarketable fruit. Damaged berries may be invaded by secondary pests, including sowbugs, earwigs, small beetles, and pathogens.

Snail and slug eggs are laid in sheltered locations in the spring or fall, though overwintering is possible. They are sensitive to dry conditions and seek shelter in moist areas. Rainfall promotes their reproduction and survival. They will be more common in humid areas of Texas versus the High Plains, although changing the microclimate using high or low tunnels can result in higher populations.

Control of snails and slugs includes removing plant debris, compost, or other hiding areas. Improving drainage and reducing excess moisture in the field or around strawberry plants will aid in suppression. If there are few, they can be handpicked and destroyed.

Homemade traps and commercial bait are effective at reducing numbers. Homemade traps, such as jar lids filled with beer and salt, may aid in control. Beer acts as an attractant while the salt dries them out. Commercial baits with metaldehyde or iron phosphate can also be purchased for control. When using baits, always read and follow the label instructions.

Strawberry Diseases

Introduction

Pathogens attacking the roots, crowns, stems, leaves, and fruit of strawberries can be destructive and difficult to control. In Texas, strawberry diseases can be costly, especially when fruit are infested during harvest. Overall, prevention is the best method for controlling diseases; however, chemical and biological fungicides should be used when needed.

Strawberry pathogens can be spread easily through wind, insects, soil movement, hand transfer, tools, and other farm implements. While strawberries can tolerate some disease damage without losing yield or quality, it is important to keep them from spreading to healthy plants.

Scouting and monitoring for diseases is critical. When the field to be planted has a previous history of strawberry diseases, then control measures should begin prior to planting. Scouting for diseases should begin with inspecting transplants for root and crown diseases. If diseases are suspected, plants should be treated with a chemical fungicide root dip. It is important to regularly scout strawberry fields to prevent diseases from becoming widespread.

Once planted, continue scouting for specific diseases that may infect the roots, crowns, leaves, stems, and fruit. When scouting, do not just walk by plants in the field, but stop at plants suspected of being infected. These should be closely inspected using a 10X or higher hand lens or the entire plant should be pulled from the soil to inspect the crown and roots.

It is critical to correctly identify the pathogens before taking any control measures, especially when considering fungicide use. Applying fungicides to unknown diseases may result in a lack of control and increased costs. Diseased plant samples can be submitted to the Texas Plant Disease Diagnostic lab on the campus of Texas A&M University. Submittal forms and more information can be found on their *website*.

Disease Resistance Management

Implementing strawberry disease resistance management programs is critical to reduce the spread of pathogens in fields across the state, as well as to reduce the spread of potential new diseases not yet found in Texas. As mentioned previously, identifying diseases is the first step to developing good management programs. If certain soil diseases are chronic issues, then the appropriate management tools are critical to understand, or significant production losses will occur. Disease resistance management can be as simple as rotating fields and selecting cultivars that are bred to resist or suppress selected pathogens. Preventing strawberry leaves from excessive periods of wetness and high humidity can reduce foliar and fruit diseases.

Good water management may reduce crown and root rots and prevent their spread to healthy plants. Many pathogens can move via water transportation and runoff from other fields. Controlling weeds around and within the fields reduces humidity levels and infections and reduces potential alternative hosts within the field. Scouting and rogueing out infected plants also reduce the spread. However, the infected plants must be removed from the field and disposed of properly to avoid continued spread.

In addition to good cultural practices, managing chemical fungicide use is critical to reduce the potential for pathogens to develop resistance to labeled active ingredients. Chemical fungicides are classified by their modes of action, target sites (single or multiple), and the risk of resistance. Fungicides with multi-site modes of action have a relatively low risk of resistance, while single-site fungicides are at a higher risk. Thus, it is important to read each label, determine its fungicide group, and follow the resistance management instructions. Often, statements saying "no more than two sequential applications" are found on the labels. Following these instructions will lower the risk of pathogens developing resistance to those fungicides.

For a list of pathogens and currently labeled fungicides, refer to Table 12.

Table 12. Selected registered conventional fungicides for use in Texas strawberries (2024)

Product names	Active ingredients	Fungicide group	Application type	Diseases controlled or suppressed	Comments
Abound	Azoxystrobin	11	Preplant root dip, drip irrigation	Anthracnose, leather rot, powdery mildew, *Botrytis* (foliar)	Begin applications before disease development. 0-day PHI.
Actigard	Acibenzolar-S-methyl	PO1	Foliar	Angular leaf spot	Ground or air at eight applications per season with 7-day interval. Begin when disease first appears. Apply to actively growing plants. 0-day PHI.
Aliette Legion	Aluminum tris	33	Preplant dip, foliar	Red stele, leather rot	Dip for 15 to 30 minutes, plant within 24 hours. Begin foliar applications 2 to 3 weeks after planting and continue at 30- to 60-day intervals. Spray at 10% bloom for leather rot.
Cabrio	Pyraclostrobin	11	Foliar	Anthracnose, leaf spot, powdery mildew, Botrytis (suppression)	Apply no later than bloom prior to disease development. Rotate with other group fungicides to reduce resistance. 0-day PHI.
Captan	Captan	M	Foliar	*Botrytis* gray mold, leaf spot, anthracnose fruit rot	Begin sprays with new spring growth and flowering. Apply through harvest after each picking, 24-hour REI, and 7- to 14-day intervals.

Table 12. Selected registered conventional fungicides for use in Texas strawberries (2024)					
Product names	**Active ingredients**	**Fungicide group**	**Application type**	**Diseases controlled or suppressed**	**Comments**
CaptEvate	Fenhexamid + Captan	—	Foliar	*Botrytis* gray mold, anthracnose	Begin applications at flower emergence. Continue applications every 7 to 10 days or when conditions are favorable for disease development. 0-day PHI, no more than two sequential applications.
Copper	Multiple	—	Foliar	Leaf spot, leaf scorch	Apply when new growth begins until harvest, every 7 to 10 days.
Elevate	Fenhexamid	17	Foliar	*Botrytis* gray mold	Repeat every 7- to 14-day intervals. No more than two sequential applications. 0-day PHI. May be applied on day of harvest.
Evito	Fluoxastrobin	11	Foliar	Anthracnose, *Botrytis* gray mold, powdery mildew, *Rhizoctonia* root rot	Apply every 14 to 21 days, no more than two sequential applications. Use higher rates and shorter intervals when disease pressure is high. 2-day PHI. Apply as banded spray in-furrow to soil for root rot control.
Fungi-Phite	Mono- and di-potassium salts of phosphoric acid	33	Foliar, transplant and furrow, preplant dip	Red stele, leather rot, foliar suppression of anthracnose, *Rhizopus*, powdery mildew	Begin applications during active growth. Repeat every 2 to 4 weeks. Soak roots for 2 minutes for preplant dip applications and plant within 48 hours. For leather rot, begin applying at 10% bloom and early fruit set.
Luna Sensation	Fluopyram Trifloxystrobin	7 11	Foliar	Anthracnose, *Phomopsis* leaf/fruit rot, *Botrytis* gray mold, leaf spot, *Rhizopus*	Apply at critical times for disease infections. Continue with 7- to 14-day spray intervals. Use higher rates and shorter intervals if disease pressure is high. 0-day PHI.
Mettle 125 ME	Tetraconazole	3	Foliar	Powdery mildew, leaf spot, leaf blight	Apply prior to disease development at 14- to 21-day spray intervals depending on severity; use 14-day interval during high disease pressure. 0-day PHI.

Table 12. Selected registered conventional fungicides for use in Texas strawberries (2024)					
Product names	**Active ingredients**	**Fungicide group**	**Application type**	**Diseases controlled or suppressed**	**Comments**
Miravis Prime	Pydiflumetofen Fludioxonil	7 12	Foliar	*Botrytis* gray mold, powdery mildew, anthracnose	Begin prior to disease development. Continue with 7- to 10-day intervals, including resistance management. Maximum two applications per year. 0-day PHI.
Orondis Gold	Oxathiapiprolin Mefenoxam	49 4	Soil	Crown rot, red stele	Two applications by drip irrigation with first immediately after transplanting. Second application 30 days before first harvest. 28-day PHI.
Pristine	Boscalid Pyraclostrobin	7 11	Foliar	Anthracnose, *Botrytis* gray mold, leaf spot, powdery mildew	Begin sprays no later than 10% bloom or prior to disease development. Apply on a 7- to 14-day interval. Maximum of 5 applications yearly. 0-day PHI.
Procure	Triflumizole	3	Foliar	Powdery mildew	Start applications at first sign of disease. Repeat applications at 14-day intervals. Protection of leaves before bloom reduces in-season disease. 1-day PHI.
Quadris Top	Azoxystrobin	11	Foliar, root dip, and soil	Anthracnose, leather rot, powdery mildew, suppression of *Botrytis* gray mold, seedling root rot, basal stem rot	Dip plants for 2 to 5 minutes and transplant immediately. Soil applications should be banded or in-furrow shortly before transplanting. Begin foliar applications prior to disease development with a 7- to 10-day interval. No more than two sequential applications. 0-day PHI.
Quilt Excel	Azoxystrobin Propiconazole	11 3	Foliar	Anthracnose, leaf spot, powdery mildew	Begin applications prior to disease development at 10- to 14-day intervals. No more than two consecutive applications. No more than four applications yearly. 0-day PHI.
Quintec	Quinoxyfen	13	Foliar	Powdery mildew	Apply at 10- to 14-day intervals with no more than four applications per season. May cause leaf spotting under certain conditions. 1-day PHI.

Table 12. Selected registered conventional fungicides for use in Texas strawberries (2024)					
Product names	Active ingredients	Fungicide group	Application type	Diseases controlled or suppressed	Comments
Rally	Myclobutanil	3	Foliar	Leaf blight, leaf spot, powdery mildew	Begin applications when disease first appears. Reapply every 14 to 21 days or when disease conditions are favorable. 0-day PHI.
Rhyme	Flutriafol	3	Foliar and drip irrigation	Powdery mildew, charcoal rot	Apply preventatively or when conditions are favorable for disease. 7-day spray intervals with only four applications per year. Apply through drip system at transplanting and at 30-day intervals with a maximum of four applications. 0-day PHI.
Ridomil Gold	Mefenoxam	4	Foliar, drip or overhead chemigation	Leather rot, red stele, vascular collapse	Apply a maximum of three times with the first application immediately following transplanting. Apply second application 30 days prior to first harvest. A third application may be needed during harvest depending on disease pressure. 0-day PHI.
Rovral	Iprodione	2	Root dip, foliar	*Botrytis* crown rot, *Botrytis* gray mold, stem end rot, *Phomopsis* soft rot, purple leaf spot, anthracnose	Apply as a preplant dip immediately prior to transplanting. Only one application per year. Apply as a foliar spray when disease conditions are favorable with one application per season prior to first flowering.
Scala	Pyrimethanil	9	Foliar	*Botrytis* gray mold	Use preventatively when favorable conditions exist. Apply from pre-bloom to harvest on a 7- to 14-day interval. 1-day PHI.
Switch	Cyprodinil Fludioxonil	9 12	Preplant dip, foliar	*Botrytis* gray mold, powdery mildew, berry anthracnose, root and crown anthracnose	Apply preplant dip to roots and crown at planting. Expose for 2 to 5 minutes and plant immediately. For continued control, follow foliar application instructions. Begin foliar applications at or before bloom with a 7- to 10-day spray interval. Maximum of four applications per season. 0-day PHI.

Table 12. Selected registered conventional fungicides for use in Texas strawberries (2024)					
Product names	Active ingredients	Fungicide group	Application type	Diseases controlled or suppressed	Comments
Thiram	Thiram	M3	Foliar	*Botrytis* gray mold, anthracnose, *Rhizopus*	Apply at or before bloom, continue every 7 to 10 days through pre-harvest. Limit of five applications per season. 1-day PHI.
Topsin Incognito	Thiophanate-methyl	1	Foliar	Anthracnose crown rot, *Botrytis* gray mold, leaf blight, leaf scorch, powdery mildew	Begin applications after establishment continuing until first bloom at 1- to 14-day intervals. For fruit and leaf diseases begin applications at early bloom and continue for 7- to 10-day intervals. 24-hour REI. 1-day PHI.
Torino	Cyflufenamid	U6	Foliar	Powdery mildew	Begin applications at first sign of disease. Only two applications per year at 14-day intervals. 0-day PHI.

* *Listing products in this table does not indicate an endorsement for use. Always read and follow label instructions for uses and timings of applications and pests indicated as controlled or suppressed. With all fungicides, practice disease resistance management according to specified instructions on the label. Active ingredients may also be labeled under generic product names.*

Fruit and Foliar Diseases

Botrytis Gray Mold

Botrytis gray mold (*Botrytis cinerea*) is a fungus that infects strawberry crowns, stems, leaves, flowers, and fruit. It is one of the most common strawberry diseases in Texas and has infected strawberries for many years. *Botrytis* can be found everywhere, even on berries inside containers shipped and sold from other states. *Botrytis* leaf infections are usually not significant, but they can lead to infection of other tissues, especially berries. Decreased marketable yield occurs when there are high infection rates in strawberry fields.

▲ **Figure 41. *Botrytis* infection of strawberry fruit (left) and both the fruit and stem of plants during harvesting (right). Infections begin from rain-splashed spores which form colonies during periods of rainfall and high humidity.**

Botrytis cinerea prefers cooler, more humid climates, which are the same conditions ideal for growing strawberries. It begins as dense, gray fungal growth on the lower parts of the plant. During its life cycle, spores are produced that can go airborne or be splashed by rainwater onto younger leaves, open flowers, and developing fruit. The fungus can overwinter as sclerotia in the soil or on dead plants.

