Chapter 2
Organic Strawberry Production in Tennessee, USA, and Areas of Comparable Climate in China

Suping Zhou, Sarabjit Bhatti, Shu Wei and Fur-Chi Chen

Abstract Strawberry production and consumption is experiencing significant growth. Production in the USA has doubled since the 1990s. As the domestic demand increases, there is potential to expand production beyond California and Florida into other regions of the country. In the 1950s, strawberries accounted for 25.3 % of the total marketable value of all fruits and vegetables produced in Tennessee, before declining in the 1970s. Acreage in the last 2 decades has been on a slow upward trend. Several counties throughout Tennessee are well suited for the growing of high-quality and high-value strawberries. Efforts are being made to promote production and consumption of organic and naturally grown local strawberries in Tennessee. Strawberry production in parts of China that have a similar climate has also seen considerable growth. Hebei, Shandong, Anhui, and Liaoning are among the largest strawberry producing provinces in the country. In 2014, over 50,000 acres of strawberries were planted in Anhui Province, accounting for over 15 % of all strawberries grown in China. This chapter discusses the production systems, cultural practices including nutrient management, the selection of cover crops, integrated pest management, and weed and disease control in strawberry

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production in Tennessee and China. Harvesting and postharvesting protocols, marketing channels, safety concerns, current constraints, and future potentials of organic strawberry production are also discussed.

Keywords Strawberry · Production · Market · Organic · USA–China

2.1 Introduction

Strawberry production and consumption is experiencing significant growth. According to the Food and Agriculture Organization (FAO) of the United Nations, world production of strawberries has exceeded 4 million tons since 2007. The USA is the world's largest producer of strawberries, producing over 36 billion pounds in 2012 and contributing approximately 29 % of the global supply (Naeve 2014). Production in the USA has doubled since the 1990s. Majority of this growth has occurred in California (89 %) and some in Florida (9 %), while there has been a decline in production for the other states with commercial strawberry industries (Rom et al. 2014). Year-round availability of fresh strawberries has significantly influenced their consumption by Americans. According to the USDA, Americans are eating more fresh strawberries grown in the USA, with annual per capita consumption doubling since 2002, to almost eight pounds in 2012. According to ERS's loss-adjusted food availability data (2012), strawberries rank the fifth most commonly consumed fresh fruit in the USA after bananas, apples, watermelon, and grapes. In terms of market value, they are the fourth most valuable fruit produced in the USA and considering only the fresh-market fruit, they are second only to apples in value. As the domestic demand increases, there is potential to expand production into other regions of the country.

Tennessee used to be among the largest strawberry producers in the USA. In the 1950s, strawberries planted on approximately 15,000 acres, accounted for 25.3 % of the total marketable value of all fruits and vegetables produced in Tennessee (Goble 1961). They were grown all over the state, particularly the Sale Creek/Soddy Daisy area near Chattanooga, Portland, and the surrounding area, and near Fruitland in Gibson County. Strawberries were celebrated as an important part of the local economy. The First Annual West Tennessee Strawberry Festival was held in Humboldt in 1934 and the Middle Tennessee Strawberry Festival in Portland goes back to the early 1940s when strawberries were the mainstay of this area. Portland, nicknamed the 'strawberry capital of Tennessee,' held that distinction until the 1960s when industrialization changed agriculture. By the mid-1970s, total acreage had dropped to just above 200 acres. Anthracnose infestation forced closure of several Arkansas and North Carolina nurseries which supplied plants (plugs) to the Tennessee growers. Acreage in the last 2 decades has been on a slow upward trend, though Tennessee does not rank in the top 10 states in strawberry production. The 2012 USDA agriculture census report lists the acreage harvested as 253 acres, up from 194 acres in 2007.

Strawberry production is scattered across the state of Tennessee. The top 5 counties in Tennessee in terms of strawberry acreage in 2002 were Unicoi, Washington, Rhea, Hawkins, and Bledsoe (Bost et al. 2003). Several other counties such as Wayne and Gibson in West Tennessee; Bedford, Coffee, Franklin, Montgomery, Moore, Robertson, Rutherford, Sumner, Warren, Williamson, and Wilson counties in Middle Tennessee; and Anderson, Bradley, Grainger, and Knox in East Tennessee; and many more throughout the state are well suited for the growing of high-quality and high-value strawberries. In East and Middle Tennessee, tobacco and row crop farmers have been looking for new ways to supplement farm income due to the uncertainty and changes occurring in tobacco production. These and other small farmers in Tennessee are open to new ideas that provide a better chance at making a living and keeping the farm in the family (Friedman 2007). Growing organic strawberries is one of their options.

US organic strawberry acreage is increasing in response to the market demands. For the past several years, strawberries have been on the 'dirty dozen' list released by the Environmental Working Group, a nonprofit organization which lists the top 12 types of conventionally grown fresh produce containing the highest amount of pesticide residues. Their recommendation is to look for organic strawberries to avoid exposure to a battery of toxins. Organic production has the potential to increase profits by providing consumers with locally grown, high-quality organic products in a rapidly growing market where the demand is greater than the supply.

Organic strawberries sold in grocery stores across Tennessee are mostly shipped from California, where organic strawberry sales have grown from $2 million in 1997 to over $63 million in 2011 (USDA/NASS). Organic certification is a vital part of ensuring that consumers are confident in the products they buy and trust that they meet USDA's organic requirements. Through the National Organic Program, USDA has helped organic farmers and businesses to achieve $35 billion annually in US retail sales. Efforts are being made to promote production and consumption of organic and naturally grown local strawberries in Tennessee. Although, the organic certification provides access to price premiums and specialty markets (Wszelaki et al. 2014), there are few growers that are certified organic. A higher percentage of farmers prefer to claim the 'naturally grown' term for their produce. They follow sustainable agricultural practices, minimizing or even avoiding the use of pesticides. As part of a project funded under the National Strawberry Sustainability Initiative (NSSI), 8 local strawberry producers in 5 Middle Tennessee counties were enlisted to participate in the initiative growing strawberries using organic practices. These farms agreed to follow sustainable strawberry production practices using preventive management to reduce problems with weeds, diseases, pests, and plant nutrition through integration of a variety of cultural, biological, and mechanical management practices. They provided 3 plots (12ft × 12ft) from which fresh strawberries were harvested for consumer preference evaluations and for studies dealing with enhancing food safety (Sect. 2.12).

In China, strawberries are cultivated on approximately 320,000 acres with a total output of over 260 million pounds in 2015. Hebei, Shandong, and Liaoning are the largest strawberry producing provinces in the country, each with nearly 25,000 acres of cultivation, followed by 20,000 acres in Jiangsu and 10,000 acres in

Anhui. Strawberry producing counties include Mancheng in Hebei, Dandong in Liaoning, Yantai in Shandong, and Changfeng in Anhui. At present, strawberries produced in China are mainly for domestic consumption and for frozen product export. Strawberry yield in China has great potential for improvement comparable to that in the USA, Japan, and Italy (Yan 2010). As of 2014, over 50,000 acres of strawberries are planted in Anhui Province, accounting for over 15 % of all strawberries grown in China (Liao et al. 2014). Changfeng with more than 30,000 acres (Yu et al. 2013) is the largest strawberry producer in Anhui.

Organic strawberry production in China began around 2000 in Liaoning Province. Although strawberries in Changfeng are largely certified as 'green food,' conventionally grown strawberries are still dominant in Anhui and other strawberry producing provinces. Until 2014, organic strawberries were planted on about 1300 acres, with total market value around $120 million. This high value per acre suggests great demands for organic strawberries in China. There were over 800 acres of organic strawberry production in Liaoning alone, which accounted for two-thirds of all organic strawberries in China (Liu 2014).

2.2 Cultural Management Systems

Since locally produced strawberries are an important cash crop in many Tennessee counties, it is imperative to maximize the yields and profits and be able to compete with the commercial growers. Selecting the best production system greatly affects the potential profit. There are basically two types of production systems utilized in Tennessee: plasticulture and the matted-row system. High Tunnel production has not gained much popularity among the small strawberry farmers, owing to the costs involved.

2.2.1 Plasticulture (Annual)

Decreased competition with weeds, less time to production, and an earlier harvest season are some of the reasons most producers would consider when using annual plasticulture. Organic as well as conventional farmers in California and Florida tend to be partial to this system (Guerena and Born 2007), even though it is quite intensive. Growers in Tennessee adopted the strawberry plasticulture production system in the late 1980s and it continues to be popular. Three-fourths of the producers participating in the project use this production system, which performs well in the milder areas of the southeast where temperatures rarely fall below 0 °F (Poling et al. 2005). It involves the planting of freshly dug bare-root plants or transplants started from runner tips (called plug plants) on raised beds covered with black plastic (Fig. 2.1a). Drip tape, buried at a depth of 2.5 in., is used for irrigation and supplemental fertilizing (fertigation).