Rainfall and overhead irrigation increase *Botrytis* infection potential by increasing humidity levels and providing wet areas to promote fungal growth and development. *Botrytis* infections can form on ripening berries that touch moist soil surfaces. Berries that are underwater during flooded conditions will certainly be infected and should be disposed of properly, not harvested for sale.

Strawberry flower infections can occur early in their development; however, the presence of an infected flower is not always visible. *Botrytis* infections usually become visible when the berries are nearly mature, at harvest, or after harvesting and during storage. Like infected leaves, berries develop a dense, gray fungal growth that can spread to nearby fruit.

Although not as common, *Botrytis* crown rot has been diagnosed in South Central Texas strawberry fields. Unless properly diagnosed by a lab, it can be confused with other crown rots, including anthracnose or *Rhizoctonia, Pythium,* and *Phytophthora*. Without proper disease identification, specific control measures may not be useful.

Controlling *Botrytis* in Texas can be difficult as it is prevalent throughout all regions. Scouting fields is critical to identify areas of infections. Cultural and preventative management techniques can be used when conditions are favorable, especially during flower bloom. Keeping rainfall and irrigation off the plants, especially during harvest, helps reduce infections. If only a few berries are infected, remove them and dispose of them away from the field to prevent other infections. Drying the leaves quickly can reduce infections. Increase air circulation in fields by removing plant debris and weeds. If growing in plastic-covered high or low tunnels, raising the sides occasionally will decrease humidity levels and help reduce development.

Plastic mulch protects plants and fruit from directly contacting *Botrytis* spores residing in the soil. If cost-effective, remove plant debris following the final harvest to reduce future potential infections. University of Florida research reports moderate resistance of selected cultivars to *Botrytis*, including Camarosa and Florida Radiance. However, most cultivars showed little to no resistance. Resistance could also be a factor of higher fruit set on some cultivars.

There are many fungicides available for controlling *Botrytis*. Each labeled fungicide has instructions on its proper application, including rotating fungicide groups to reduce potential future resistance to the chemicals.

Anthracnose Fruit Rot

Anthracnose is an important disease that attacks not only the strawberry fruit but the foliage, runners, and crowns. It is caused by several species, including *Colletotrichum acutatum, Colletotrichum fragariae,* and *Colletotrichum gloeosporioides*. Fruit rot and crown rot are the most destructive forms. The disease is often introduced from infected plant material.

When conditions are ideal, *Colletotrichum* spp. form whitish, tan, or light brown water-soaked lesions on the fruit, usually up to 3 millimeters (mm) in diameter. The lesions eventually turn brown to dark brown, are sunken, and eventually may coalesce to damage the entire fruit. It can attack during any stage of crop development.

▼ Figure 42. A strawberry fruit infected with anthracnose. This disease is more widespread during periods of high rainfall, which spread spores from infected tissues to healthy plant parts.

The fungus survives on old dead leaves and fruit or on other plant debris within the field. Its spread is favored by warm (77 to 86 degrees F), humid, and rainy conditions. It can be spread by splashing rain, farm equipment, wind, and hand laborers. Under favorable conditions, it can spread very quickly throughout a field.

Management is like other diseases; however, there are fungicides labeled for its control. For best results, fungicides should be used as protectants applied before symptoms are present.

Powdery Mildew

Powdery mildew on strawberries is caused by the fungal pathogen *Podosphaera aphanis* (syn. *Sphaerotheca macularis* f. sp. *fragaria*). It is more common in regions of high humidity, including inside high and low tunnels. It is less likely to be found in fields on the High Plains, though it has been reported in high tunnels in that area.

Powdery mildew is identified as white, powdery spores on infected leaves and fruit, resulting in decreased plant growth and lower yields. Infected leaves start with white patches on their undersides but can become solid white underneath with the leaves curling upward, turning red to brown, then dying. Early infection of flowers and developing berries reduces quality and yield, causing berry rot. Flower infection also inhibits fruit maturation and may cause berry malformation. The infection and spread of powdery mildew are aided by high humidity and temperatures ranging between 60 to 80 degrees F. However, overhead irrigation, rainfall, and morning dew can inhibit the development and spread of powdery mildew.

Powdery mildew overwinters as cleistothecia, or small, black, pepper-like resting structures that can remain dormant for extended periods until there are suitable growing conditions. *Podosphaera aphanis* (syn. *Sphaerotheca macularis* f. sp. *fragaria*) is host-specific to strawberries, and thus unable to survive without them. In Texas, the fungus is usually introduced to new fields through infested nursery bare roots or plugs.

▲ **Figure 43. Powdery mildew is less common than other diseases in Texas. It mostly infects the upper and lower parts of leaves in regions of high humidity.**

To prevent spread, plants—both plugs and bare roots—purchased from nurseries outside of Texas should be inspected to ensure they are disease-free before planting. Always purchase plants from reliable sources and inspect them for any signs of infection. If powdery mildew is suspected, quickly send a sample to the Texas A&M Plant Diagnostic Lab in College Station.

In open fields, increasing air movement by removing weeds decreases the risk of infection by reducing humidity levels around the plants. In high and low tunnels, raising the sides also improves air circulation and reduces inside humidity.

Florida research shows that selected cultivars have shown some resistance to powdery mildew, including Brilliance, Cabrillo, Sweet Ann, and Rikas. However, cultivars like Festival, Monterey, and Radiance are susceptible to the disease. Under the breezy and somewhat drier conditions around Texas, there have been few reports of powdery mildew causing economic damage.

Leaf Scorch

Leaf scorch (*Diplocarpon earlianum*) is a fungal pathogen that spreads by the splashing of spores through the air. The fungal spores land on non-diseased plant parts and begin infection. *Diplocarpon earlianum* growth is favored by long periods of leaf wetness from rainfall or overhead irrigation. The disease generally begins on older and middle-aged leaves, especially those near the soil surface, eventually spreading to other leaves when favorable conditions exist. Leaf scorch infections spread best between 60 degrees F and 77 degrees F for optimal growth.

Proper identification of *D. earlianum* is needed as symptoms can be misdiagnosed as leaf spot (*Mycosphaerella fragariae*). Leaf scorch symptoms begin as small, purplish-to-brown spots or blotches on older leaves. Under ideal conditions, *D. earlianum* leaf spots begin to enlarge and coalesce, eventually turning the leaves brown, leading to marginal leaf curl and necrosis. The fungus also infects strawberry petioles, flowers, and fruit. Leaf scorch can be controlled or suppressed with regular fungicide applications.

Preventative control methods include purchasing disease-free plants and resistant cultivars. If previous infections in the field have been severe, selecting resistant cultivars will help reduce infections. Crop rotation will also help break the *D. earlianum* life cycle. Removing infected, dead plant debris during the strawberry season and at the end of the harvest helps prevent transmitting the infection to future plantings.

Figure 44. Common leaf scorch is spread by splashing spores from infected plant tissue to healthy tissues. Long periods of leaf wetness encourage its growth and spread.

Common Leaf Spot

Common leaf spot is a fungal disease caused by the pathogen *Mycosphaerella fragariae*. As with leaf scorch, symptoms begin on leaves with small, purplish spots or blotches; however, for this disease, the leaf spots (or lesions) enlarge to about 6 mm with centers that turn a light tan color. The spots rarely coalesce unless under heavy infections, which may also cause the death of those leaves. Symptoms can be confused with other leaf diseases; therefore, disease identification may be required to improve control.

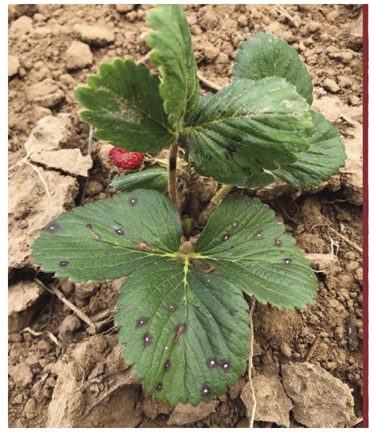


Figure 45. Common leaf spot can be found in most strawberry fields. It is found mostly on the upper leaf surfaces but can also infect flowers and fruit.

Common leaf spot lesions start on the upper leaf surface and are usually not found on the underside. On younger leaves, the spots generally remain light brown. Leaf spots can also be found on strawberry fruit, calyxes, petioles, and runners. Under high humidity, black spots approximately 0.25 inch across may appear on developing berries and around groups of seeds.

Common leaf spot has an asexual stage that produces conidia (small spores). These conidia are dispersed by overhead irrigation and splashing rainfall. The optimal temperature range for infection is somewhat wide, being between 50 degrees F and 80 degrees F.

Interestingly, symptoms can differ based on the cultivars planted as well as the specific fungal strain and temperature ranges. Purchasing disease-free plants improves the prevention of common leaf spot. When previous infections have been severe, select resistant cultivars and rotate crops or fields.

Cercospora Leaf Spot

Cercospora leaf spot is caused by fungi within the *Cercospora* genus. On strawberries, it is generally caused by *C. fragariae*. Although it is common throughout Texas strawberry production, it only causes minor leaf spots on strawberry leaves.

With favorable conditions, *Cercospora* leaf spot begins as small, round, purple spots mostly found on the upper side of leaves. As the leaf matures, the center of the spot becomes tan or gray and then almost white while the edges of the spot remain purple. On the underside of the leaf, the spots are bluish or tan in color. *Cercospora* generally occurs in older plantings; thus, the annual plantings common in Texas are less likely to become infected. While it does infect strawberry leaves, it is not known to infect the fruit. Like other leaf diseases, *C. fragariae* spores are spread by splashing water, either from rainfall or overhead irrigation.

Preventative measures to control *Cercospora* leaf spot include good field sanitation, mowing, and burying infected leaves to destroy reproductive structures. Removing weeds and other plant debris can improve air movement to minimize wet leaf surfaces, which increases infection. Closer plantings within strawberry beds may increase the potential for leaf spot infections; thus, 12-inch spacings are recommended. Rows planted farther apart may help reduce infections but may also impact yield. There are fungicides labeled for controlling *Cercospora* leaf spot in strawberries.

Phomopsis Leaf Blight

Phomopsis leaf blight is caused by the fungal pathogen *Phomopsis obscurans*. Leaf symptoms begin as small, purplish spots or blotches that gradually enlarge to become elliptical to V-shaped along the major veins of the leaves. Older lesions develop dark brown centers surrounded by a light brown margin which progresses to a chlorotic to red or purple halo.

Leaf blight also infects strawberry runners, petioles, fruit calyxes, and the fruit itself. On the fruit, symptoms become more visible as the berry matures from pink to red. Initial symptoms include round, light pink, and water-soaked lesions. In advanced stages, lesions turn light brown at the margins, then darker brown and crusty towards the center of the lesion. Small black pycnidia (asexual reproductive structures) may also be present on the fruit.

Figure 46. *Phomopsis* leaf blight symptoms begin as small, purplish spots or blotches that can enlarge into elliptical or V-shaped patterns along the major veins of the leaves. This disease is not as widespread as common leaf spot.

Phomopsis reproduces best in humid climates, including South and East Texas. It spreads through water splashing from rain and overhead irrigation onto uninfected plants. *Phomopsis* can be introduced into new fields through infected plugs and bare-root transplants. Though rarely a concern, it is possible for it to cause economic losses in non-rotated fields.

Preventative control methods include purchasing disease-free plants. Check bare roots and plugs for the presence of disease prior to transplanting. Removing dead plant debris during and at the end of the season helps prevent transmitting infection to future growing seasons. There are currently no resistant cultivars.

Pestalotia Leaf Spot and Fruit Rot

Pestalotia is caused by the fungus *Neopestalotiopsis* sp. There have been recent outbreaks in Florida and, in 2022, in strawberry fields in Louisiana. There have also been reports of *Neopestalotiopsis* in South Texas strawberry fields. Growers should be vigilant in scouting for this disease as it can be very economically devastating. When unsure if the disease is present in a field, send samples to the Texas Plant Disease Diagnostic Lab in College Station.

This disease can be difficult to control. It was previously considered a weak or secondary pathogen on strawberries, but it has been isolated along with other root pathogens, including *Colletotrichum acutatum* and crown rot pathogens, like *Colletotrichum gloeosporioides, Phytophthora* spp., and *Macrophomina phaseolina*. It was not considered a major concern until recently. For more information, visit this article titled *Neopestalotiopsis disease in strawberry: What do we know?*

Symptoms of *Pestalotia* leaf spot and fruit rot are characterized by light to dark brown spots of varying sizes on the leaves. The spots are distributed irregularly throughout the leaf. Spots often become circular but as they enlarge, they become irregular in shape. In the advanced stages, the spots increase and can merge into one large lesion.

Fruit symptoms can be confused with anthracnose fruit rot as it starts as dry, light tan, slightly sunken misshaped lesions, usually 2 to 4 mm across. Lesions continue to expand and soon cover the entire fruit. Lesions may become covered by dark fruiting bodies that produce spores in shiny dark liquid.

As with other leaf and fruit diseases, under ideal conditions (extended rainy periods), *Pestalotia* produces spores that infect plants through rainfall and overhead irrigation. Spread can also occur by farming operations (cultivation, hoeing, harvesting, etc.). The optimal temperature for growth is between 77 degrees F and 86 degrees F. Epidemics can occur when these conditions are favorable.

Pestalotia is currently difficult to control. There are no fungicides currently labeled for control of *Pestalotia*; however, several fungicides, including Switch and Thiram, appear to offer some suppression. Prevention through good field sanitation practices, scouting and proper identification, and avoiding overhead irrigation are best practices.

Rhizopus and *Mucor* Fruit Rots

There are two fruit rot diseases found in Texas fields, which generally occur during harvest. *Rhizopus* and *Mucor* are two fungal pathogens with similar symptoms, including water-soaked (leaky) fruit, which often drips or oozes sticky, red juice from infected berries. Eventually, infected berries cannot be picked up. Other symptoms of *Rhizopus*- and *Mucor*-infected fruit include fuzzy black and white fungal growth.

▲ **Figure 47. *Neopestalotiopsis* is a relatively new disease in Texas. It often comes in on new plantings on either bare roots or plugs. It can infect strawberry roots (left), the plant crown (middle), or the fruit (right).**

Rhizopus and *Mucor* infections should not be confused with *Botrytis* gray mold, as *B. cinerea* does not usually cause leaky fruit. An easy method to indicate infections includes seeing berry leakage running down the sides of the plastic mulch.

Beyond symptomology, *Rhizopus* and *Mucor* are different in appearance when examined with a hand lens or under a microscope. It is generally not critical for growers to identify each pathogen separately, but a description can help. For *Rhizopus*, the sporangia (tiny, dark brown or black spherical structures bearing spores) appear to be dry, while with *Mucor*, they are wet and sticky looking. With *Mucor*, the sporangia line up in parallel rows, while for *Rhizopus*, they appear more random. The spores are airborne and dispersed by wind.

▲ **Figure 48. *Rhizopus* and *Mucor* fruit rot symptoms include water-soaked or leaky fruit, often oozing sticky, red juice from the berries, which cannot be picked up. Other symptoms of infected fruit include fuzzy black and white fungal growth.**

In Texas, *Rhizopus* and *Mucor* infections appear more frequent after heavy rains or with overhead irrigation. Infections are more likely to occur in more humid growing regions of the state. While both pathogens can survive typical Texas winters, they are more active in warmer months.

When harvesting berries, minimize damaging healthy fruit as open wounds become infected quickly. This can be difficult in U-pick operations where less care is taken when harvesting berries. Cooling the fruit quickly after harvesting helps reduce spread and development.

Preventative methods to reduce *Rhizopus* and *Mucor* infections include field sanitation, removing dead leaves and fruit, or deep disking. Using plastic mulch and drip tape helps minimize fruit contact with the soil and splashing water. Remove and dispose of infected berries away from healthy plants and fruit. Several fungicides are labeled for controlling these pathogens; however, check with the appropriate state labels for timing and rates of application. Often the disease is reduced during warmer, drier weather.

Root and Crown Diseases

Strawberry root and crown diseases can be very destructive to Texas production. They can be easily misdiagnosed without lab analyses; therefore, correct identification is critical. If root and crown diseases are suspected, send samples to the Texas Plant Disease Diagnostic Lab as soon as possible.

Root and crown diseases may spread quickly through fields, with spores and reproduction structures passing through irrigation, including drip systems. Wet, soggy soils, overwatering, and heavy rainfall increase the spread of these diseases. While many fungicides and biofungicides are labeled for controlling strawberry root and crown diseases, prevention is best for overall control.

Well-drained sandy soils aid in suppressing root and crown rots. Crop rotation is the most effective measure and should be practiced to reduce infections and increase control with fungicides. The following root and crown diseases are some of the most common found in Texas strawberry fields.

Anthracnose Crown Rot

(*Colletotrichum* spp.)

As mentioned previously, *Colletotrichum* spp. are fungi that cause crown rot, stem lesions, leaf spot, flower blight, and fruit rot in strawberries.

A common name for *Colletotrichum* diseases is anthracnose. Anthracnose crown rot has been recorded throughout Texas. Under high humidity or during high rainfall seasons, the disease spreads rapidly, including where the crop is grown under protective plastic coverings. Furrow irrigation may also spread and cause plant infections.

The disease grows rapidly in high humidity at 68 degrees F and above. Spores spread through the air and by rain splash. Crown infections appear as sunken, necrotic lesions and typically kill the entire plant. Necrotic spots also develop on infected leaves. Anthracnose crown rot symptoms are identified in Figure 49.

It is critical to inspect all newly purchased bare roots and plugs to ensure that the plants are free of *Colletotrichum* crown rot diseases. Root

Figure 49. While anthracnose infections are more common on strawberry fruit—which can also infect the plant, especially the crown and roots—symptoms are like other crown rots. Therefore, to improve control, correct identification is needed.

dips and protectant fungicides can help prevent the disease but will not control existing infections. It is important to avoid overhead irrigation and carefully remove infected plants from the field. It is best to place infected plants in garbage bags and throw them into dumpsters for disposal. Do not throw infected plants around field edges. Applying lower rates of nitrogen fertilizer also helps manage this disease.

Phytophthora Diseases

Phytophthora fungi generally cause problems in wet or poorly drained soils, though some species can attack strawberries regardless of conditions. Strawberries grown in higher clay soils are more at risk for *Phytophthora* infections.

Two species, including *Phytophthora citricola* and *P. fragariae*, cause root and crown rot and red stele root rot, respectively. Another species, *P. cactorum*, may also cause crown rot as well as leather rot in fruit. Other *Phytophthora* species may affect strawberries but do not cause disease as frequently. With *Phytophthora* spp., symptoms include plant and leaf dieback and leaf or stem chlorosis. Symptoms may differ slightly according to species. If unsure of the disease present in a field, send samples to the Texas Plant Disease Diagnostic Lab in College Station.

Root rot from *P. fragariae* causes a red discoloration of the stele (core) of the root. *P. citricola* is aggressive and may kill the plant rapidly. Other *Phytophthora* species cause problems only in low-lying areas where water drains poorly. Over-irrigating fields or strawberry beds, even through drip systems, may increase infections of *Phytophthora* spp. Crown or stem injury while planting may result in open wounds for the pathogen to gain entry.

Leather fruit rot (*P. fragariae*) can cause significant losses. Berries can become infected at any stage, turn brown, and have a leathery texture. Leather rot may include white mycelium growing on the fruit surface. Infected berries also develop a disagreeable odor and taste.

Spores of *Phytophthora* are spread by soil, water, or rain splash, so overhead irrigation is discouraged. The spores can remain in the soil for extended periods and cause infections the following season.

Managing *Phytophthora* pathogens typically combines cultural and chemical controls. Fungicide root drenches and dips can be useful to prevent infections. Other methods include using disease-free plants, improving drainage on poorly drained sites with drainage tiles or raised beds, and planting resistant cultivars.

Figure 50. *Phytophthora* root rot symptoms include plant wilting (A) and a red discoloration to the core of the root (B).

Photo source: Phytophthora Crown Rot of Strawberry (UF/IFAS Publication #PP350, 2023).

Black Root Rot

Black root rot is a disease complex of multiple root-infecting pathogens, including *Rhizoctonia* spp., *Fusarium* spp., and *Pythium* spp., and may include some nematode species. The disease complex is mostly found in fields with long histories of strawberry production, especially where there has been little to no crop rotation. In Texas research, the spread of black root rot was found to increase annually where strawberries were grown without rotation. In those studies, yields decreased significantly over time. Therefore, crop rotation is essential to reduce these pathogens in strawberry fields.

The disease complex usually builds up over time and plants may grow normally for several months before symptoms appear. Symptoms include stunting, low plant vigor, and dieback of leaves and fruit. Stunting is usually associated with older, outer leaves dying or completely dead leaves. Plants will have few runners and fewer and smaller berries. Infected plants can often be pulled easily from the soil as the crown rots.

Black root rot can be difficult to diagnose due to the many different pathogens potentially involved. For example, in some fields, the disease may be predominately caused by *Rhizoctonia* spp. or *Pythium* spp., while in other fields, it may be *Fusarium* spp. or even nematodes. These species can often be found in low levels on root samples sent for diagnoses for other issues and may not necessarily be the direct cause of disease symptoms. Based on Texas A&M AgriLife research, plants grown in annual systems in high tunnels are at greater risk than those grown in open fields. Black crown rot symptoms are shown in Figure 51. If plants are dying from crown rot, send samples to the Texas Plant Disease Diagnostic Lab in College Station for proper diagnosis. Identification of the pathogens is the first step to managing this disease complex.

For control of black root rot, use disease-free plants and preplant fungicides to suppress diseases. Black root rot is best controlled by crop rotation, with strawberries out of the field for at least 3 years. Do not rotate strawberries with crops that are hosts to any of these pathogens, including cruciferous and leguminous crops. Rotation with grass crops is a good idea.

▲ **Figure 51. *Rhizoctonia* crown rot is one of several fungi in the disease complex called black root rot. It can be difficult to diagnose due to the many different pathogens (*Rhizoctonia, Fusarium,* and *Pythium* spp.) potentially involved. It can spread quickly down the strawberry bed.**

Avoid fields with low-lying areas that create standing water and lack good drainage. Soils with higher clay content may not drain as adequately as sandy soils. Raising strawberry beds at least 8 to 12 inches will improve drainage from irrigation water and reduce overwatering around the roots and crowns.

Botrytis Crown Rot

Botrytis crown rot is the same fungus as *Botrytis* gray mold of the fruit, but it is less common. However, it has been identified in strawberry crowns in Texas. It is similar in appearance to other root and crown rots, so proper identification is critical for its control. *Botrytis* crown rot symptoms can be seen in Figure 52.

Botrytis crown rot is most common in late winter and early spring when conditions are cool and wet. Excess plant growth or planting at high densities can increase disease spread. *Botrytis* crown rot can be found on the crowns and roots of bare-root transplants; therefore, it is important to thoroughly inspect plants upon arrival to reduce the spread of this disease.

Like the other crown rots, use disease-free plants and preplant fungicides for suppression. *Botrytis* crown rot is suppressed by a 3-year crop rotation. Rotation with grass crops is a good idea. Do not plant in fields where low-lying areas create standing water or have areas that lack good drainage. Raising strawberry beds at least 8 to 12 inches improves drainage around the roots and crowns.

Figure 52. *Botrytis* crown rot is not as common as other diseases but can cause infections in late winter and early spring when conditions are cool and wet.

Weed Control

Introduction

Successful strawberry production requires excellent weed control from the time of transplanting through final harvest. Weeds present in strawberry fields will reduce plant size and berry quality through competition for space, sunlight, nutrients, and water. Weeds create higher levels of disease by increasing humidity levels around the berries and harbor insects, mice, and other varmints. Weeds in the field during the harvest season interfere with work crews and U-pick customers, costing time and money.

Mature weeds left uncontrolled will increase seed production and, thus, future weed populations, resulting in higher control costs. For strawberries, a good weed management program combining preplant soil-applied herbicides, plastic mulch-covered beds, postemergence herbicides, and hand-weeding will increase yield, quality, and profitability.

Integrated weed management is the best approach to control weeds in strawberry fields. Integrating multiple control methods reduces the risk of weeds causing economic damage to the crop. Integrated weed management includes the following five principles of control and suppression: (1) preventing new weed seed production by not allowing them to grow to maturity, (2) the use of cultural methods through field rotation, (3) physically controlling weeds through cultivation and hand-weeding, (4) biological control of weeds, and (5) controlling weeds with herbicide spray applications.

Integrating two or more of the above integrated weed management principles will improve weed control, reduce costs, and potentially reduce dependency on chemicals. Although herbicides are an important method of weed control, they should be the last line of defense after integrating one or more of principles 1 through 3. In strawberries, herbicide applications are the most important strategy for reducing overall hand-weeding costs and should not be ignored.

There are registered herbicides in Texas for strawberry production, and using one or more products will significantly reduce hand-weeding costs. Herbicide applications have been shown to annually save up to $1,500 per acre of hand-weeding costs. Applying preplant soil herbicides with residual control reduces weed competition. Soil-applied herbicides that have different active ingredients may not have the same length of residual activity. Furthermore, soil-applied herbicides may be influenced by application timing and method, soil temperature, soil moisture, and rainfall.

In addition to soil-applied herbicides, Texas growers have products registered for postemergence grass control. Regardless of the method, weeds must be controlled to achieve high yield potential. The following sections provide useful information to assist growers with the decision-making process related to strawberry weed control.

For a current list of registered herbicides in strawberries, see Table 13.

Table 13. Registered conventional herbicides for use in Texas-grown strawberries in 2024

Active ingredient	Product names	Application timing	Methodology	Comments
Carfentrazone	Aim EC	Preplant burndown	Postemergence contact	Broadcast, directed spray, hooded spray applications allowed.
Clethodim	SelectMax	Postemergence to grasses	Systemic through leaves	Control grasses only, broadcast over the top, surfactant improves control.
DCPA	Dacthal	Preplant soil-applied	Residual with incorporation	Control on grasses including sandbur, some broadleaves, and carelessweed.
Flumioxazin	Chateau	Preplant broadcast	Postemergence contact + soil residual	Apply preplant 30 days prior to transplanting. It has some postemergence activity on small weeds as a burndown.
Glyphosate	Many	Preplant postemergence	Apply post-directed to row middles only	Avoid contact with strawberry leaves or injury and death may occur. Spray when wind speeds are reduced.
Gramoxone	Gramoxone	Postemergence	Post-directed between rows	Avoid contact with leaves, plants, and fruit or spotting will occur.
Optogen	Bicyclopyrone	Postemergence	Post-directed between rows	Newly registered in 2023. Avoid contact with leaves, plants, and fruit or spotting will occur.
Oxyfluorfen	Goal 2XL	30 days before planting	Preplant	Plastic mulch should be applied immediately following application for the best results. No incorporation needed but may result in less crop injury. Trials have not been conducted in Texas.
Pendimethalin	Prowl H2O	Preplant soil-applied	Soil residual	Good preemergence grass control.
Pelargonic acid	Scythe	Postemergence	Contact with leaves/stems	Preplant burndown, directed, or shielded spray applications.
Sethoxydim	Poast	Postemergence	Systemic through leaves	Grasses only, broadcast over the top, surfactant improves control.
Sulfentrazone	Spartan 4F	Preemergence	Soil residual	Good soil residual, nutsedge activity.