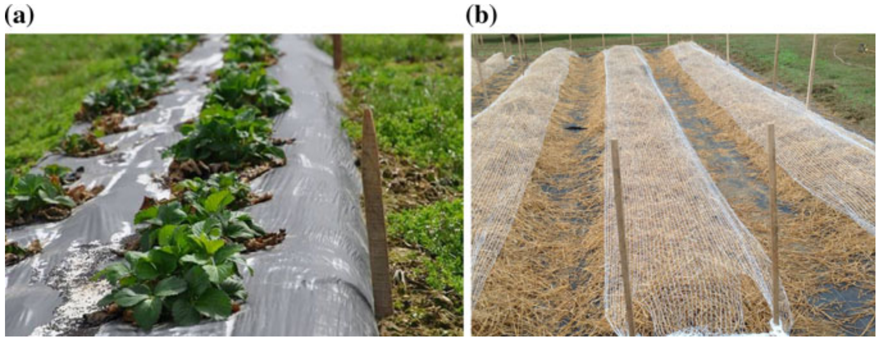

Fig. 2.1 Strawberry production using plasticulture on a farm in middle Tennessee. **a** Raised bed plasticulture; **b** beds mulched and netted for winter. *Photo Credit* Tennessee State University

There are 2 types of raised beds used in plasticulture. In narrow beds, plants are spaced at about 12–14 in. in staggered double rows with one drip line running between the rows. The wide beds normally have two drip lines running between 4 rows of plants that are also spaced about a foot apart. Plants are set out at densities of 15,000–17,500 plants per acre (Poling et al. 2005). Strawberries grown using this system need to be intensely managed. It becomes extremely critical to control soilborne diseases and pests through soil treatments, crop rotation, green manure crops, and compost. The daily decision making regarding production and pest management strategies can have a major impact on yields and profit. There is also considerably more risk involved in terms of timing, frost and freeze strategies, and marketing using the plasticulture production system than the matted-row system.

Plug plants are planted through the plastic in late summer or early fall; dormant plants are planted in July. Lightweight plastic material with small holes is used for covering the beds for winter protection in the late fall (Fig. 2.1b). Growers in Tennessee prefer using the dual-purpose plastic mulch that allows penetration of soil warming radiation while eliminating light to prevent weed growth (Guerena and Born 2007). Raised beds provide good drainage; however, plants may be prone to freeze damage. Therefore, colder winter temperatures do create challenges for adopting this system. Strategies to best protect plants from winter injury may include using a thick row cover and applying the cover early. Rivard et al. (2014) reported that using a 1.2 oz/yd plastic as opposed to a 1 oz/yd cover resulted in a higher early yield. Both row cover thicknesses provided excellent protection to the crop even when temperatures fell below 10 °F; minimum temperatures under the covers were never less than 25 °F.

The raised beds allow for easier and faster picking and earlier harvesting (Poling et al. 2005). A north–south orientation of strawberry beds encourages a more uniform plant development and ripening on both sides of the double-row bed (Poling 1993). In most cases, berries can be harvested in 7–8 months after planting. Growers in Tennessee typically do not hold their plantings beyond the first year due to potential disease problems. If they choose to continue into a 2nd or 3rd year of production, runners must be removed each year. Higher yields and returns per acre are generally obtained using this production system. The majority of strawberries produced under annual plasticulture systems are June-bearing varieties, with ‘Chandler’ being the most commonly grown cultivar (Bost et al. 2003). In the northern part of TN, growers typically have a shorter harvest season (about 5 weeks) and lower potential yields per plant compared to the southern part (1 lb berries/plant vs. 1.5 lbs/plant). It is, however, still possible for them to make a profit with this yield which is equivalent to 15,000 pounds per acre (Safley et al. 2004).

2.2.2 Matted-Row System (Perennial)

A large percentage of strawberries grown in Tennessee are produced in matted-row production systems (Fig. 2.2). Franklin, Cheatham, Sumner, and Coffee counties in Middle Tennessee have historically been known for growing strawberries using this system. Though an old method of growing strawberries, it is still the predominant production method used by growers with great success. It is more commonly used in regions with a colder climate. The initial cost is low, since the matted-row system allows the plants to multiply into the rows to maximize production. In this production method, strawberry plants (crowns) are set out early to mid-spring on well-prepared soil at regularly spaced intervals (between 12 and 24 in. apart) within regularly spaced rows (36–52 in. apart). Planting in late spring causes fewer runners (stolons) to be produced, so the space between the plants must be reduced (Pritts 2002). From the initial planting, daughter plants from runners are established within the row and the intertwining network of runners creates a matted tangle of plants, giving the name ‘matted row.’ The daughter plants will produce their own strawberries for harvest the following spring. Weed management is the biggest challenge faced by farmers during the first year since there is much bare soil surface; frequent regular cultivation and hand weeding will greatly increase the life of the strawberry planting (Pritts 2002).

Fig. 2.2 Strawberry production using matted rows on a farm in Middle Tennessee. Matted rows with TSU experimental plots marked (*photo credit* Tennessee State University)

In the past, overhead irrigation was used more often, but currently matted-row growers are opting to use drip irrigation. During the spring, the overhead irrigation has a protective function to save the plants from frost damage. Drip irrigation users must use row covers for frost protection. The matted-row system takes a full year before a crop is harvested. Yields of anywhere from 12,000 to 25,000 lbs/acre are possible during the second year and onwards using this system. Each matted row is allowed to produce until the plants lose their productive ability (i.e., yields and berry size decline over time), which is usually between 3 and 5 years before rotation or replanting occurs. The most commonly grown cultivars in matted-row systems in Tennessee are 'Earliglow,' 'Allstar,' 'Delmarvel,' and 'Cardinal.'

One of the drawbacks of the matted-row system is that the strawberries require tending all year long. The strawberry renovation process must be done each year after harvest to prevent overcrowding caused by an excess number of runner plants rooting. This involves removing the foliage, narrowing the rows using a tiller, and then allowing runner plants to fill in the rows again.

An alternative to the matted row is a 'ribbon-row' high-density planting system, which has fewer weed problems and produces some fruit in the planting year and very high yields in the first fruiting year (up to 30,000 lbs/acre). This system is used if planting is done in late spring or early summer.

2.2.3 High Tunnel Production

A desire to extend the strawberry season has led to a great deal of interest in high tunnels. Also known as hoop houses, these greenhouse-like structures are covered with simple polyethylene, but they usually do not have exhaust fans or sources of heat. Temperatures and ventilation are controlled manually by opening and closing sides. Location and orientation of the high tunnel are very important for the success of this production system. The structure needs to be on a fairly level area protected from high winds, but on ground that is slightly higher than the surrounding area to help keep water away during heavy rainfall. High tunnel production is more expensive than open field production due to the costs involved in constructing and maintaining the structure. It still provides a reasonably low-cost investment considering that tunnels can extend the production season (both early and late in the season) and marketing window of strawberries in Tennessee. Late summer plantings in the tunnels allow the strawberries to produce a first crop in late fall and a second one in early spring (Wszelaki et al. 2013).

High tunnels provide crop protection from adverse weather conditions and better control of the growing environment. This significantly improves the survival rate of strawberry plants, as well as providing berries earlier (Wright 2012). Growers who are able to supply the customers with the earliest locally grown strawberries are often able to demand a premium price. As long as the plants are kept healthy and the environment in the high tunnels is appropriate, the strawberry harvest season will continue. High temperatures usually cause the harvest season to end (Wright 2012).

However, the tunnel environment does have limitations. The warm humid conditions are very conducive to pests such as white flies, aphids, and spider mites and *Botrytis*.

2.2.4 Cultural Management Systems in China

In China, national standards for organic strawberry production dictated by the Ministry of Agriculture (MOA) require no or minimum levels of chemicals present in the fruit (Liu 2014). There is tremendous variation in climate conditions in China. Therefore, strawberry cultivation systems differ significantly. Before the 1980s, strawberries were cultivated mainly in open fields. Since the 1990s, open field cultivation, small shed cultivation, normal greenhouse cultivation, and plastic greenhouse forced cultivation have all been in practice.

The climate of Anhui is fairly similar to that of Tennessee, with the average winter temperatures around 35–52 °F. There is a huge market for fresh strawberries in winter or early spring in China, when the popular Spring Festival is celebrated. This has led to the adoption of solar greenhouse production of strawberries all over the country, including Anhui during the winter months. The solar greenhouses are about 23 ft in width and 230–260 ft in length (Fig. 2.3b). The 20 in. wide beds

Fig. 2.3 Production systems in China. **a** Glass greenhouse; **b** Plastic greenhouse; **c** Strawberries planted on bed in greenhouse; **d** Strawberrries planted in open field

allow for two rows of strawberries (Fig. 2.3a, c). Strawberry plantlets can be planted at densities of 72,000 plants per acre; after the first harvest the density can be reduced by 50 %. In this way, strawberry growers are able to significantly increase early yields (Lan et al. 2012).

In open field cultivation, strawberries are planted in the fall. Plug plants are grown on raised beds as shown in Fig. 2.3c, quite similar to plasticulture. Plants are set out at densities of 48,000–60,000 plants per acre (Zhang and Yang 2010), which is about 3 times that in the USA (Poling et al. 2005).

Regardless of the production system used, there are some key factors which cannot be ignored. The selection of a site for growing strawberries must consider size (to allow crop rotation), well-drained soil, adequate water supply for irrigation and also for frost protection, and good air movement (Carroll et al. 2014). Knowing soil conditions, such as pH, major and minor nutrients, infection by nematodes, and previous cropping history allows for better management decisions. For organic certification, the fields may not have been treated with prohibited products for 3 years prior to harvest. In the USA, a farm plan which describes production, handling and record-keeping is required by the USDA National Organic Program (NOP).

2.3 Cover Crops

Cover crops are essential to organic strawberry production to protect, maintain, and enrich the soil (Wszelaki et al. 2013). They have a beneficial effect on organic matter, encourage beneficial soil microbes, retain soil moisture, prevent erosion, and help control insects and diseases. Thus, the choice of cover crop (Table 2.1) depends on the specific goals of the production system. Growers in Tennessee usually plant these a year or two prior to establishing the strawberry crop so that they can succeed in suppressing weeds and in reducing nematode populations in the soil (Pritts 2002). There are two broad groups of cover crops commonly used in strawberry production in Tennessee: legumes and grasses. An emerging area of research has added a third group, the mustard family, which is being planted to suppress pests and also for its biofumigant activities. Cereal crops such as oats and rye have been used for their allelopathic properties and have the ability to suppress weeds and suppress pathogen and nematode pressure (Bhowmick et al. 2003). Oats are the most widely used cover crop in matted-row organic strawberry production in Tennessee.

Table 2.1 Common cover crops (lbs/acre) for strawberry production in Tennessee

Annual ryegrass	14–30	Temporary N tie-up when turned under, rapid growth, heavy N and moisture users, leaves behind heavy root system
Brassicas, e.g., mustards, rapeseed	5–10	Good cover and forage, cold hardy, mow or incorporate before seed formation, biofumigant properties
Buckwheat	35–134 60–70[a]	Use for site with low soil pH, matures in 70–90 days, low–moderate biomass, drought tolerant, will winter kill, incorporate shortly after bloom, scavenges nutrients, not a host for AMF
Cereal rye	60–200	Cold-tolerant cover crop, good catch crop, rapid germination and growth, incorporate before seed formation, temporary nitrogen (N) tie-up when turned under
Cowpea 'Iron clay'	100–130[a]	Moderate to good weed control, drought and heat tolerant legume (provides 100–150 lbs N/acre), good for beneficial insects
Hairy Vetch	30–40	Fast grower, mow or incorporate before seed formation
Marigold	5	Biofumigant properties, can be plowed under in 90 days, will winter kill
Pearl millet	30[a]	Excellent weed control, drought tolerant, does not get as tall as Sudan or Sorghum-Sudan, adapted to poor soils
Sorghum-Sudan	35–50 20–90[a]	Biofumigant properties, smothers weeds, tremendous biomass producer (4–6ft) in hot/dry weather; extra time to decompose thick stalks
Soybean 'Laredo'	110–130[a]	Moderate weed suppression, may need irrigation, more biomass than cowpea
Spring oats	60–100	Ideal quick cover crop, incorporate in early June if planted in spring, killed by successive frosts
Sudan	20–90	Excellent weed control, some drought tolerance, high biomass, adapted to poor soils
Velvet bean	80–100[a]	Very good weed control, good heat tolerance, very high biomass producer for legume, resistant to nematodes, seeds may be a bit more costly and less readily available than other legumes
Wheat	80–100	Mow or incorporate before seed formation

Adapted from Carroll et al. (2014) and McWhirt (2015)
[a]Rate used when planted with companion crops

No cover crops are used during strawberry cultivation in China. However, some cash crops (Fig. 2.4) are planted along with the berries to make better use of time or space (Table 2.2).

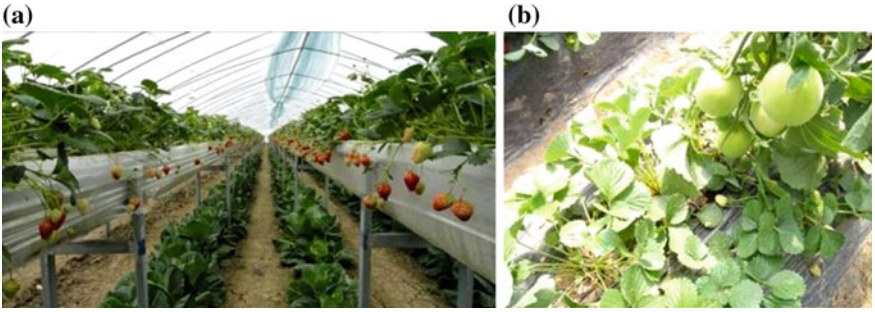

Fig. 2.4 Intercropping of strawberry and other crops in China. **a** Intercropping with vegetables; **b** intercropping with netted melon

Table 2.2 Common intercropping crops for strawberry production in China

Netted melon	7200 plants per acre	50 % net profit increase (Huo et al. 2008)
Rice		Soil improvement; decreased use of chemicals; 20 % increase in strawberry production
Cabbage		Planting May–Oct after strawberry is removed; early fruit; 20 % increase in strawberry production
Maize	1 row of corn per raised bed	Weed control; sun protection; pick corn and let the plant grow till Sep
Muskmelon	20–25 in. (row spacing)	Weed and insect control, soil improvement; exposed to solar for 40–50 days before strawberry plant
Tomato	Between 2 rows of strawberries, row spacing: 10 in.	Increased net profits (Zhang et al. 2011)
Luffa	row spacing: 5ft × 2ft	Planted March–July; increased net profits (Cheng 2007)
Watermelon	row spacing: 20 in.	15–20 % increase in net profit (Liu et al. 2008)

2.4 Variety Selection

Strawberry varieties are very sensitive to local conditions. A variety that performs well in one area may fail miserably in another area. Therefore, it is extremely critical to evaluate performance of the varieties under local conditions and select the right cultivars for optimum strawberry production. Selecting well-adapted varieties that are heat and humidity tolerant are very important in Tennessee. In organic production, the selected variety's relative resistance or susceptibility to diseases is extremely critical since there are a limited number of organic pesticides available for disease management (Carroll et al. 2014). Those varieties that exhibit disease

Table 2.3 Strawberry cultivars and their susceptibility to diseases in Tennessee

Variety	Leaf spot	Leaf scorch	Leaf blight	Anthracnose	Red stele	Verticillium wilt	Powdery mildew
Albion	M	–	–	M	R	R	M
Allstar	R	R	S	S	R	R	R
Annapolis	S	S	–	–	R	M	S
Cardinal	R	M	–	S	S	S	–
Chandler	S	M	S	S	S	–	R
Cavendish	R	R	–	–	R	M	S
Delmarvel	R	R	M	R	R	R	M
Earliglow	M	R	M	M	R	M-R	M
Honeoye	R	R	–	–	S	S	M
Idea	M	S	M	R	R	R	–
Latestar	M	R	–	–	R	R	–
Primetime	R	R	–	–	R	R	–
Redchief	S	R	S	S	R	M-R	R
Surecrop	M	M	–	M	R	R	R
Sweet Charlie	N	–	S	R	–	–	–

R Moderate to high resistance, *M* Moderate resistance to moderate susceptibility, *S* Moderate to high susceptibility, – Unknown
Modified from Bost et al. (2003)

and pest resistance (Table 2.3) for the area will have much better results. The market demand in terms of the qualities preferred also needs to be taken into consideration when selecting cultivars (Wszelaki et al. 2012a, b). Most Tennessee farmers grow strawberries for local consumption, so choosing varieties that have good shelf life to withstand shipping is not as critical.

Strawberry varieties are classified as either ‘June-bearing’ (short-day varieties) or ‘Ever-bearing’ (day-neutral varieties). ‘June-bearing’ start forming flower buds as the day-length gets shorter (in the fall) and temperatures get cooler. ‘Ever-bearing’ are insensitive to day-length and produce fruit throughout the season as long as nighttime temperatures drop below 60 °F (Strand 1993). June-bearers were developed after years of breeding for their attributes and are the type most often grown by commercial growers. They are preferred for their size and productivity and are recommended for early season production in a tunnel. June-bearing varieties are rated as early, midseason, or late according to when they bear fruit. Ever-bearing varieties are highly productive and favored for their flavorful berries. They bear fruit throughout the growing season, with three production peaks each year: June, mid-summer, and late summer to frost.