** Listing products in this table does not indicate an endorsement for use. Always read and follow label instructions for uses and timings of applications and pests indicated as controlled or suppressed.*

Weed Identification

Like diseases and insects, identifying weeds in strawberry fields is the first step for their control. Strawberries are planted during the cool season; therefore, fall and winter weeds are likely to be the most common species found, though as spring turns to summer, more warm-season species emerge.

Many weed species can be found in strawberry fields, including both annual (single season), biennial (two seasons), and perennial (more than 2 years) weeds. Annual weeds can be easier to control than perennials. Perennial weeds generally have underground reproductive structures that can be difficult to control. Herbicides are best at controlling perennial weeds.

To date, weeds identified in Texas strawberry fields include henbit (*Lamium amplexicaule*), London rocket (*Sisymbrium irio*), Shepherd's purse (*Capsella bursa-pastoris*), purslane (*Portulaca oleracea*), common mallow (*Malva neglecta*), yellow nutsedge (*Cyperus esculentus*), carpetweed (*Mollugo verticillata*), field bindweed (*Convolvulus arvensis*), sandbur (*Cenchrus longispinus*), bermudagrass (*Cynodon dactylon*), Palmer amaranth (*Amaranthus palmeri*), crabgrass (*Digitaria* spp.), Russian thistle (*Salsola tragus*), among many others.

If unsure about specific weed identification, contact the nearest Texas A&M AgriLife Extension county office for help. Additionally, the Weed Science Society of America offers a free resource on their *weed identification site*.

Preplant Weed Management

Understanding the following techniques before bed shaping and laying plastic is important to improve weed control in strawberry production.

Field History

Knowing the field history or suspected weed populations allows for better preparation to kill difficult-to-control weeds. When planting in any field, keep accurate records of what has previously been grown, what herbicides have been used, and what weeds are problematic. When renting land, discuss field histories with the landowner before planting strawberries. Planting into fields with high populations of aggressive perennial weeds can be problematic and costly.

Crop Rotation

Rotating strawberries between fields can suppress weed populations by growing different crops, applying alternative herbicides, or using cover crops for weed competition. Crop rotation also reduces potential root diseases and insect pests. Applying systemic herbicides to perennial weeds in the year prior to strawberries can reduce their growth the following year.

Field Disking and Rototilling

It is essential to have a weed-free field prior to applying soil-residual herbicides, bed shaping, and plastic mulch laying. Annual weeds can be controlled with proper disking; however, perennial weeds are more difficult. Disking fields with perennial weeds may help spread their growth. Spraying perennial broadleaf and grass weeds with a systemic herbicide before disking will help. Rototilling fields will create a more uniform soil for improved bed shaping.

Preplant Burndown Herbicides

Several herbicides are labeled for preplant burndown. Before disking the field, burndown herbicides with no residual activity can reduce future weed populations. They are best applied when weeds are small, following a rain when they are actively growing.

Preemergence Herbicides

After the soil has been prepared or shaped for laying plastic, applying a preemergence herbicide will reduce weed pressure during early plant growth, a critical stage of development. While most herbicides do not control all weeds, a significant reduction in weed populations will reduce future hand-weeding and reduce costs. There are several good preemergence options registered for use in strawberries.

Preventing Future Weed Populations

Allowing weeds to mature and produce seeds increases future weed populations, resulting in increased efforts and costs for their control. Fields that are expected to be planted with strawberries should have weeds controlled by disking or postemergence herbicides before seeds mature. Some weed species can produce thousands to a hundred thousand seeds from one plant. An ounce of prevention is worth a pound of cure regarding weed seed.

In-season Weed Control

Hand-weeding

Specific attention to removing weeds growing in the transplant holes is necessary. Weeds should be removed when small. Often, the most susceptible time is during early crop growth after transplanting. Leaving weeds in transplant holes until larger may weaken strawberry root systems when pulled, reduce potential nutrient uptake, and increase potential disease and insect infestations (Fig. 53). Field workers should be sufficiently trained so as not to injure the strawberry crop when hand-weeding. Hand-weeding row middles may be required. Care should be taken to avoid crop injury. Perennial weeds are more difficult to control than annuals.

▲ **Figure 53. Weeds in strawberry fields can reduce plant size and berry quality through competition for space, sunlight, nutrients, and water. Weeds also create higher levels of disease by increasing humidity levels around the berries and can harbor insects, mice, and other varmints.**

Cultivation

If equipment is available, cultivating the row middles using a tractor or rototiller can reduce weed populations without costly hand-weeding. It is best done when weeds are small and easily controlled. Care should be taken to stay clear of buried plastic edges. Weeds along the plastic edge should be pulled, hoed, or chemically controlled with a directed spray or shielded application.

Herbicides

Always read and follow herbicide label instructions before making an application or crop injury, plant loss, yield reduction, and even crop destruction may occur. Use only herbicides and products labeled for strawberries in Texas. Growers can be heavily fined by the TDA or have the strawberry crop destroyed if using non-registered products. Product labels are found on the herbicide container or at manufacturer, distributor, and sales websites. Pesticide label websites like CDMS or Greenbook can be searched for updated labels. If unsure about a product's use, contact the local Texas A&M AgriLife Extension county office or a sales representative.

As with any pesticide, herbicide activity may vary depending on farm location, including soil type, pH, percent organic matter, and the climate during and after application. Herbicide residual for soil-applied products may vary depending on rainfall and irrigation and the soil conditions mentioned previously. Product labels provide details on how to use the herbicide under specific soils and climates. Loss of control or crop injury may occur if directions are not followed.

Row Middle Applications with Soil-residual Herbicides

Applying herbicides labeled for row middle applications can save weed control costs compared to hand-weeding alone. Depending on bed spacing, herbicide use can be reduced by 20 percent to 50 percent, resulting in cheaper costs of production and reduced risk of crop injury from broadcast preemergence applications.

Postemergence Grass Control with Systemic Herbicides

Systemic grass-killer herbicides have been around for decades and are useful for controlling small annual and some perennial grasses in strawberry beds and in row middles. They can be applied over the top of the strawberries or spot sprayed on grass weeds as needed. Sethoxydim and clethodim are the active ingredients for two grass herbicides labeled in strawberries. Control is significantly improved when grass weeds are not under moisture and heat stress.

Postemergence Herbicide Control

While postemergence grass herbicides are labeled for over-the-top strawberry applications, there are currently no broadleaf postemergence herbicides labeled for annual production in Texas. For the best control, hand-weeding the transplant holes and the plastic edge is currently the only strategy. For the row middles, shielded/hooded application options are available. Shielded/hooded sprayers are best to prevent plant contact. Care should be taken to avoid contact with strawberry plants. Applying in the early morning or late evening will reduce wind drift potential. Avoid spraying or drifting onto the runners or hitting the plastic where leaves and stems may come into contact with the product. Burndown herbicides can also be used with good success.

Mowing Weeds in Row Middles

If herbicides are not an option, weeds growing in row middles can be mowed using a tractor shredder (if rows are wide enough) or mowed using a hand-pushed lawn mower. Many mowed and shredded weeds may not be killed as the growing points are often below where the blades make contact. These weeds continue to take up moisture and nutrients from the soil. Multiple mowings will likely need to be done throughout the season. Care must be taken not to injure ripening berries with mower clippings thrown into the strawberry beds.

Cover Crops for Row Middles

Cover crops planted in the row middles can provide weed suppression during the strawberry season. Grain crops like wheat or rye grains can be planted early following transplanting and then killed with a grass herbicide. This will provide cover to the soil with stubble or residues that can suppress weeds. Preemergent soil-residual herbicides can also be banded to the row middles at the same time to aid in further suppression.

Weed Fabric for Row Middles

For small-acreage producers, organic growers, and home gardeners, woven polypropylene weed fabric placed between the strawberry beds significantly reduces weed populations. The benefits of weed fabric include weed suppression and a reduction in hand-weeding costs. Weed fabrics are porous and allow rainfall to reach the soil. They keep middle rows clean and more accessible for harvesters and customers. The initial cost of weed fabric can be high, but if properly cared for, they can be reused for many years. Some weeds are still difficult to control even with weed fabric. For example, yellow nutsedge and some grasses may still emerge through the fabric. These can be controlled by hand-pulling or spot spraying with a postemergence herbicide.

Post-harvest Weed Control

Following the final harvest, weeds should be controlled immediately to prevent them from interfering with plastic mulch and drip irrigation removal. Large weeds can damage farm equipment. Weeds should be controlled by mechanical means or with postemergence herbicides (especially perennials). When left to mature, certain weed species can deposit up to 100,000 seeds per plant. Perennial weeds with underground shoots/rhizomes can continue growing and increase future weed control costs

Vertebrate Pests

Not all strawberry pests are diseases, insects, and weeds. Vertebrate pests include deer, birds, rabbits, skunks, raccoons, prairie dogs, mice and rats, and other burrowing animals. Deer can cause significant damage and are known to chew on young strawberry leaves, especially following transplanting. Deer fencing and electric fencing may be useful but can be expensive. If the transplants are not rooted well, deer can also destroy plants by pulling them up from the soil. There are deer repellent formulations available, but they should be inspected for whether they can be legally sprayed on strawberry plants. They may be useful if the area surrounding the fields is sprayed instead of inside the strawberry field.

Birds may also create significant problems, especially during berry harvest. Birds damage the berry by eating both the flesh and seeds. When birds are a significant problem, they can be controlled by placing bird netting around the plants or, in the case of high tunnels, around any exposed entry. However, it may be costly depending on the size of the strawberry production field.

Bird netting can be purchased from retail stores or purchased online in selected lengths. It is best to use low tunnel hoops to support the netting. Open-field production will require placing the netting over the hoops and temporarily removing them for harvesting. Netting should

▲ **Figure 54. Small and large mammals can cause significant damage to strawberry plants and fruit during the season. The above photos include damage to strawberry leaves and stems from deer feeding (left), damage to fruit from bird feeding (middle), and damage where only the seeds are eaten from mice feeding (right).**

be placed tight so birds are unable to get beneath it. Be sure that the bird netting squares are wide enough for bees to move through freely for pollination.

Mice, rats, voles, rabbits, skunks, raccoons, and other burrowing animals can infest strawberry fields by living and breeding in plant debris and in shrubs and brush in areas surrounding the fields. They can also live in holes beneath the plastic mulch as they search for moisture. Burrowing animals can be difficult to manage enough to reduce fruit damage. They can also cause significant damage to the drip tape, resulting in cuts in the lines that reduce irrigation efficiency and cause muddy areas. When left uncontrolled they will breed rapidly and overrun strawberry fields. There are baits available for controlling mice, but they cannot be placed inside strawberry fields. Always read and follow labeled directions for any bait used to control rodents. Repellents may be useful as well.

Harvesting and Handling

In Texas, harvesting strawberries can begin as early as January in some southern regions but is dependent on planting time, winter temperatures, and freezes that injure viable blossoms. Extreme low temperatures can also injure leaves, stems, and crowns. In most regions, peak harvest begins in early spring, around late March or early April, and is usually complete by the end of May or early June.

Growers' production systems can also influence the number of days until the first berry harvest. Growing strawberries in the open field or in low and high tunnels results in differences in crown development and plant growth, which also influences flower production. On the High Plains, strawberries planted in high tunnels in September can produce ripe berries by late November. In open-field production, berries will not be ripe until late March at the earliest. Yields in high and low tunnels are generally higher by as much as 40 percent or more.

When strawberries are transplanted in late October or early November, cooler soil and air temperatures slow down plant growth and crown development and delay harvesting, which can reduce yields by as much as 1.5 percent for every day that planting is delayed.

In northern climates, early harvests during the winter months will be lower than during the peak harvest. Strawberry growers in the High Plains and Panhandle regions must use either high or low tunnels to achieve profitable yields. Growing strawberries on the High Plains is difficult without plastic covers, and yields can be reduced by 80 percent to 90 percent.

Growers in East, Central, and South Texas can delay planting until cooler night temperatures (usually mid-October) allow for optimal growth; however, the delay may also impact future yield. Producers growing in those regions should wait until average daytime temperatures are less than 85 degrees F to avoid leaf scorching or plant death.

Harvesting Berries

During peak season, berries may need to be harvested several times a week. Strawberries grown for retail sales are harvested and packed by hand. Proper handling and care should be stressed to all employees to avoid damaging the fruit. Never toss berries into buckets or containers as this leads to bruising. Bruising increases post-harvest fruit diseases, less storage time, and lower overall product quality. Unless required by wholesale contracts, never wash berries before storage or retail sales. Washing berries can cause damage, and excess water on the fruit will lead to increased fruit diseases, mostly *Botrytis* gray mold. Harvesting berries while they are wet or in the rain will also increase fruit disease potential and should be avoided when possible.