It is quite possible to grow 2–3 different cultivars using plasticulture in the southeast to extend the harvest season over a four-to-eight-week period based on the temperature during the season (Poling et al. 2005). ‘Sweet Charlie’ (early variety), ‘Chandler’ (early- midseason variety), and ‘Camarosa’ (mid-season variety) are all adapted for Tennessee. Four of the producers involved in this project grew 'Chandler' exclusively or as one of the varieties, along with 'Camarosa,' 'Ozark,' 'Haneoye,' and 'Sweet Charlie.' Others preferred 'Earliglow,' 'Allstar,' 'Santa Rosa,' 'Red Chief,' and 'Surecrop.' 'Chandler' is well liked by consumers for its attractive red color, size, and flavor (see Sect. 2.11). It is relatively cold hardy and does not generally require winter protection and also has high yields. However, row covers are recommended if temperatures dip below 10 °F for extended periods in the particular area, as this may cause significant flower damage and crown injury. 'Sweet Charlie' fills the early market niche. It can be ready anywhere from a week to two earlier than 'Chandler' and in some years, growers can have a second crop of 'Sweet Charlie' berries in the final week of the strawberry season (Poling et al. 2005). These are preferred for their high sugar to acid ratio. 'Camarosa,' bred at the University of California, is the most widely planted variety in the world. This variety has high yields and the fruit itself is large and very firm. This firmness makes it ideal for distant shipment or for long-term storage. For best flavor, 'Camarosa' is picked when the berries have taken on a darker color, just past the glossy bright red stage. If the color turns wine red, the berries are already too ripe. In Tennessee, 'Chandler' (Fig. 2.5a) and 'Camarosa' are typically grown in plasticulture production systems, while 'Earliglow' (early season), 'Allstar' (mid-/late season) (Fig. 2.5b), 'Delmarvel,' and 'Cardinal' are commonly grown in matted-row systems. 'Albion,' 'Tribute,' '300 Seascape,' and 'Festival' are also popular in Tennessee. 'Albion' has shown to be cold hardy in the Middle Tennessee area. A producer participating in the NSSI project harvested 'Albion' strawberries from his plasticulture production system in Middle Tennessee as late as the first week in November, before the first sub-freezing temperatures.

In China, varieties with large fruit were introduced in the early twentieth century. In the mid 1950s, many strawberry varieties were introduced from the former Soviet Union, Poland, and Yugoslavia. By the early 1980s, some excellent varieties had been screened and genetically improved and were being widely used for production. Among the cultivars grown, 'Cart1' and 'Elsanta' are usually used for

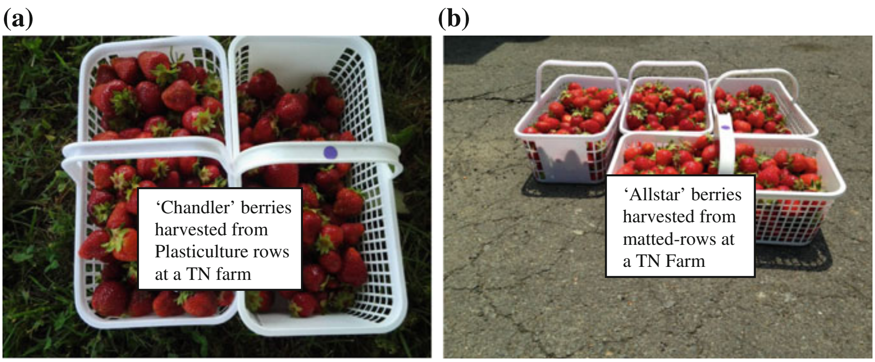

Fig. 2.5 Strawberries harvested from farms in Middle Tennessee in 2014

fresh consumption, while ‘Honeye,’ ‘TuD La,’ ‘Darselect,’ ‘Senga Sengana,’ and ‘Darsanca’ are used for processing (Liu 2014). The most widely planted cultivar in Changfeng is ‘Confidante’ (Lan et al. 2012).

More improved varieties are needed to increase production and capture a larger share of the local market. The University of Kentucky has been evaluating the performance of a new variety called ‘Flavorfest.’ This variety, which was developed at the USDA-ARS station in Beltsville, is showing great potential in terms of production, comparable to Chandler and is also exhibiting some disease and pest resistance (2015 news bulletin). Owing to similarity in growing conditions, ‘Flavorfest’ may show potential for growth in Tennessee in the coming years.

2.5 Soil Fertility/Nutrient Management

The need for balancing nutrition for strawberries can be greatly facilitated by improving soil organic matter content. Organic systems improve soil quality by increasing soil fertility, and promoting soil biological activity. Soil quality is further enhanced through management practices such as incorporating compost, animal manures, cover crops, and green manures (Wszelaki et al. 2012a, b). It is very critical to create a soil that is capable of holding nutrients and water since this is the basis of a good strawberry crop. The connection between soil, nutrients, pests, and weeds is so great that it can make a difference between the crop success and failure. Strawberry growers initiate soil preparation a year or two before establishing plants. Decomposing organic matter provides plant available nutrients in organically managed systems (Carroll et al. 2014).

Beneficial soil inoculants are added to the soil to introduce or re-establish ‘good’ soil microbes. These were initially put into practice to re-introduce ‘good bacteria’ back into the soil after fumigation. Now that chemical fumigation is being phased out, the soil inoculants continue to be popular. Two types that are commonly used are (1) vermicompost (compost made by earthworms), which has high microbial activity, and (2) arbuscular mycorrhizal fungi (AMF), which are fungi that form beneficial relationships with plant roots and help the plants find nutrients. Mycorrhizal cultures inoculated around strawberry plants (Fig. 2.6b) could improve phosphorus (P) availability in the soil. Compost applications encourage diverse soil microbe populations. Adding beneficial soil inoculants to the planting hole with the plug media have been shown to increase yields as compared to non-inoculated ones (McWhirt et al. 2015). Arancon et al. (2004) reported that vermicompost applications (2.02–4.05 ton/acre) increased strawberry growth and yields significantly. Welke (2004) reported a 20 % increase in yields with the foliar application of aerobically prepared compost tea, compared to the control.

Animal manure is the most traditional and widely recognized fertilizer used in organic systems. According to the US Department of Agriculture’s (USDA) National Organic Program (NOP) standards, raw manure must be applied and incorporated into the soil at least 120 days prior to harvest of a crop that grows

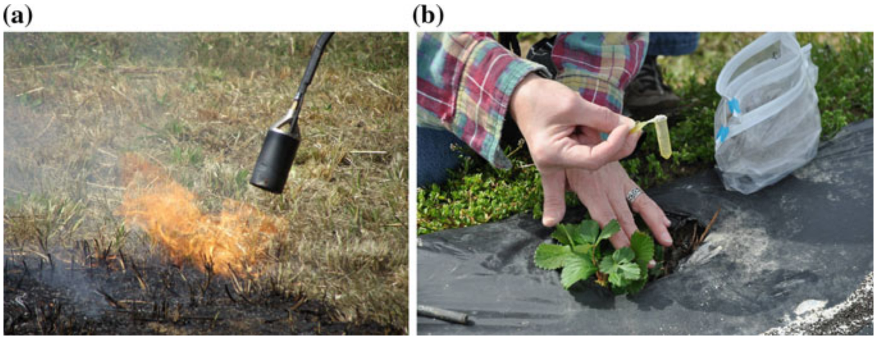

Fig. 2.6 Weed Control and soil fertility practices. **a** Flame burning for weed control in a Robertson County farm; **b** inoculating biovam mycorrhizae around strawberry plant

close to the soil, such as strawberries. Due to food safety concerns, the use of raw manure is not recommended; the use of composted manure is preferred. However, manure-based compost can have high phosphorus or salt concentrations, leading to nutrient toxicities (McWhirt 2015).

Soil pH of 6.0–6.5, in the slightly acidic range, is recommended for strawberries to maintain nutrients at their optimum availability and help avoid micronutrient deficiencies (Carroll et al. 2014). A low pH or acid soil will have reduced availability of nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), and molybdenum (Mo), while a high pH or alkaline soil will have reduced availability of zinc (Z), boron (B), iron (Fe), manganese (Mn), and copper (Cu). Results of the soil analysis (Fig. 2.4c) determine whether pH needs to be adjusted by using either dolomitic lime (raise pH) or elemental sulfur (lower pH) during the soil preparation stage and will also determine the addition of nutrients. Generally, one-third of the N, half of the K, and all of the required P should be incorporated before planting (Poling 1993). Once the plantings are established, fertilizer applications are based on leaf analysis.

Many types of organic fertilizers (Tables 2.4 and 2.5) are available to provide supplemental nutrients during the growing season. However, the application timing is very critical. For instance, June-bearing strawberries (matted-row systems) must be fertilized in late summer, to give the organic fertilizer enough time to break down and release nutrients for the plants in the fall when the berries are setting buds for next year's crop (Guerena and Born 2007). It is important to balance the total plant nutrition taking into account competing characteristics of all fertilizer elements. Cover crops or compost alone might be inadequate to fulfill the late N demand of strawberry crop in organic production (Muramoto 2004). Due to the unpredictability of N mineralization from organic fertilizers and soil organic matter, providing the optimum amount of N to meet the needs of strawberries can be challenging in organic systems. Gaskell (2004) tested different sources of organic fertilizers such as guano, feather meal, liquid fish emulsion, fish meal, chicken manure, compost, and a green manure and found great variability in N availability.