Once harvested, strawberries do not ripen. Therefore, berries should be harvested only if they are at least 75 percent red. Berries should be carefully pulled off the plant without damaging nearby stems, flowers, leaves, or other berries. Some growers leave the stems on when harvesting and packing to prevent the fruit from spoiling quicker. However, this can also make packing more difficult, as berries with stems can damage other berries and promote disease.

During harvest, do not leave fresh-picked berries in the sun, especially during hot, dry conditions. If no coolers are available, place harvested berries in shady areas or harvest in the early morning or late evening. Storage quality varies as certain cultivars produce softer berries than others. A firmer berry generally stores longer.

Strawberries should not be packed too deep or tightly in containers. Strawberry fruit bruises easily, and bruising may cause berry rot in containers before they are sold. Harvested berries that are not sold or consumed within a few hours should be placed in protective containers and cooled to 34 degrees F to 36 degrees F. For coolers with ice or dry ice, place a barrier of Styrofoam or wax paper between the ice and strawberries to keep them dry. When stored between 34 degrees F to 36 degrees F, the berries should stay fresh for up to a week.

Berry Taste and Sweetness

Texas growers pride themselves on growing sweet, tasty, high-quality berries that consumers enjoy. It is well known that local strawberries generally taste better than those imported to grocery stores since they are picked and sold fresh. Taste is subjective and depends on consumer preference. Interestingly, in Texas A&M AgriLife Extension blind taste tests, 55 percent of participants showed a preference for store-bought berries over locally grown berries. While this seems contradictory, it is largely due to what consumers perceive as to what a strawberry should taste like. It is what they are accustomed to. Generally, when participants discovered that the other berries were grown locally, they requested the location of where they could be purchased. Growers should always educate customers on the benefits of locally grown berries versus retail chain store berries.

Berry taste can also depend on other factors, including the cultivar grown, the climate during and prior to harvesting, fertilization, the irrigation level prior to harvest, and the physiological ripeness of the berries at harvest.

Berry sweetness depends on the amount of sugars, typically sucrose as well as other soluble solids like glucose, fructose, and organic acids.

Figure 55. Harvesting berries at the correct time is critical to improving flavor and sugar (brix) levels. In the photo on the top, the two berries on the right are 75 to 100 percent red (ripe). When cut (bottom), they also are riper on the inside. Instructing U-pick customers and harvesting crews on which berries to pick is very important and will improve overall sales.

Table 14. The average Brix levels for the fruit of 20 strawberry cultivars evaluated during 2023 at the Texas A&M AgriLife Research and Extension Center at Lubbock

Cultivar	Brix	Cultivar	Brix	Cultivar	Brix
Sierra	11.2	Albion	10.2	Victor	9.5
Monterey	10.7	Sweet Ann	10.1	Cabrillo	9.4
Rikas	10.6	Camino Real	9.9	Brilliance	9.3
Camarosa	10.6	Festival	9.8	Medallion	9.2
Ruby June	10.5	Chandler	9.8	Fronteras	9.0
San Andreas	10.4	Valiant	9.8	Radiance	7.6
Beauty	10.3	Royal Royce	9.8		

Note: Fruit measured using a hand-held digital Brix meter.

It is measured and reported as Brix content or percent sugar. The higher the Brix, the sweeter the berry. Generally, strawberries should have a Brix content above 7.0 to be considered sweet. However, this is often dependent on strawberry cultivar. Table 14 shows the differences in Brix levels of 20 strawberry cultivars grown in Lubbock during 2023 field trials.

Brix is measured by using either a hand-held refractometer or digital hand-held Brix meter. Refractometers are much cheaper than digital Brix meters; however, Brix meters are more accurate. Although not necessary, knowing the Brix level for the individual cultivars grown can be a good selling point for growers when asked about sweetness by customers.

Figure 56. A digital Brix meter (shown) or a hand-held refractometer can indicate the sugar levels of harvested berries. Sugar levels may range from 7.5 percent up to 14 percent depending on cultivar or berry ripeness.

Post-Harvest Field Management

Following harvest, it is important to shred the plants to let the leaves and stems dry out and to remove the plastic mulch and drip tape quickly. Shredding the plants helps allow for easier mulch removal. Plastic mulch lifters are available for removing the plastic mulch and drip tape. The initial cost may seem expensive to small-acreage growers, but depending on the field size, they could easily pay for themselves when compared to hand removal. Plastic mulch lifters would be best used in fields with heavier soils as the edges could be difficult to remove.

Following the removal of the plastic mulch and drip tape, fields should be immediately disked to bury plant debris and weed residues. Turning over the soil to bury plant debris increases root, stem, and leaf breakdown, turning it into organic matter and potentially reduces any pathogens, insects, and weed seeds present during the crop season. In some fields, planting cover crops may be an option; however, in the fall, care should be taken to not leave any crop residues on the surface when shaping the beds and laying plastic for the upcoming season. Leftover plant debris and cloddy soil disrupt the smooth surface of the strawberry bed and may poke holes in the plastic mulch.

As mentioned in the section on weed control, post-harvest field preparation should include killing any perennial weeds. Herbicides with systemic modes of action are best for killing these weeds. Two or more applications may be needed for difficult-to-control weeds or those with deeply buried reproductive structures.

Sanitation and Food Safety

Every consumer expects safe, clean, and healthy strawberries. Food safety begins on the farm and growers should be properly trained to ensure their products are safe. Good Agricultural Practices (GAP) are methods used to reduce and prevent microbial, chemical, or physical contamination of strawberries from planting to harvest. Microbial contaminants of strawberry fruit include viruses, bacteria, and protozoan parasites that can cause mild to severe human illness. Contaminant sources include animal feces, irrigation water, organic fertilizers and manures, and unclean hands while handling strawberries. Understanding GAP and following the methods listed in the subsequent sections can help growers avoid contaminating strawberry products.

Employee Hygiene

It is critical that all employees wash their hands effectively before handling strawberries during harvesting, sorting, packing, and other handling procedures. Microbial contamination is a leading cause of foodborne illnesses but can be prevented by proper handwashing. Scrubbing the backs of hands, palms, between fingers, and under nails with potable water and soap for at least 20 seconds reduces potential contamination. Hands should then be dried with a clean, single-use towel. The towel can be used to turn off the water and open the door. Using sterile nitrile gloves can help but can be expensive to use.

Customer Hygiene

Visitors and U-pick customers should follow all the same hygiene and sanitation rules as farm employees. If portable latrines are used, proper handwashing stations should be available.

Cleaning and Sanitizing

Cleaning surfaces where berries are to be placed is important to reduce contamination. Cleaning means washing or removing debris from an item or surface. Sanitation is the secondary process that refers to using a product or number of products to reduce or kill unwanted microorganisms on cleaned surfaces. This is critical where berries are sorted and handled. Use sanitizers safely by following label instructions.

Equipment and Supplies Sanitation

Clean equipment prevents the spread of contaminants from one location, plant, or product to another. Clean farm equipment and sanitize clippers and harvest containers after each use. Store equipment and supplies where they will not be contaminated.

Irrigation Water

Water is critical to successful strawberry production but is also a key source for spreading disease and contamination. It is important to know where your water source is located and whether it can be easily contaminated. Do not draw water from irrigation ponds located near pastures where livestock feed. Water sources, including wells and surface water, should be tested regularly by a certified laboratory, especially at the beginning of the season. If using municipal water, consult annual water reports for potential contamination.

Fertilizers

Synthetic fertilizers, due to their active ingredients, do not usually pose microbial contamination risks. However, organic fertilizers, including compost, must be completely processed (reaching the appropriate heat level) and should not contain any raw manure. Raw manure may contain bacteria that are significant sources of human pathogens. Plant-based composts, although lower in nitrogen, are considered safer than those from animal byproducts. Never spread manure in or around strawberries, especially during harvesting.

Animal Feces and Other Contaminants

Animal feces and hairs can be a source of strawberry contamination. It is critical to monitor strawberries for wild and domestic animal intrusion. Examples of animal feces include that of birds, rodents, coyotes, raccoons, mice, dogs, cats, etc. Place fencing or nets around the field if needed. Use traps or other deterrents as needed. Do not put poison control products in the field where children and field workers may be exposed. Always read and follow label instructions for animal control.

Pesticides

It is important to monitor the use of both synthetic and organic chemicals in strawberry production. Only knowledgeable and trained staff should be applying pesticides. Record accurately each time these products are used, including how much was used and who applied it. Keeping records can help should fields be inspected by the TDA or other regulators. Just like synthetic chemicals, organic pest control products can be harmful if not used properly or according to their labels. Do not assume organic or natural products are safe for human contact.

Organic Strawberry Production

The following section was supported by a previous USDA Sustainable Agricultural Research and Education (SARE) grant (LS16-275) titled *Evaluating Organic Pest Control Products for Strawberries in Combination with High and Low Tunnels for Limited Resource Farmers in the Mid-South*.

Introduction

Consumer demand for organic produce has steadily increased over the past several decades. Organic strawberry production is on the rise, and Texas is an excellent state for potential organic strawberry production.

Organic strawberries can be difficult to produce since growers need to address fertility, weeds, insects, and diseases without using synthetic chemicals. While organic strawberry production relies on natural products and practices, it is not simply replacing synthetic chemicals. Purchasing organically grown bare roots or plugs can be difficult as plants should be certified disease-free prior to sales.

Whether fair or not, strawberries have been labeled by environmental advocate groups as the food crop sprayed with the greatest amount of synthetic pesticides. This may be true for both conventional and organic systems. The heavy use of pesticides is correlated to the potential economic loss of high-value strawberries.

The number of organic strawberry acres existing in Texas is unknown, and the number is likely small. Most Texas growers, regardless of the production system, use very little amounts of pesticides to control insects and diseases and use them only on an as-needed basis. However, because organic berries demand a premium price, producers are increasingly interested in growing strawberries organically.

Increased organic production is associated with the use of natural and sustainable pest control options. However, small-acreage growers have limited resources, and organic pest control is challenging. There are many commercially available organic fertilizers and biopesticides labeled for strawberries, and the number increases annually. This section provides information on selected commercial biopesticides and provides recommended options for controlling pests and weeds in organic strawberries.

While organic production continues to rise, product and labor costs continue to rise, and organic strawberries may be more intensive than conventional production. There are higher risks of plant and fruit losses in organic production, even with some control efforts. Several Texas organic growers reported berry losses of 50 percent to 90 percent during rainy harvest seasons due to *Botrytis* gray mold and anthracnose fruit rot.

Unless a farm is certified organic, producing strawberries should not be limited to organic products. Growers should determine the best products that fit within their budget and management system. In some cases, saving the crop is more important than what is used if it is a legal application. Most conventional growers use a combination of chemicals, biostimulants, and biopesticides. Regardless of the production system, growers should consider whether the plethora of products available are effective and economically sustainable on their farms.

Organic Soil Fertility and Nutrition

It is important for growers to understand that the nutrient requirements for organic strawberries are the same as conventional production. For example, strawberry roots recognize and absorb nitrogen in its elemental form, whether it is provided naturally from manure and compost sources or as a synthesized chemical fertilizer.

A healthy organic field begins with soil fertility. Healthy soils improve beneficial microbe populations associated with strawberry roots, which improves nutrient uptake. For healthier plants, manage soils by providing the required essential macro and micronutrients needed for optimal strawberry production. Strawberries are relatively heavy nutrient feeders. It is important to boost soil fertility before planting and continue supplementing the root zone as the season progresses. Careful management is needed during the final third of the harvest, as this is where a significant part of the profits is made. For more information on soil nutrients in strawberries, see the *Fertilization* section.

As mentioned previously, composting fields with fresh manure can increase soil productivity but can also be detrimental to strawberry production if done incorrectly. No application of fresh manure should occur in the field or surrounding area after the strawberries are planted, especially during harvest season. Manure and improperly processed compost may cause plant damage and may have a higher risk of foodborne pathogens that contaminate berries and cause foodborne illnesses.

Fresh compost and manure contain salts, which, in high amounts, can damage plant roots and leaves. Care should be taken when applying compost to strawberry fields. Irrigating with enough water or allowing enough rainfall to push salts out of the root zone can help. Waiting a year or two after compost application may also reduce salt damage to plants and improve yields.

Crop Rotation

Rotating strawberries with other crops is critical and allows the soil to regenerate with natural microbes and nutrients. Generally, rotating the field out of strawberries every 2 to 3 years is ideal. Rotating with leguminous crops (beans, peas, etc.) increases soil nitrogen levels naturally. If unable to rotate fields, a cover crop during the summer fallow months may be helpful. Giving fields a break from the heavy nutrient-feeding strawberry plants allows the soil to recharge minerals from amendments or the breakdown of crop residuals. Fall-planted strawberries may benefit from a cowpea cover crop the preceding summer.

Leaving the field fallow is helpful, but weeds must still be controlled. Crop and weed debris should be disked and rototilled thoroughly into the top 6 inches of soil within enough time to allow it to break down. Plant debris can interfere with plastic mulch laying. Research evaluating cover crops and crop rotation sequences for strawberry production in Texas has not been conducted.

Organic Weed Control

Regardless of the crop grown, weeds are considered the most important economically damaging pest in organic production, including strawberries. Many cool-season weed species emerge following fall planting, especially during early crop growth and development. These weeds are very competitive if not controlled.