Table 2.4 Available potassium in organic fertilizers

Sources	Available potassium
Sul-Po-Mag	22 % K_2O also contains 11 % Mg
Wood ash (dry, fine, gray)	5 % K_2O, also raises pH
Alfalfa meal (non-GMO)	2 % K_2O, also contains 2.5 % N and 2 % P
Greensand or granite dust	1 % K_2O
Potassium sulfate	50 % K_2O

Carroll et al. (2014)

Table 2.5 Available phosphorus in organic fertilizers

Sources	Available phosphorus
Bone meal	15 % P_2O_5
Rock phosphate	30 % total P_2O_5
Fish meal	6 % P_2O_5 (also 9 % N)

Carroll et al. (2014)

Though more N is utilized by strawberries in the mid to later growth stages than the early stage, it should be supplied over the entire production period to ensure optimum yields and high quality (May and Pritts 1990). Depending on the soil type, 150–220 lbs N/acre may be needed for new plantings and 75–120 lbs N/acre for established plantings. Excellent strawberry production requires about 1 lb N/acre per day during the harvest season.

Strawberries may require 100–150 lbs/acre of K, much of it being needed during flowering and fruit set, and continuing on into fruit maturation. The amount needed depends on the soil test results. The K:Mg ratio must be maintained at 4:1 to prevent magnesium deficiency, which is quite common in strawberries. Excess K affects Mg availability; recommendations call for providing 10–40 lbs/acre Mg in established plantings that are deficient in magnesium (Carroll et al. 2014). The most common source of Mg currently used to maintain soil Mg concentrations is dolomitic limestone, which contains a significant percentage of Mg, in addition to Ca. Epsom salt, also known as magnesium sulfate ($MgSO_4$), is another way to add Mg to the soil and may also be applied to plants as a foliar spray. Calcium (Ca) levels are usually adequate in the soil if the pH is in the appropriate range (6.0–6.2).

Tennessee soils contain sufficient amounts of phosphorus for good strawberry growth and as long as soil pH is within the 5.5–7.3 range, phosphorus is available for uptake. Supplemental amounts are generally worked into the soil prior to planting (25–30 lbs/acre).

The other important micronutrients for strawberries include boron (B) and zinc (Zn). Although B is often recommended as a nutrient supplement for strawberries, excessive levels can be toxic to the plants. Amounts applied to a field should not exceed one pound of actual boron per acre in any year. Zn is more available to plants under low soil pH; availability may be reduced with heavy applications of lime and/or phosphorus. It is typically applied as part of a fertilizer blend to the soil, or applied as a foliar spray. Elements such as iron, copper, and molybdenum, while still required for good growth, are needed in very small amounts. As soil pH has a strong influence on nutrient availability, it needs to be regularly monitored and adjusted as needed.

Fertilizers in China are mainly divided into 3 categories: (i) organic fertilizers which include animal manure, green manure, and straw and composted manure. (ii) microbial fertilizers which contain microbes that benefit plants, e.g., rhizobium and azotobacteria (Zhang and Yang 2010); and (iii) foliar nutrients such as amino acids, vitamins, sugar, and some trace elements (Liu 2014). Manure and the organic fertilizer may introduce insects, ovums, and weed seeds; therefore, manure must be kept at over 70 °C for over 5 days to kill them (Zhang 2012).

2.6 Weed Control

Weed management during the establishment of strawberry plants can have a major effect on optimal plant growth and yields. During the short-term production cycle of strawberries in Tennessee, it is extremely critical to control weeds within the rows, as weeds compete for water and nutrients and provide alternate hosts for pests. The use of cover crops helps to eliminate or suppress weeds (Sect. 2.3; Table 2.1). The preparation of the soil during the preplanting years also pays dividends by eliminating perennial weeds. Growers in Middle Tennessee occasionally use flame burning (Fig. 2.6a) to control weeds, though Wildung (2000) found that it is not as effective in new plantings as normal cultivation and hand weeding. Therefore, to prevent the weeds from going to seed, producers find manual cultivation to be the best approach. Weeder geese were once commonly used for weed control before the widespread popularity of herbicides. National Organic Program rules state that manure must be incorporated 120 days prior to strawberry harvest, so geese may only be employed to control weeds earlier in the production cycle.

Mulches provide weed control by smothering weed seedlings and blocking light from the soil surface, and preventing the germination of weed seeds. As an added benefit, they help to regulate soil temperature by shading soils in the warm summer months, insulating the soil during cool weather, retaining soil moisture by preventing water losses through evaporation, and protecting the soil from erosion from heavy rains. Mulches commonly used in organic production in Tennessee include straw, hay, sawdust, and wood chips. Some producers choose to use compost, grass clippings, plastic, biodegradable mulch, and landscape fabric as mulches.

Weed management in organic strawberry production can be carried out using commercially available lemongrass oil-based organic herbicides, containing the active ingredient citrus extract *d*-limonene. Rowley et al. (2011) evaluated weed control provided by mulches and organic herbicides alone or in combination and found that organically certified herbicides such as clove oil displayed 41–95 % weed control when applied without mulch. Some mulches and organic herbicide combinations provided weed suppression similar to conventional herbicide application.

For weed control in China, flame burning is done in late autumn prior to strawberry cultivation. After the soil is plowed, the beds are prepared and covered with black plastic to inhibit weed germination and growth; manual weeding must continue as needed (Liu and Zhu 2008). Moreover, as previously mentioned, corn and muskmelon intercropping can also help to control weeds (Table 2.2).

2.7 Insect Control

While appealing to humans, the strawberry fruit is also attractive to pests, rodents, and various fruit insects, and mites. In addition to reducing fruit quality and crop yield, these pests also are potential vectors for pathogens. Bost et al. (2003) listed the following pests commonly encountered in strawberry productions: strawberry crown borer (*Tyloderma fragariae*), strawberry leafroller (*Ancylis comptana fragariae*), strawberry rootworm (*Paria fragariae*), strawberry weevil (clipper) (*Anthonomus signatus*), lygus bugs (*Lygus lineolaris, Lygus Hesperus*), stink bugs (brown: *Euschistus servus*, green: *Acrosternum hilare*), whitefringed beetle (*Naupactus leucoloba*), spittlebugs (*Philaenus spumarius*, *P. leucophthalmus*), aphids (*Chaetosiphon Fragaefolii* and other genera), two-spotted spider mites (*Tetranychus urticae*), cyclamen mites (*Steneotarsonemus pallidus*), sap beetles (*Stelidota geminata*), flea beetles (pale-stripped *Systena balanda* and eggplant flea beetle *Epitrix fuscula*), root weevils (*Otiohynchus* spp.), and potato leafhopper (*Emposasca fabae*). Rhainds et al. (2002) measured the incidence of pests in strawberries under conventional and organic management systems through four fruiting seasons and found that the proportion of fruits damaged by plant bugs was higher in organic than in conventional plots, even higher than incidence of damage by gray mold or slugs.

Integrated pest management (IPM) involves the implementation of preventive practices before planting the crop (Rondon et al. 2003, revised 2009). The grower's first line of defense in a pest management program in organic strawberry production is to select varieties with pest and disease resistance (Wszelaki et al. 2012a, b). Plants must be inspected prior to transplant and only clean non-infested plants should be used. Other control measures include crop monitoring to detect pest presence and activity as well as identification of insects and diseases. The use of sticky traps is very beneficial for trapping of pests such as aphids. They can be used indoors such as in the high tunnels or in the fields hung from fence stakes.

Biological controls are most effective before the pests reach critical levels, so regular monitoring is very important (Guerena and Born 2007). Organic systems rely on populations of beneficial insects (Table 2.6) to maintain a natural balance between pest and predator species. It is possible to eliminate or reduce the use of pesticides on strawberries through early identification of arthropod problems and the use of living agents to suppress or destroy the undesirable pests (Rondon et al. 2003, 2009). Planting habitat for beneficial organisms may encourage populations of the 'good' insects (McWhirt et al. 2015).

Table 2.6 Some of the beneficial insects used in strawberry production

Pests	Biological agents	Common name	Category
Western flower thrips	*Neoseiulus cucumeris* *Orius insidiosus*	Cucumeris Minute pirate bug	Predator Predator
Cotton or melon aphid	*Hippodamia convergens* *Coleomegilla maculata* *Chrysoperla rufilabris* *Aphidius colemani*	Lady beetle Spotted lady beetle Chrysopa- green lacewing Aphidius wasps	Predator Predator Parasitoid Predator
Two-spotted spider mites	*Phytoseiulus persimilis* *Neoseiulus californicus*	Persimilis Californicus	Predator Predator
Caterpillars	*Bacillus thuringiensis* (*Bt*)	Dipel, MVP, MVP II and others	Pathogen derived
Strawberry leafroller (larvae)	*Macrocentrus ancylivrous* *Cremastes cookie*		Parasitoid Parasites
Lygus bugs	*Beauveria bassiana*	BotaniGard ES and Mycotrol O	Fungal pathogen
Cyclamen mites	*Amblyseius*		Mites
Whiteflies	*Beauveria bassiana*	BotaniGard ES, Mycotrol O	Fungal pathogen
White grubs (larvae of scarab beetles)	*Steinernema carpocapsae* *Heterorhabditus bacteriophora*		Nematodes Milky-spore bacteria
Strawberry root weevil	*Steinernema carpocapsae* *Heterorhabditus bacteriophora*		Nematodes Milky-spore bacteria

Modified from Rondon et al. (2003) and Bost et al. (2003)

Organic systems make great use of trap crops and companion planting. The principle of trap cropping is based on the pest's affinity for a particular plant which keeps it away from the main crop, thus eliminating the need to use insecticides (Wzselaki et al. 2012a, b). When designing a strawberry field to incorporate cover crops, it is helpful to know the target insect and its behavior.

There has been considerable interest in the use of certain crops as biological fumigants ahead of crop production to reduce the need for chemical fumigation. Advances in biopesticides with fumigant properties have been stimulated by the phase-out of methyl bromide, which was labeled for use in conventional strawberry production to target multiple pests. Plants in the mustard family, such as mustards, radishes, turnips, rapeseed, and sorghum species (sudangrass, sorghum-sudangrass hybrids), have shown the potential to serve as biological fumigants (see Sect. 2.3; Table 2.1). Plants from the mustard family produce chemicals called glucosinates, which are released from the roots or the foliage when the plant is cut. Glucosinates are further broken down into isothiocyanates that act like chemical fumigants. Sorghum also produces a syanogenic glucoside compound called dhurrin, which releases cyanide when the plant tissue is damaged.

Kirkegaard et al. (1999) identified compounds in Brassica roots and demonstrated their toxicity to fungal inoculum. Results from these agents have, however, been inconsistent in Delaware, often showing minimal benefits (Johnson 2009). Success with biofumigant crops depends on a number of factors. Firstly, using varieties bred for higher levels of active compounds will result in more effective chemical being released; secondly, plant material must be finely chopped and incorporated thoroughly for best results (Johnson 2009). However, even with these existing limitations, incorporating the biomass from the biofumigants adds rich organic matter to the soil. Sams and Kopsell (2011) found beneficial effects of different combinations of mustard meal and compost applications on vegetable production in terms of yield and quality, and protection from early blight. The application also increased the yield of strawberry plants and protected them against Anthracnose.

More recently, anaerobic soil disinfestation (ASD), also known as biological soil disinfestation, has been investigated as a potential fumigation alternative. This is a process whereby anaerobic soil conditions are created by incorporating organic soil amendments (substrate), covering with plastic mulch, and irrigating the soil to saturation for 2–6 weeks. The filling of the soil pores with water causes a reduction in soil oxygen, creating anaerobic conditions (Shrestha et al. 2014). Many soilborne pathogens and nematodes of concern showed susceptibility to ASD treatment. Muramoto et al. (2014) conducted anaerobic soil disinfestation using a range of carbon inputs and in field trials conducted at multiple sites in California and found that using rice bran as the carbon source (substrate) provided yields equivalent to those from preplant fumigation sites.

Insect control in China is primarily physical and biological. Physical control includes the removal of contaminated leaves by hand, trapping and killing using light, use of yellow boards and sex pheromones. Biological control is mainly protecting the predator (Liu and Zhu 2008).

Insect and mite populations vary from field to field and from year to year. When the pest population surpasses the established thresholds, chemical control measures may have to be used. It is still important to use pesticides that are compatible with the biological control agents. The reduction on chemical dependency is good for the environment, safe for people and in general good practice.

2.8 Disease Control

Diseases affecting the strawberry fruit cause a direct loss of the harvested product. A slight blemish by the pathogen can quickly engulf the entire fruit by the time it reaches the market. Anthracnose fruit rot (caused by the fungus *Colletotrichum*) affects not only the fruit, but also many other parts of the plant and may cause severe problems in perennial systems. The United States Department of Agriculture–Agricultural Research Service (USDA-ARS) initiated the development of anthracnose-resistant strawberry cultivars adapted to the southeastern USA in 1976 after an epidemic of anthracnose crown rot and this resulted in the release of 4 anthracnose-resistant breeding lines and one cultivar (Smith 2006).

Gray mold (caused by the fungus *Botrytis cinerea*) is the most commonly observed fruit contaminate in the market. Fuzzy brown to gray spores develop and cause fruit to rot. The gray mold fungus develops on dead plant material and is readily airborne. Local varieties such as 'Earliglow' and 'Delmarvel' are resistant to the gray mold. Leather rot (caused by *Phytophthora cactorum*) is not as devastating as the other two, but can be of concern in areas of poor drainage. Berries infested with leather rot appear normal, but have a sour odor and an unpleasant taste (Bost et al. 2003).

Good Agricultural Practices (GAP) demands that growers make smart choices for disease management. Planting disease-resistant varieties or less susceptible varieties will eliminate or greatly reduce the need for disease control. The first vulnerable area is the transplant nurseries, so disease-free healthy plants should be purchased from reputed nurseries that follow good propagation and cultural practices. Healthy soil with adequate organic matter will help maintain beneficial organisms that may suppress soilborne pathogens (Guerena and Born 2007). Other cultural controls include picking fruit frequently and removing infected fruits since pickers handling infected berries can spread the infection to healthy berries. If disease is spotted, sprinklers should be used only for frost protection, not for irrigation. Care must be taken to ensure that there is good air movement, proper drainage and no water retention between rows.

Field sanitation practices include removal, burning, or deep cultivation of crop residues to help prevent the spread of disease in a field. Diseased plant material can also be tilled into the soil to prevent the spread of spores in the wind and to hasten the breakdown of the disease pathogens by beneficial fungi, nematodes, and bacteria. It is good practice to remove winter-killed foliage before bloom, to eliminate a food base for fungi, and also to properly clean-up the matted rows after harvest. Additional sanitation practices include removing weedy habitat that may shelter pests and cleaning equipment to prevent the spread of disease or weed seed from field to field. Good sanitation practices can go a long way in preventing pest problems in organic strawberry production. However, practices such as deep plowing and burning may cause erosion, decrease soil organic matter, and reduce biodiversity. Therefore, these practices should be used with caution on a limited basis.

As discussed in Sect. 2.3, the use of biofumigant cover crops such as *brassica* can encourage beneficial soil microbes and help control insects and diseases. Pinkerton et al. (2002) demonstrated the potential of solarization in management of root diseases in strawberry production in hot and dry areas. Heat trapped under the clear plastic mulch, laid on moist soil, raises the soil temperature, and kills pests. Welke et al. (2004) reported a reduction in the incidences of *Botrytis* with the foliar application of aerobically prepared compost tea. Serenade, Mycostop, and Promot are some of the biorational products available commercially for *Botrytis* control (Guerena and Born 2007). If pesticide applications are needed prior to bloom, it is better to stick with biologicals (Table 2.7). Sprays should be used strategically and sparingly; 50 % of the applications are unnecessary (Schnabel and Peres 2015). Integrated pest management and weed control techniques can greatly reduce pesticide use in strawberry production.

Leaf diseases appearing on strawberries can cause significant damage to the plant causing it to be more susceptible to winter injury. Leaf blight, common leaf spot, and leaf scorch are caused by fungi and are best controlled by following the cultural practices described above. Angular leaf spot, caused by a bacterium, caused major problems in Tennessee strawberry production in the 1990s (Bost et al. 2003).