Hand-weeding and cultivation are typically the main weed control strategies in organic production systems. However, there are organically labeled bioherbicides that can be applied in strawberries. It is important to remember that organic herbicides can also result in leaf or fruit damage if not applied according to the label. Organic herbicide products can be costly and often require multiple applications on very small weeds for effective control.

It is important to remember that organic herbicides are typically processed or synthesized products. They include plant oils and other derivatives from processing. The Organic Materials Review Institute (OMRI) is a good source that lists products approved for certified organic production. Certified products can be found on the *OMRI website*.

Table 15 lists selected organic herbicide products currently available that have been evaluated in Texas. This list is representative and does not include all available products. It is important to understand that organic herbicide products are only contact products, and no systemic products are currently available. Therefore, perennial weeds may be more difficult to control, and alternative methods may be needed.

Table 15. Bioherbicide active ingredients and products labeled for weed control in strawberries

Active ingredient	Selected product names	Application timing	Methodology	Comments
D-limonene	Avenger	Postemergence	Contact	Annual broadleaves and grasses. OK on weeds up to 1 inch. Multiple applications for extended control.
Ammonium nonanoate	Axxe, BioSafe Weed and Grass Killer	Postemergence	Contact	Annual broadleaves and grasses. OK on weeds up to 6 inches. Multiple applications for extended control.
Acetic acid (23%) + citric acid	AllDown	Postemergence	Contact	Annual broadleaves and grasses. OK on weeds up to 1 inch. Multiple applications for extended control.
Citric acid + clove oil	BurnOut	Postemergence	Contact	Annual broadleaves and grasses. OK on weeds up to 1 inch. Multiple applications for extended control.
Caprylic and capric acids	Suppress	Postemergence	Contact	Annual broadleaves and grasses. OK on weeds up to 1 inch. Multiple applications for extended control.

** Listing products in this table does not indicate an endorsement for use. Always read and follow label instructions for uses and timings of applications and pests indicated as controlled or suppressed.*

Organic production is a long-term proposition; natural solutions for weed control should be implemented seasons ahead of planting dates. Continual rotation with smothering cover crops can greatly reduce weed populations. It is essential to know the soil and seasons so weeds can be disrupted and reduced cyclically.

Before planting strawberries in open ground, several passes with tillage equipment a few weeks apart should effectively pregerminate weed seeds and reduce weed problems for the season. However, this may be dependent on rainfall. If allowed, many producers have opted to use plastic mulch for their strawberry plantings. There are also biodegradable mulches (bioplastic and paper) that may be used; however, Texas research has shown biodegradable mulches can break down too early or, in some cases, stick to the berries, making them unmarketable. Caution should be used when using biodegradable mulches. Growers should experiment on a small section of the farm prior to full use.

Soil solarization is a natural method for controlling weeds, as well as soil pathogens. Solarization requires placing a clear plastic mulch or tarp over a field or desired area to heat up the soil and kill germinating seeds and weeds. It can be expensive for large areas. The process can take months if the sun and daytime temperatures are not sufficient. Moisture down to 12 inches is needed for successful control. Plastic edges must be sealed to prevent heat and moisture loss. High temperatures of at least 110 to 125 degrees F for at least 4 to 8 weeks are required. Unfortunately, solarizing the soil may also reduce natural beneficial organisms.

Controlling Diseases Organically

Strawberry pathogens can be difficult to control, especially in the humid climates of the state. They attack the crowns, roots, stems, leaves, and fruit. The diseases in organic strawberry production are the same as previously described in the disease section of this guide.

There are commercially available biocontrol products, also called biofungicides, that help suppress and control diseases in organic strawberries. Biofungicides are most effective when applied according to the product label, and this includes timing and climate. Diseases are host-specific, and biofungicides may control only specific pathogens and only at certain times in the disease life cycle. Thus, it is important to properly identify the disease for which control is needed.

Biofungicides perform best under specific environmental conditions. Some biofungicides are dormant spores that germinate in the presence of pathogens or grow on roots and other plant parts, while others are living organisms or plant extracts and oils. Application methods will be described on the product label. Some products may have multiple methods of application and may be applied to the roots at transplanting, as a drench, or through drip systems. Other products are labeled specifically for foliar applications. Products may or may not require an organic spreader/sticker to enhance control.

The timing and method of applying biofungicides is critical. In most cases, the product must be present before a pathogen attacks or must contact the host pathogen. Always read and follow product labels for an accurate description of application timings as well as proper storage conditions. It is important to store products according to their label, thus reducing the potential loss of efficacy. Table 16 contains a partial list of biofungicide products labeled for controlling diseases in organic strawberries.

Table 16. Biofungicide active ingredients and product names for control of specific strawberry diseases		
Pathogen (disease)	**Active ingredient**	**Product name***
Angular (bacterial) leaf spot (*Xanthomonas fragariae*)	*Bacillus amyloliquefaciens* strain FZB 42	Double Nickel
	Bacillus amyloliquefaciens strain MBI 600	Serifel
	Copper oxychloride + copper hydroxide	Badge
	Copper octanoate	Cueva
	Copper sulfate pentahydrate	CS 2005
Anthracnose (*Colletotrichum acutatum*)	*Bacillus amyloliquefaciens* strain FZB 42	Double Nickel
	Bacillus amyloliquefaciens strain MBI 600	Serifel
	Bacillus subtilis strain QST 713	Serenade Opti
	Copper octanoate	Cueva
	Hydrogen peroxide	PERpose
	Neem oil	Trilogy
	Potassium bicarbonate	Agricure, GreenCure, MilStop, Kaligreen
	Reynoutria sachalinensis	Regalia
	Streptomyces lydicus WYEC 108	Actinovate AG
***Alternaria* leaf spot** (*Alternaria* spp.)		
***Botrytis* gray mold** (*Botrytis cinerea*)	*Bacillus amyloliquefaciens* strain FZB 42	Double Nickel
	Bacillus amyloliquefaciens strain MBI 600	Serifel
	Bacillus subtilis strain QST 713	Serenade Opti
	Cinnamon oil	Cinnerate
	Copper octanoate	Cueva
	Gliocladium catenulatum strain J1446	Prestop
	Hydrogen dioxide + peroxyacetic acid	Oxidate, TerraClean
	Hydrogen peroxide	PERpose
	Paraffinic oil	JMS Stylet-Oil
	Potassium bicarbonate	Agricure, GreenCure, MilStop, Kaligreen
	Potassium silicate	Sil-Matrix
	Reynoutria sachalinensis	Regalia
	Streptomyces lydicus WYEC 108	Actinovate AG
***Cercospora* leaf spot** (*Cercospora* spp.)	Potassium bicarbonate	Agricure, GreenCure, MilStop, Kaligreen
Charcoal rot (*Macrophomina phaseolina*)	*Bacillus amyloliquefaciens* strain FZB 42	Double Nickel
	Bacillus amyloliquefaciens strain MBI 600	Serifel
***Fusarium* root rot** (*Fusarium* spp.)	*Bacillus amyloliquefaciens* strain FZB 42	Double Nickel
	Bacillus amyloliquefaciens strain MBI 600	Serifel
	Gliocladium catenulatum strain J1446	Prestop
	Potassium bicarbonate	Agricure, GreenCure, MilStop, Kaligreen
	Streptomyces lydicus WYEC 108	Actinovate AG
	Trichoderma asperellum strain ICC 012 + *Trichoderma gamsii* strain ICC 080	BIO-TAM
	Trichoderma harzianum strain T-22 + *Trichoderma virens* strain G-41	RootShield Plus

Table 16. Biofungicide active ingredients and product names for control of specific strawberry diseases		
Pathogen (disease)	**Active ingredient**	**Product name***
Leaf scorch (*Diplocarpon earlianum*)	*Bacillus amyloliquefaciens* strain MBI 600	Serifel
	Basic copper sulfate	Basic Copper 53
	Copper oxychloride + copper hydroxide	Badge
	Copper octanoate	Cueva
	Copper sulfate pentahydrate	CS 2005
Leaf spot (*Mycosphaerella fragariae*)	*Bacillus amyloliquefaciens* strain MBI 600	Serifel
	Copper oxychloride + copper hydroxide	Badge
	Copper hydroxide	Champ WG, Nu-Cop
	Copper sulfate pentahydrate	CS 2005
	Cuprous oxide	Nordox
	Neem oil	Trilogy
Leather rot (*Phytophthora* spp.)	*Bacillus amyloliquefaciens* strain FZB 42	Double Nickel
	Bacillus amyloliquefaciens strain MBI 600	Serifel
	Gliocladium catenulatum strain J1446	Prestop
	Hydrogen dioxide + peroxyacetic acid	Oxidate, TerraClean
	Potassium bicarbonate	Agricure, GreenCure, MilStop, Kaligreen
	Reynoutria sachalinensis	Regalia
	Streptomyces lydicus WYEC 108	Actinovate AG
	Trichoderma asperellum strain ICC 012 + *Trichoderma gamsii* strain ICC 080	BIO-TAM
	Trichoderma harzianum strain T-22 + *Trichoderma virens* strain G-41	RootShield Plus
Mucor* fruit rot and *Rhizopus (*Mucor piriformis*)	Copper octanoate	Cueva
***Phomopsis* leaf blight** (*Phomopsis obscurans*)	Basic copper sulfate	Basic Copper 53
	Copper oxychloride + copper hydroxide	Badge
	Copper sulfate pentahydrate	CS 2005
	Cuprous oxide	Nordox
Powdery mildew (*Sphaerotheca macularis* f. sp. *fragariae*)	*Bacillus amyloliquefaciens* strain FZB 42	Double Nickel
	Bacillus amyloliquefaciens strain MBI 600	Serifel
	Bacillus subtilis strain QST 713	Serenade Opti
	Cinnamon oil	Cinnerate
	Copper oxychloride + copper hydroxide	Badge
	Copper octanoate	Cueva
	Garlic + cottonseed + corn oils	Mildew Cure
	Gliocladium catenulatum strain J1446	Prestop
	Hydrogen dioxide + peroxyacetic acid	Oxidate, TerraClean
	Hydrogen peroxide	PERpose
	Mineral oils	Glacial Spray, Pure Spray Green, SuffOil-X, TriTek

Table 16. Biofungicide active ingredients and product names for control of specific strawberry diseases		
Pathogen (disease)	**Active ingredient**	**Product name***
Powdery mildew (*Sphaerotheca macularis* f. sp. *fragariae*) continued	Paraffinic oil	JMS Stylet-Oil
	Potassium bicarbonate	Agricure, GreenCure, MilStop, Kaligreen
	Potassium salts of fatty acids	M-Pede
	Potassium silicate	Sil-Matrix
	Reynoutria sachalinensis	Regalia
	Streptomyces lydicus WYEC 108	Actinovate AG
	Sulfur	Acoidal, Defend, Microthiol Disperss, Golden Micronized Sulfur, Sulfur DF, Thiolux, and others
***Phytophthora* crown rot** (*Phytophthora* spp.)	*Bacillus amyloliquefaciens* strain FZB 42	Double Nickel
	Bacillus amyloliquefaciens strain MBI 600	Serifel
	Gliocladium catenulatum strain J1446	Prestop
	Hydrogen dioxide + peroxyacetic acid	Oxidate, TerraClean
	Reynoutria sachalinensis	Regalia
	Streptomyces lydicus WYEC 108	Actinovate AG
	Trichoderma asperellum strain ICC 012 + *Trichoderma gamsii* strain ICC 080	BIO-TAM
	Trichoderma harzianum strain T-22 + *Trichoderma virens* strain G-41	RootShield Plus
***Pythium* root rot** (*Pythium* spp.)	*Bacillus amyloliquefaciens* strain FZB 42	Double Nickel
	Bacillus amyloliquefaciens strain MBI 600	Serifel
	Gliocladium catenulatum strain J1446	Prestop
	Streptomyces lydicus WYEC 108	Actinovate AG
	Trichoderma asperellum strain ICC 012 + *Trichoderma gamsii* strain ICC 080	BIO-TAM
	Trichoderma harzianum strain T-22 + *Trichoderma virens* strain G-41	RootShield Plus
Red stele (*Phytophthora fragariae*)	*Bacillus amyloliquefaciens* strain FZB 42	Double Nickel
	Gliocladium catenulatum strain J1446	Prestop
	Hydrogen dioxide + peroxyacetic acid	Oxidate, TerraClean
	Hydrogen peroxide	PERpose
	Reynoutria sachalinensis	Regalia
	Streptomyces lydicus WYEC 108	Actinovate AG
	Trichoderma asperellum strain ICC 012 + *Trichoderma gamsii* strain ICC 080	BIO-TAM
	Trichoderma harzianum strain T-22 + *Trichoderma virens* strain G-41	RootShield Plus
***Rhizoctonia* root rot** (*Rhizoctonia* spp.)	*Bacillus amyloliquefaciens* strain FZB 42	Double Nickel
	Bacillus amyloliquefaciens strain MBI 600	Serifel
	Gliocladium catenulatum strain J1446	Prestop
	Streptomyces lydicus WYEC 108	Actinovate AG
	Trichoderma asperellum strain ICC 012 + *Trichoderma gamsii* strain ICC 080	BIO-TAM
	Trichoderma harzianum strain T-22 + *Trichoderma virens* strain G-41	RootShield Plus

Table 16. Biofungicide active ingredients and product names for control of specific strawberry diseases		
Pathogen (disease)	Active ingredient	Product name*
***Verticillium* wilt** (*Verticillium dahliae*)	*Bacillus amyloliquefaciens* strain FZB 42	Double Nickel
	Bacillus amyloliquefaciens strain MBI 600	Serifel
	Gliocladium catenulatum strain J1446	Prestop
	Reynoutria sachalinensis	Regalia
	Streptomyces lydicus WYEC 108	Actinovate AG
	Trichoderma asperellum strain ICC 012 + *Trichoderma gamsii* strain ICC 080	BIO-TAM

* *Listing products in this table does not indicate an endorsement for use. Always read and follow label instructions for uses and timings of applications and pests indicated as controlled or suppressed.*

Controlling Insects Organically

Controlling insect pests in organic strawberry production can be very frustrating. There are many tools for insect biocontrol, including regular crop rotation, planting alternative hosts, employing trap crops, using nets for exclusion, and applying bioinsecticides.