Table 2.7 Biological pesticides used for disease control in strawberries

Trade name	Active ingredient	Product rate	Type of control	Comments
Regalia Biofungicide	*Reynoutria sachalinensis*	1–3 qts/acre	Leaf blight, leaf spot, gray mold, anthracnose, red stele, black root rot, verticillium wilt	Start at first sign, then every 7–14 days
Actinovate-AG	*Streptomyces lydicus* WYEC-108	3–12 oz/acre	Powdery mildew, gray mold, anthracnose, leather rot, red stele, black root rot, verticillium wilt	Foliar application, apply before onset of disease, reapply at 7–14 day intervals
Double Nickel 55	*Bacillus amyloliquefaciens* str. D747	0.25–3 lb/acre	Powdery mildew, gray mold, anthracnose, leather rot, red stele, black root rot, angular leaf spot, verticillium wilt	Foliar application
Double Nickel LC	*Bacillus amyloliquefaciens* str. D747	0.5–6 qt/acre	Powdery mildew, gray mold, anthracnose, leather rot, red stele, black root rot, angular leaf spot, verticillium wilt	Foliar application

Carroll et al. (2014)

This disease is difficult to treat and prevention is still the best means of control. Red stele and Phytophthora crown rot are most often found in poorly drained areas of the field. Most current varieties are resistant to red stele, but none are known to be resistant to Phytophthora crown rot. Elemental copper and sulfur have been used by conventional and organic growers as pesticides for foliar bacterial diseases and powdery mildew, respectively (Guerena and Born 2007). A commercial formulation of *Bacillus pumilis* has been approved by OMRI (Organic Materials Review Institute) for the control of powdery mildew in strawberries. Table 2.8 lists some of

Table 2.8 Pesticides labeled for disease management in strawberries in Tennessee

Trade name	Active ingredient	Product rate	Type of control	Comments
Badge X2	Copper hydroxide, copper oxychloride	0.75–1.25 lb/acre	Leaf blight, leaf scorch, leaf spot, angular leaf spot	
Champ WG	Copper hydroxide	2–3 lb/acre	Leaf blight, leaf spot, angular leaf spot	May cause crop injury under certain conditions
CS 2005	Copper sulfate pentahydrate	19.2–25.6 oz/acre	Leaf blight, leaf Scorch, leaf spot	
Cueva Fungicide Concentrate	Copper octanoate	0.5–2.0 gal/ 100 gal	Leaf blight, leaf scorch, leaf spot, powdery mildew, gray mold, anthracnose, angular leaf spot	Applied as a diluted spray at 50–100 gal/A
Milstop	Potassium bicarbonate	2–5 lb/acre	Leaf blight, powdery mildew, gray mold, anthracnose	Not compatible with alkaline solutions
NuCop 50DF	Copper hydroxide	2–3 lb/acre	Leaf blight, leaf spot	Discontinue if phytotoxic
OxiDate 2.0	Hydrogen dioxide Peroxyacetic acid	32 floz-1 gal/100 gal water	Leaf blight, powdery mildew, gray mold, angular leaf spot	At planting and existing planting foliar application
PERpose Plus	Hydrogen peroxide/dioxide	1 fl oz/gal initial/curative 0.25–0.33 fl oz/gal weekly/ preventative	Leaf blight, leaf spot, powdery mildew, gray mold, anthracnose, leather rot, red stele, black root rot, angular leaf spot, verticillium wilt	Curative for 1–3 consecutive days Preventative every 5–7 days
Trilogy	Neem oil	0.5–1 % solution	Leaf blight, leaf spot, powdery mildew, gray mold, anthracnose, angular leaf spot	Apply in 25–100 gal water/A

Carroll et al. (2014)

the pesticides used in Tennessee to manage a broad spectrum of diseases in strawberries. The selection of disease-resistant varieties (Table 2.3) will minimize losses due to plant damage. There is effort placed in producing more disease-resistant varieties, but currently there are no major marketable varieties available with high levels of resistance to multiple pathogens (Mossler 2004).

The main strawberry diseases in China are white leaf spot, powdery mildew, and nematodes. In the early stage of white leaf spot of strawberry, peptaibol biological bactericide (200–300×) is used, but stopped 3 days before harvesting. For powdery mildew, the infected leaves and fruits are removed in the early morning. Eguenol (600×), a mixture of terramycin and streptomycin, is used to control the disease. Treating plants in hot water (35 ^{o}C and 45 ^{o}C each for 10 min) significantly reduced nematode population (Liu 2014).

2.9 Harvest and Postharvest Handling

In the State of Tennessee, harvest from plasticulture production systems typically begins during the third week of April to second week of June and matted row begins the second week of May and extends through mid-June. Harvest may be advanced by 1–2 weeks by the use of mulch covers and row covers. Strawberries are hand-picked in April–early June. Since the quality of strawberries does not improve after harvest, it is advisable to only pick fully colored strawberries at the peak of flavor; the fruit shoulders and tip should not be green or white (Wright 2012). The fruit must be firm and free from rot. When harvested at the right time and handled properly, strawberries remain in good condition for up to five days, in terms of appearance and taste. Strawberries are extremely perishable and have unusually demanding postharvest handling requirements. Proper handling will ensure the relative longevity of the fruit. Pelayo et al. (2003) found that the 3 strawberry cultivars that they investigated had a postharvest life (based on appearance) of 7–9 days when stored at 5 °C. However, the maximum period of storage during which the fruit maintained a flavor profile similar to freshly harvested fruit was shorter (5 vs. 7 days) for 'Diamante' and 'Aromas' and remained the same (9 days) for cultivar 'Selva.'

Strawberries remain alive and produce heat as a natural consequence of respiration even after they are harvested (Boyette et al. 1914). Fruits must be chilled rapidly by forced-air cooling (to 40 °F) within an hour of picking to remove the field heat and increase shelf life and must not be allowed to rewarm. Most strawberry producers pick the fruit early in the day, while temperatures are cool. This makes a significant difference in the shelf life of the berries, when combined with the postharvest cooling. This also keeps the fruit rots from developing or they develop more slowly. As the time difference between harvesting and cooling lengthens, more berries are lost to deterioration. Growers using the Pick-Your-Own (PYO) method of distribution do not need to be concerned about handling and storage since these are performed by the consumers. If they use other markets, such as grocery stores, restaurants and farmers' markets, they do need to maintain the quality of the product after harvesting with the right cooling, handling, and storage methods.

In China, strawberries are hand-picked when their surface is 70 % red. Picking is usually done at early morning and late afternoon to keep the fruit fresh, and picked fruits are cooled with wind (1 h at 1 °C after picking), then stored at low temperature till marketing.

2.10 Economics and Marketing

Strawberries, especially organic, are a high-value crop with special production requirements. They are highly perishable and time sensitive. The brief marketing season is very intense. So it makes sense to maximize the profit potentials. The initial investments in preparing the land, irrigation costs, and other equipment can range from about $2,000 per acre (for matted-row system) to $10,000 (for plasticulture systems). The yields obtained with plasticulture are almost double that of matted-row system and the harvest season is extended. The earlier harvest allows producers to receive higher 'beginning of season' prices. Since their production costs are higher, the berries must be sold at a premium in order to make a profit. In areas where the local market demand is fairly strong, prices tend to be higher (Guerena and Born 2007). Strawberry growers who sell direct to customers have great control over price, so usually they can set the price sufficiently high to make a profit. Consumers who are willing to pay higher prices for locally produced foods place importance on product quality, nutritional value, methods of raising a product and the effect of those methods on the environment, and support for local farmers (Martinez et al. 2010). Prices for fresh-market strawberries have been stable in recent years because of demand. With current yields and prices, strawberries continue to be a profitable crop to grow.

Organic strawberry growers support the idea of long-term land stewardship. However, they often choose production practices based on costs and yield potentials. Research has shown a direct link between incorporation of a practice and increases in strawberry yields, some resulting in immediate benefits, while others can result in yield benefits in the long run. The extension agents in the state provide support and resources for those who are currently farming and those who want to transition into organic production of this potentially lucrative specialty crop.

The organic strawberry market is seeing exponential growth. The number of organic strawberry growers continues to grow, with 160 registered with the California Organic Program as of 2004. Organic strawberries now rank sixth among all California organic fresh commodities. Even with growers in California, Florida, Oregon, and Washington producing 95 % of reported US output, there is immense opportunity for local growers to tap into the remaining 5 % of the market share. Growers outside the western USA will likely be called upon to offset shortages of strawberries caused due to the severe drought that has plagued California since 2013.

The surge in popularity of farmers' markets, and the CSAs (Community Supported Agriculture) is seeing an unprecedented growth. In 2009, USDA launched the 'Know Your Farmer, Know Your Food' initiative, an agency-wide effort to create new economic opportunities by better connecting consumers with local producers. The Tennessee Department of Agriculture started the 'Pick Tennessee Products' campaign in 1986 to encourage consumers to buy products grown or manufactured in the state. Their Web site maintains an active directory of farmers/producers who sell their products at farmers' markets, online, on the farm, or are strictly pick-your-own operations such as the strawberries growers. Recent studies show that more Tennessee farmers are selling directly to consumers. For smaller farms, direct marketing to consumers accounts for a higher percentage of their sales than for larger farms (Martinez et al. 2010).

Consumers want to know where their food is coming from. This has opened up the opportunity for the relatively small-scale producers who have had to contend with severe competition from the large companies. When it comes to perishable produce like strawberries, this gives the farmers a larger share of the local sales. In most locations, demand for locally produced strawberries exceeds the available supplies. Small-scale producers can thus receive higher returns from strawberries than from most other crops. Promoting local organic strawberry production means better access for shoppers to quality strawberries and better profitability for the farmers growing the crops. To avoid spoilage during shipping, most California and Florida grown strawberries are harvested before they are fully ripe. They cannot compete with the locally produced tasty and fresh berries which are picked at ripeness for the local market.