Rotating strawberry fields is the primary method for breaking the life cycles of root-feeding insects, including grubs and worms. Rotating with non-host plants will decrease damage to strawberry roots and allow other control measures to be used more effectively.

Another means of suppressing insect pests is by planting alternative crops within or around strawberry fields. Fortunately, nature provides natural enemies for many insect pests. Alternative crops can attract and maintain beneficial insects that feed on destructive pests. They attract beneficials by serving as an alternative food source and breeding ground. Unfortunately, there has been no Texas research on alternative hosts for strawberries.

Bioinsecticide products are labeled for use in organic production and can be used to help knock down insect pest populations. There are currently many bioinsecticide products available but choosing the correct one can be difficult. Many products target only one or several pests for each application. They can also be expensive to apply. However, if strawberries are grown organically, they may be the only options available. For a list of currently available products, refer to Table 17.

Table 17. Selected list of registered bioinsecticides for use in strawberries. Some active ingredients have multiple product names that may not be listed, and others may be labeled for control of certain diseases. Other products may be mixed active ingredients.

Product names	Active ingredients	Certification	Application type	Insects controlled or suppressed	Comments
Agree WG	*Bacillus thuringiensis* ssp. *aizawai* strain GC-91	OMRI	Foliar	Lepidopterous larvae	Begin applications with first sign of feeding larvae. 3- to 7-day spray intervals. Use higher rates under heavy pressure. Continue applications as needed for larval control.
Aza-Direct AzaGuard Neemix Molt-X	Azadirachtin	OMRI	Foliar	Spider mites	Spray when pests first appear. Complete coverage is needed. Make two to three applications at 7-day intervals. Early morning or evening sprays reduce potential crop injury. 0-day PHI.
BioCeres WP	*Beauveria bassiana* spp. strain ANT-03	—	Foliar, drip	Aphids, plant bugs, bed weevil, thrips, whiteflies	Begin applications when larvae and nymphs are young and population is low. Repeat as needed every 5 to 7 days. Thorough coverage is needed. 0-day PHI.
Botanigard Mycotrol	*Beauveria bassiana* strain GHA	—	Foliar	Aphids, thrips, leafhoppers, weevils, plant bugs, leaf-feeding insects, grasshoppers, whiteflies	Apply when insect pressure is low to normal. Reapply every 5 to 10 days. Repeat as long as pests are present. 0-day PHI.
Deliver	*Bacillus thuringiensis* ssp. *kurstaki* strain SA-12	OMRI	Foliar	Lepidopterous larvae	Apply when larvae are young and newly hatched. Apply as needed to maintain control. 0-day PHI.
DiPel	*Bacillus thuringiensis* ssp. *kurstaki (Btk)* strain ABTS-351	OMRI	Foliar	Lepidopterous larvae	Treat when larvae are young, as they must be actively feeding for control. Apply as needed every 3 to 14 days to maintain control. Use higher rates under heavy pest populations. 0-day PHI.

Table 17. Selected list of registered bioinsecticides for use in strawberries. Some active ingredients have multiple product names that may not be listed, and others may be labeled for control of certain diseases. Other products may be mixed active ingredients.					
Product names	**Active ingredients**	**Certification**	**Application type**	**Insects controlled or suppressed**	**Comments**
Entrust SC	Spinosad	OMRI	Foliar	Lepidopterous larvae, thrips, red imported fire ants	Apply when pests appear, targeting eggs or hatched larvae. For thrips, 3- to 4-day spray interval if population is high. Spray interval no less than 5 days apart. No more than three applications per season. 1-day PHI.
Grandevo	*Chromobacterium subtsugae* strain PRAA4-1 and spent fermentation media	OMRI	Foliar	Armyworms, cutworms, leafrollers, aphids, lygus bugs, mites, thrips, whiteflies	Spray at first sign of new populations or recently hatched larvae and nymphs. Best applied when the population is low. Thorough coverage is needed for mites and aphids. For high populations, use knockdown spray in combination. Repeat applications to maintain control.
JMS Stylet-Oil	Paraffinic oil	OMRI	Foliar	Aphids, spider mites	Begin sprays as soon as plants emerge. Spray weekly or twice weekly and continue through harvest. Spray at no less than 400 psi. Check compatibility with other products. 0-day PHI.
M-Pede	Potassium salts of fatty acids	OMRI	Foliar	Aphids, mites, thrips, whiteflies	Apply to leaves until wet. Complete coverage is needed for control. Make applications at 7-day intervals. Only three sequential applications. 0-day PHI.
Omni Supreme	Narrow-range oil Paraffin base	—	Foliar	Spider mites, whiteflies	Make the first application when pests are at a moderate level. Apply at 14-day intervals. Do not apply product during peak bloom or fruiting or when temperatures are higher than 75°F for several days.

Table 17. Selected list of registered bioinsecticides for use in strawberries. Some active ingredients have multiple product names that may not be listed, and others may be labeled for control of certain diseases. Other products may be mixed active ingredients.

Product names	Active ingredients	Certification	Application type	Insects controlled or suppressed	Comments
PFR-97 20WDG	*Isaria fumosorosea* Apopka Strain 97	OMRI	Foliar, soil drench	Aphids, mites, plant bugs, thrips, whiteflies, root weevils, caterpillars	Apply at first sign of pests. Spray for thorough leaf coverage with minimal runoff. Repeat applications every 3 to 10 days. Use higher rates under heavy foliage.
Plant extracts and oils (and their mixes)	Canola Clove Corn Cottonseed Garlic Linseed Peppermint Rosemary Soybean Thyme	See individual product labels	Foliar	Aphids, mites, whiteflies	See individual product labels for application instructions.
Pyganic 5.0	Pyrethrins	OMRI	Foliar	Aphids, beetles, caterpillars, crickets, grasshoppers, lygus bugs, mites, thrips, weevils	Spray to wet but not to runoff. Direct sprays into canopy. Product must contact pest for control. No more than 10 applications per season. Do not apply within 3-day intervals. 0-day PHI.
Organishield	Sucrose octanoate esters	—	Foliar	Aphids, caterpillars, mites, plant bugs, thrips, whiteflies	Apply directly to leaves when pests are present. Contact with target pests is needed for effective control. Reapply every 7 to 10 days as needed. 48-hour REI.
Rango	Neem oil	OMRI	Foliar, root dip, drip	Aphids, lepidopterous larvae, mites, thrips, plant bugs, whiteflies, nematodes	Thorough coverage is needed. Early morning or late evening applications reduce risk of leaf burn. Reapply every 7 to 10 days. Do not apply above 90°F or to wilted, stressed plants. 0-day PHI.
Sil-MATRIX	Potassium silicate	OMRI	Foliar	Aphids, mites, whiteflies	Begin applications when pests are first spotted. Repeat applications a minimum of 7 days. 0-day PHI.

Table 17. Selected list of registered bioinsecticides for use in strawberries. Some active ingredients have multiple product names that may not be listed, and others may be labeled for control of certain diseases. Other products may be mixed active ingredients.

Product names	Active ingredients	Certification	Application type	Insects controlled or suppressed	Comments
SuffOil-X TriTek	Mineral oil	OMRI	Foliar	Aphids, mites, sawflies, scales, whiteflies	Complete coverage is needed for control. Spray leaves until wet but before runoff. Spray as needed. Do not spray during periods of drought or moisture stress. 0-day PHI.
Trilogy	Neem oil	OMRI	Foliar	Aphids, spider mites	Apply when mite and aphid levels are low. Thorough coverage is needed for control. Apply at 7- to 21-day intervals. Do not apply to newly planted crops. 0-day PHI.
Venerate CG Arber	*Burkholderia* spp. strain A396	OMRI	Foliar, soil drench, soil injected	Aphids, lepidopterous larvae, lygus bugs, mites, whiteflies	Apply when pest populations are low. Thorough coverage is needed for control. Repeat applications every 3 to 10 days as needed. 0-day PHI.
XenTari	*Bacillus thuringiensis* ssp. *aizawai* strain ABTS-1857	—	Foliar	Lepidopterous larvae	First apply when larvae are young and actively feeding. Use higher rates under heavy pressure. Repeat spray intervals every 3 to 14 days depending on weather. 0-day PHI.

General Biocontrol Information

Organic strawberries are expensive to produce, and a grower's pesticide arsenal is limited. In general terms, strawberry biocontrol means controlling or suppressing economically damaging effects of root, foliar, or fruit diseases and insects through one or multiple applications of beneficial organisms, plant extracts/oils, or other natural methods. The best approach to organic pest control in strawberries is to act proactively and use preventative strategies. Enhancing soil nutrients and beneficial organisms will improve overall plant health to help fight disease and insect pests. As with many crops, the first line of defense in strawberries should be resistant cultivars.

Biological control or biocontrol is best described as using natural and/or living organisms or byproducts to control economic pests. Products are called biopesticides. They are manufactured to kill pests or disrupt their life cycles in similar manners to chemicals. According to the US Environmental Protection Agency (EPA), "Biopesticides are certain types of pesticides derived from such natural materials as animals, plants, bacteria, and certain minerals."

During the past 40 years through studies by governments, universities, and private companies, biopesticides from fungi, bacteria, and plant extracts have been researched, developed, manufactured, and marketed for crops, including strawberries. Some products are more successful than others, while some are very host-specific. In Texas, evaluations of several commercially available biopesticides have been conducted.

When used accordingly, biopesticides provide excellent control, though they perform best in controlled environments like greenhouses and high tunnels. In open-field production, where climate and other conditions are less controlled, growers must recognize inherent risks associated with biopesticides. For example, crops, location, and climate may influence biocontrol product efficacy, especially those containing living organisms.

The environmental conditions that influence biopesticide efficacy include temperature, humidity, soil type and pH, and annual rainfall. Plant variety, population density, production system, and irrigation and fertilization frequency may also influence biopesticide efficacy. Finally, improperly storing biocontrol products may reduce their potency, longevity, and effectiveness to control pests.

Certain products, including several evaluated in Texas, may also stimulate plant growth and health. Their application can lead to enhanced control as healthier plants have increased resistance to pests. There are many biostimulants, but they are not considered biopesticides. Care should be taken to evaluate biostimulants with on-farm trials to determine their effectiveness.

According to the EPA website:

> *Before a pesticide can be marketed and used in the United States, the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) requires that EPA evaluate the proposed pesticide to assure that its use will not pose unreasonable risks of harm to human health and the environment.*

This includes biopesticides. Biopesticide active ingredients are classified into two categories: biochemical and microbial. In 2018, there were over 350 active ingredients on the EPA list. In this guide, we concentrate on four classes: fungi, bacteria, plant extracts, and chemicals.

Are Biocontrol Products More Costly to Use?

The simplest answer is yes and no. Like synthetic pesticides, manufacturers price products according to their use and efficacy and their potential profitability. Some products will be more expensive than others. Are you prepared to pay more for biopesticide products? Are you prepared to potentially apply products more often? Do you have the right application equipment if needed? Do you have proper storage conditions for the products? These and other factors should be considered and may result in an increase in overall production costs.

Do Cultural Practices Influence Pests and Product Efficacy?

As with all farming systems, good cultural practices reduce the effects of diseases and insects and improve crop health and production. They will also help to create a better environment for biocontrol products to work more efficiently.

Raised beds in an annual plastic mulch system help reduce root diseases by improving water drainage. Plastic mulch improves berry quality by reducing berry-soil contact where diseases can penetrate and cause infection. In rare situations, the plastic-covered beds have kept the humidity high around the berries and caused disease issues. Using high and/or low tunnels helps keep rain from contacting berries, reducing *Botrytis* and anthracnose fruit rots and crown and leaf diseases. If practical, removing dead leaves from around the plants, especially when fruit is present, improves airflow and reduces humidity levels that increase disease growth. Removing diseased plants reduces the spread of certain diseases. These should be disposed of a good distance away from strawberry fields.

Weeds not only compete for soil moisture and nutrients; they can harbor insects and diseases. Weeds should be controlled as much as possible.

Crop rotation significantly benefits soils by reducing pests and improving overall strawberry production. In Texas research, strawberry yields produced inside a high tunnel for 7 consecutive years, including with organic methods, declined almost 50 percent compared to open-field production. Yields decreased although the high-tunnel strawberries were harvested 23 times compared to only nine harvests in the open-field production.

The environment where strawberries are produced also influences pests and yields. Diseases in this trial included both *Rhizoctonia* root rot and *Botrytis* gray mold. Results showed that *Rhizoctonia* root rot was 2.5 times greater inside the tunnel compared to open-field production. In contrast, *Botrytis* gray mold infections were almost 6 times greater in the open field. Differences in *Rhizoctonia* root rot inside the tunnel were likely due to higher humidity levels compared to open-field production, while the higher levels of *Botrytis* gray mold infections in the open field were due to rainfall events. Additionally, marketable yields in the open field were lower and likely more influenced by the *Botrytis* infections than did *Rhizoctonia* in the high tunnels.

Biocontrol Products and Their Modes of Action

Research into biopesticides continues to improve and new products are brought to market annually. There are four generally accepted modes of action for biopesticides. Some products may have only one mode of action while others may have multiple. These modes of action include the following:

1. Improve root and foliar plant health,
2. Competitive exclusion,
3. Induced systemic resistance, and
4. Metabolite production.

To better understand these products, it is important to have a basic understanding of how these modes of action work. These modes are described in the following sections.

Figure 57. Biocontrol and biostimulant products can improve overall strawberry plant growth compared to non-treated plants (left). In Texas trials, a biocontrol product improved overall plant growth (middle) which was comparable to the chemically treated plants (right).

Improved Root and Foliar Plant Health

Some products improve overall plant growth. These include both biostimulants and registered biofungicides. Healthy plants have a better chance of resisting diseases and insects compared to ones that are under stress, even if the stress is temporary. Many biopesticides not only suppress or control pests but enhance the health of plant systems, especially the roots. Healthier root systems absorb more moisture and nutrients, which supports improved plant growth and development. Thus, even biostimulants that enhance root systems may be beneficial in suppressing pests. However, it is important to note that biostimulants are generally not registered as biopesticides and, therefore, cannot make claims of pest control efficacy. Texas research has shown that selected biopesticides can increase yield by improving plant health.

Competitive Exclusion

Many biopesticide products with living organisms work through a process called competitive exclusion. Competitive exclusion means that two microbes or species that compete for the exact same plant space and resources cannot coexist. In other words, the first microbe to colonize the roots or soil wins. This is the case for many root-applied biopesticides. These products, when applied before a disease attack, colonize the roots with beneficial fungi or bacteria and, thus, block or prevent diseases from attacking. These products may not work well if the plants are already infected with disease. Products containing beneficial strains of *Bacillus* and *Trichoderma* are good examples of competitive exclusion.

Induced Systemic Resistance

Induced systemic resistance is a mechanism where growth-promoting bacteria, fungi, and plant extracts, when sprayed or applied to leaves, "prime" plants for enhanced defenses against diseases and insects. Basically, think of it as a preventative vaccine to inoculate against pests. When plants are first infected by a pathogen, their leaves and roots signal to other areas that an infection is underway. The plant produces antimicrobial compounds that attempt to inhibit other infections. Root-associated beneficial fungi and bacteria, including *Pseudomonas*, *Paenibacillus*, *Bacillus*, and *Trichoderma* species and plant extracts (*Reynoutria sachalinensis*), can increase plant immune systems without causing yield losses.

Metabolite Production

In some cases, beneficial microbes release enzymes that dissolve pathogen or insect cell walls, aiding in their control. Additionally, some biopesticides contain isolated metabolite products that act as control agents. For example, *Trichoderma harzianum* not only competes for space on plant roots but has been found to produce a metabolite called harzianic acid, which aids in the control of root diseases. The combination of these modes of action improves disease control.

Controlling Pathogens with Biopesticides

IPM involves using a combination of several methods to control pests, including biological and chemical. At times, biopesticides may work better when chemicals do not. However, product coverage and application timing are critical for controlling any pest with biopesticides. Like chemical pesticides, not all biopesticide products will work on all pests or under certain environmental conditions.

As previously described, biopesticides can be applied as broad-spectrum oils and plant extracts, while living microbes are generally targeted for specific pests. Understanding the targeted pests and investigating each product prior to use is critical. Many biopesticides are more expensive to apply on an acre basis compared to chemical pesticides, so it is important to understand how each product works.

Many pesticides must contact pests to control them, and this is also true for biopesticides. Many pests, including aphids, spider mites, thrips, whiteflies, and lepidopterous worms, are found on the underside of leaves or on the flowers. Others are found in or on the soil surface. These products must be applied so there is sufficient contact with the pest to be controlled. Product applications must be timed according to specific label instructions, including when pest populations are low, to prevent significant outbreaks. In some cases, insect pests must feed on the product for control to be effective (*Bacillus thuringiensis*), while others must smother (plant oils) or break down protective barriers to reach the pests. To reduce the risk of product failure, always read and follow the biopesticide label instructions.

Influence of Soil Type on Soil-applied Biopesticides

It is always best to know what potential pathogens may be present in strawberry production fields. If diseases have been identified previously, finding the appropriate biopesticide is easier. However, if plants are infected, it is critical to know what diseases are present. Plant samples can be sent to the *Texas Plant Disease Diagnostic Lab at Texas A&M* in College Station.

Just like the ambient air environment, soil type and soil environment may influence the efficacy of soil-applied biopesticides. If the biopesticide's active ingredients are living organisms, then soil type, pH, temperature, alkalinity, and organic matter may influence microbial growth and their ability to reproduce and control root-inhabiting pests.

Soils vary depending on the many growing regions of Texas. This may also be the case when rotating from one field to another on strawberry farms. A grower's cultural practices may also influence the soil. Where cover crops or crop rotation are used, pathogen populations may be lower or higher depending on what is grown before strawberries. Where previous crops were infected by high levels of root pathogens, especially those that may infect strawberries, waiting a year or so may be beneficial. If that is not possible, apply biopesticides at their maximum label rate and application timings to improve efficacy.

Sandy soils usually contain less organic matter than loamy or clay soils. Some microbes use organic matter and other organisms in the soil as alternate feeding sources. Composting soils may help increase microbial activity, though some composts contain high levels of salts, which may influence microbe growth in the short term. Continuously dry or waterlogged soils affect crop growth and the performance of biopesticide products. Adequate soil moisture and oxygen levels are needed for microbe growth and development. Therefore, it is critical to maintain adequate soil conditions that allow both good microbial and root growth.

For most soil-applied products, preventing pest attacks is critical to their efficacy. Under extreme infections, biopesticides may not be effective, and a chemical application may be necessary to save the strawberry crop. Most soil-applied biopesticides should be applied at or close to planting. Many products can be drenched onto flats of strawberry plugs or as dips for bare-root plants. This will get the product directly onto the roots more efficiently. Multiple applications may be required to keep the microbial activity at peak performance. Many products can be applied directly to the strawberry root zone through the drip system, though follow label instructions to prevent emitter clogging.

Remember, it is more difficult to control pests, especially diseases when already present on a plant root, than it is to prevent attack. For soil-applied products, it is important to read, understand, and follow the label instructions.

Irrigation Effects on Biopesticide Efficacy

The type of irrigation system used and the amount of water applied to the crop can have a major influence on pest populations and product efficacy. Like plants, biopesticides containing living organisms do best when the root zone is uniformly moist and not too dry or too wet. When soil is too dry, living microbial products (biopesticides) may not have healthy roots on which to reproduce and protect plants effectively. This may also be the case if the root zone is not watered uniformly. When plant roots are waterlogged for extended periods, soil microbes may be killed or populations reduced. Root pathogens can then overwhelm biopesticides and reduce their ability to protect

against diseases. Multiple applications of the biopesticide will likely be needed.

Overhead sprinkler systems are generally not recommended during the production season, except during plant establishment in hotter climates. When used on strawberries during flowering and fruiting, overhead watering can increase *Botrytis* fruit infections as well as common leaf spot and leaf scorch by splashing pathogen spores onto leaves. Drip systems are highly recommended for annual production systems, especially where plastic mulch or high tunnels are used. An advantage of drip irrigation systems is that many root-applied biopesticides can be delivered directly to the roots during the season.

Applying Biopesticides

Before applying any biopesticide, it is important to know how the product works, which pests are controlled, and how the pest's life cycles may influence efficacy. Misuse of biopesticides can result in poor efficacy and wasted money. For information on significant strawberry pests in Texas, review the disease and insect sections of this guide. Regular scouting of strawberry fields and correctly identifying pests will improve control and reduce potential future outbreaks

Applying biopesticides with the appropriate application equipment is critical to obtain higher rates of efficacy. All spray and granular application equipment should be properly calibrated before use to ensure the correct amount of product is applied. Every product label states when the appropriate timing is for applications to improve product efficacy, prevent unnecessary applications, and save costs.

With most biopesticides, pests must contact the product for control or suppression. Active ingredients with living microbes must be able to grow on or be near the pest. In some situations, the lack of activity was due to the living microbes dying due to mishandling of the product before application. Plant extracts and oils must contact, cover, or smother pests to be effective. This means getting the product to the correct site for optimal control. For example, oils used to control spider mites or aphids in strawberries must be sprayed on the underside of leaves to be effective.

Always Read and Follow Label Instructions

Like conventional pesticides, for any registered biopesticide, the label is the law. Labels are available on the container or found online at manufacturer or distributor websites. Also, like conventional pesticides, misapplications or misuse may result in a lack of pest control or suppression. Always use the recommended rates and number of applications according to each label.

Some biocontrol products require specific storage conditions and have expiration dates. They may need to be refrigerated. Products packaged as dormant bacteria and fungi may have an extended shelf life. Store all biocontrol products according to their labels and use them before they expire. Storing living beneficial organisms above recommended temperatures may kill them and result in loss of efficacy. Many products cannot be returned, especially if they are past their expiration date.

Biocontrol products are manufactured using different formulations, including powders, liquids, liquid suspensions, and granules. Depending on the formulation, products can be applied through drip irrigation systems or overhead sprinklers or during fertigation. Many biocontrol products are compatible with synthetic pesticides; however, check the label for mixing instructions.

Biopesticides may be applied as dusts, drenches, dips, in-furrow sprays, or granules mixed into soilless media at seeding. Selected products can be applied to both the foliage and roots. Depending on the carrier (inert ingredients in the product), there are some biopesticides that require agitation during application, especially powders and liquid suspensions. Diluting a product or going below its labeled rate may result in loss of efficacy. Follow label application and mixing instructions regarding the correct amount of water to use.

Some active ingredients can be drenched onto plug trays a day or two prior to transplanting. This will allow the dormant beneficial fungi or bacteria (active ingredients) to begin growing on the plant roots so there is protection when planted into the soil.

Many biopesticides require repeat applications. Often spray or drip irrigation applications may need to be applied every 10 to 14 days or even sooner. For living beneficials, it is important to keep populations high enough to control or suppress the pests. Product labels will have this information.

Finally, Texas A&M AgriLife Extension conducted research on a limited number of commercially available biopesticides. Trials were conducted to compare plant response, disease control, and effects on strawberry yield from recommended product label applications (drip irrigated) to standard chemical applications.

The results in Table 18 show that none of the root-applied biocontrol products performed equal to the chemical control. However, plant vigor (health) from four biocontrol products improved compared to non-treated control. Reduction in black root rot (*Rhizoctonia* spp.) infection was good to excellent in general, and in some cases, biopesticides outperformed the

Table 18. Estimated response of selected commercially available biocontrol products evaluated at the Texas A&M AgriLife Research and Extension Center at Lubbock (2018–2019)			
Product name	Increase in plant vigor compared to non-treated control	Reduction in *Rhizoctonia* root rot compared to non-treated control	Marketable yield increase compared to non-treated control
Non-treated control	—	—	—
Chemical control	Excellent	Good	Good
Actinovate	Good	No difference	Good
AmyProtec 42	Good	Excellent	Good
Aviv	Fair	Excellent	Fair
Double Nickel LC	Good	Good	Excellent
Regalia	Poor	No difference	No difference
RootShield Plus	Good	No difference	Fair
TerraStart + Oxidate + PVent	No difference	Fair	Fair
TerraStart + Oxidate + TerraGrow	No difference	Good	No difference
Timorex Act	No difference	Excellent	No difference
Timorex Gold	Fair	Good	Fair

Remarks: No difference = No change in yield; Poor = Equal or less than 5% increase; Fair = 5% to 10% increase; Good = 10% to 20% increase; Excellent = 20% to 50% increase.

Note: These results are not intended to promote or eliminate the use of any of the above-mentioned products.

chemical control. Only one product (Double Nickel) had higher yields compared to the chemical control.

In Table 19, commercially available biopesticides were applied to the foliage of plants to control *Botrytis* gray mold on strawberry fruit. Weekly to biweekly applications were made throughout the season according to label instructions.

The results indicated that only one product (Oxidate) showed promise for *Botrytis* control. Most products performed poorly, including the chemical control. These results suggest that not only is *Botrytis* difficult to control, but that both biopesticides and chemicals may have difficulty controlling this important disease. Growers should consider the options of whether fungicide applications are economically profitable.

Table 19. Response of commercially available biocontrol products for foliar *Botrytis* control evaluated at the Texas A&M AgriLife Research and Extension Center (Lubbock) in 2019	
Product name	Reduction in *Botrytis* infected berries by treatment
Non-treated	—
Chemical control	Poor
Aviv	No difference
Calcium chloride + Boron	No difference
Double Nickel alt. w/ Cueva	Poor
LifeGard alt. w/ Cueva	Fair
Cueva	Poor
LifeGard	Poor
Oxidate	Good
Oxidate followed by PVent	Fair
MilStop	Fair
T-77	Poor
Regalia	Poor
Timorex Gold	Poor

No difference = No change; Poor = Less than 10% control; Fair = 10% to 20% control; Good = At least 20% control; Excellent = 25% control or better.

Note: These results are not intended to promote or eliminate the use of any of the above-mentioned products.

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