Assessment of the strawberry market potential in the area and the possible methods of marketing the fruit is a critical first step in the successful management of any strawberry farm (Himelrick et al. 2002). Most small farmers find great success from direct marketing through roadside farm stands and PYO operations. Bringing people to the farm for 'u-pick events' results in greater profits. In North Carolina, majority of the strawberry production is marketed toward u-pick customers (McWhirt et al. 2015). In recent years, more producers have been offering pre-picked strawberries for sale instead of PYO to maximize their profits. Other direct and niche marketing strategies can boost profits. The 'farm to table' concept, which is pushing more specialty restaurants to either partner with or buy locally grown foods directly from the producer, is proving to be another important channel for small strawberry growers. These types of restaurants typically open in places where consumers are highly supportive of the local foods movement (Martinez et al. 2010). Small, independent grocery retailers are better positioned to offer local food as they develop a strong relationship with local farmers and prefer products that have traveled a short distance.

2.11 Market Demand for Desirable Properties

Consumers, producers, and distributors all agree that freshness, good shelf life, and firmness are largely what determine the quality of strawberries. Consumers and retailers also attach importance to taste, while yields are important to the growers. Several studies, both national and on a smaller scale, have explored consumer preferences for locally produced food. In recent decades, public health promotion of healthier lifestyles has led to increased demand for fresh produce in many industrialized nations. The sustainability of the strawberry industry depends on its ability to satisfy the changing demands of its customers. So it is important for the producers to know their target audience, to explore consumers' preferences toward different sources of strawberries, specifically store-bought, industrially grown strawberries and locally grown, farm raised strawberries. In addition to raising awareness about the local production, it also helps in gathering public opinion. Surveys conducted on the campus of Tennessee State University and during the 2014 Middle Tennessee Strawberry Festival held in Portland revealed consumer preferences when it comes to choosing between organic vs. non-organic strawberries (Fig. 2.7). Five locally grown varieties were subjected to a blind taste test. Nine quality attributes were evaluated: color, freshness, size, appearance, smell, firmness, sweetness, juiciness, and overall quality. Locally grown and store-bought strawberries were judged to have similar appearance and firmness. Though the store-bought strawberries had a slight edge in terms of their size and color, the local varieties were picked for freshness, smell, sweetness, juiciness, and overall quality. Respondents rated the local strawberries as 'excellent' as compared to the store purchased ones which were rated 'very good.' People were willing to pay 33 % more for the local berries. 'Albion' was the most favored cultivar for color, size,

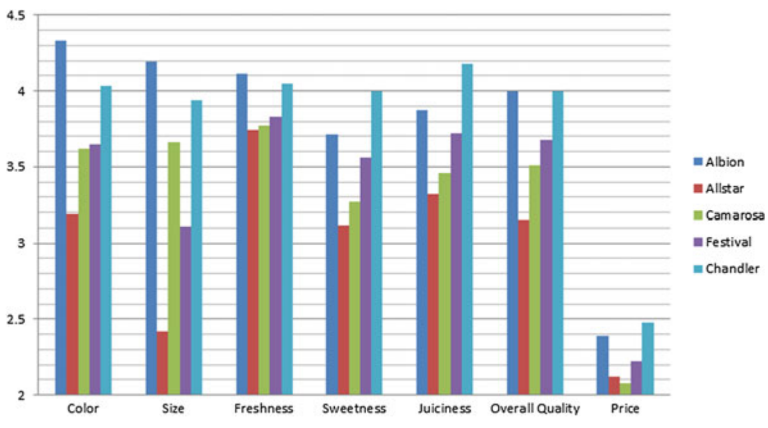

Fig. 2.7 Consumer preference of local varieties based on various attributes. Data from a Consumer Preference Survey conducted at Tennessee State University in Nashville (May 2014)

and freshness. ‘Chandler’ ranked number one in sweetness and juiciness. Both ‘Albion’ and ‘Chandler’ ranked highest for overall quality.

In China, size, color, and sweetness are preferred, as evidenced from the popularity of ‘Confidante.’

2.12 Current Constraints and Future Potentials

While there continues to be a demand for locally produced organic berries, there are particular challenges related to growing strawberries in Tennessee. Many farms currently producing strawberries throughout the southeast have converted from intensive tobacco production to intensive strawberry production (McWhirt et al. 2015). This practice of using a single plot of land for annual production leads to a decline in nutrients and soil organic matter. Each year, plants are replanted in the same location, possibly due to land availability issues. Due to a lack of crop rotation, insect and pathogen populations increase, often resulting in an increased need for chemical inputs, whence destroying helpful biological life that contributes to soil health. The long-term viability of strawberry production needs to be maintained. Production systems must incorporate practices that not only improve the short-term productivity of the land but also contribute to long-term land stewardship (McWhirt et al. 2015).

The National Strawberry Sustainability Initiative administered by the University of Arkansas and funded by a grant from the Walmart Foundation has been supporting research at land-grant public universities across the country to study sustainable strawberry production that will benefit not only consumers, but also provide an economic boost for local farmers, from the production level through the supply chain to the market and finally to the consumer. Tennessee State University (Nashville) and the University of Tennessee (Knoxville) have strong agricultural research programs to solve problems facing farmers. The aim of research conducted is to expand the areas where crops such as strawberries can be grown, enabling shorter trips for the berries between farm and consumer. This helps provide the much needed boost for organic strawberry research to address critical issues facing the marketability of fresh strawberries. The county extension agents at these universities seek to move the science and technology developed in laboratories and experimental farms into the producers’ fields.

In China, there is a need for virus-free strawberry nurseries to be established for providing growers with healthy plant varieties of excellent quality, high productivity, and strong stress resistance. Different cultivation procedures and protocols have to be established and standardized for major varieties, cultivation systems, and control of pests and diseases to further improve berry quality and yield.

2.13 Food Safety Concerns

Changing population structures and demographics along with a growing awareness of food safety issues have created a market for fresh strawberries that are free of microbial contamination, particularly those organisms that are known to cause diseases in humans. The increased consumption of fresh strawberries brings an higher risk of foodborne illnesses. Strawberries have been the culprit in numerous outbreaks of *Salmonella*, hepatitis A, norovirus, and *E. coli O157:H7* (Palumbo et al. 2013). An *E. coli* O157:H7 outbreak in 2011 occurring in Oregon resulted in 15 illnesses and two deaths (Palumbo et al. 2013). It was the first reported instance in which strawberries contaminated by deer feces were associated with an *E. coli* outbreak (Laidler et al. 2013). Ensuring the safety of fresh strawberry crop is of prime importance as every incidence of illness resulting from fresh fruits and vegetables contaminated with pathogenic microbes erodes consumer confidence and results in significant losses to the growers and retailers. The use of sanitizing solutions or vigorous washing is not possible for strawberries without causing mechanical damage to the delicate structure of the berries. Providing specific guidance and strategies to minimize potential contamination is important for all parties engaged in the production, marketing, and consumption aspects of the industry.

Consumers of fresh produce are always concerned about microbial populations whether organic or non-organic. A recent study on fresh produce-associated bacteria found that fruits and vegetables harbor diverse bacterial communities. Bacterial population from organically-grown produce is less complex than inorganic analogs. Thus, consumers are exposed to substantially different bacteria when eating conventionally and organically farmed varieties (Leff and Fierer 2013).

In March 2015, the North Carolina Strawberry Association along with North Carolina State University offered a workshop to provide farmers with strawberry-specific tools needed to identify potential food safety concerns. Strategies are needed to minimize potential contamination. Zhou and her group at Tennessee State University have developed an easy to use tool (dip-stick assay) to rapidly and reliably detect the presence of human pathogens on fresh strawberries, thus providing a guarantee on the safety of the produce. Gazula et al. (2014) studied the survival analysis and detection of pathogens (*Salmonella typhimurium, Listeria monocytogenes and Escherichia coli*) on mature strawberries from participating farms as part of a project conducted at Tennessee State University in Nashville and funded by the National Strawberry Sustainability Initiative (2013–2014). Results showed that the surface of strawberries did not support the growth of these pathogens (Unpublished data) suggesting that harvesting of strawberries following good agricultural practices reduces the risk of contamination. Having a science-based strategy and providing specific guidance on how to manage microbial contamination are very important for all parties engaged in the production, marketing, and consumption aspects of the industry. It eliminates the risk of foodborne diseases and the financial loss due to recall of contaminated foods.

2.14 Conclusion

Consumer preference for purchasing organic fresh strawberries is a growing trend in the fresh strawberry market. Therefore, it is highly desirable to develop an organic strawberry production system in Tennessee and neighboring states in the US, as well as in China as the living standard of the citizen continures to improve. The unique characteristics inherent to strawberry farming such as ability to harvest a high-yield crop on a small amount of land and heavy consumer demand support an environment for small farmers to operate successful businesses. Based on an assessment of available information, we have identified potential problems and possible solutions that will support the establishment of a sustainable strawberry industry, especially as an alternative crop for small farmers.

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