An Introductory Guide to Strawberry Plasticulture

E. Barclay Poling
Professor and Extension Specialist (Small Fruits)
Department of Horticultural Science, NC State

Section 1. Introduction

Strawberries are one of the most economically important fruit crops in North Carolina and throughout the Southeast. In 2001, North Carolina led the Mid-South region with an estimated 1800 acres, followed by Arkansas (500 A) and Virginia (500 A), South Carolina (400 A), Tennessee (350 A), and Alabama (240 A) (Table 1).

Table 1. Strawberry Production (Thou. Acres)

Year	NC	VA	TN	SC	GA	AR	AL	Totals
2001	1.80	0.50	0.35	0.40	0.25	0.50	0.24	4.04
2000	1.70	0.50	0.30	0.40	0.20	0.40	0.23	3.73
1999	1.70	0.45	0.30	0.35	0.20	0.21	0.25	3.46
1998	1.60	0.40	0.15	0.35	0.20	0.18	0.22	3.10
1997	1.50	0.40	0.10	0.36	0.20	0.21	0.18	2.95

The 4,040-acre strawberry plasticulture industry represented by these seven southeastern states is highly de-centralized and almost entirely based on small family farm units producing several acres of berry production for direct marketing (U-pick, ready-pick, roadside stands, and farmers markets). The main harvest months for this region are April and May, but coastal regions in Georgia and South Carolina have production beginning in early to mid-March in most years.

The primary purpose of this guide to give an overview of the "Strawberry Plasticulture Production System" that is now the main commercial growing system for North Carolina and other states in the Mid-South. "Strawberry Plasticulture" is technically the annual hill training system in which "green" strawberry transplants (fresh dug plants or plugs) are planted in early fall in double rows at densities of approximately 15,000 to 17,500 plants/acre on methyl bromide fumigated, raised beds that are covered with black plastic mulch. It is a relatively recent production technology for our region as it was only first introduced to the Mid-South by researchers at NC State University in the early 1980s. Strawberry plasticulture has now virtually replaced the older "matted row" system in our seven-state region. A single acre of strawberry plasticulture can be 2 ½ times as productive as an acre of bare-ground matted-row production, but, it is also a production system that is far more management-intensive than matted-row. There is considerably less margin for error in regards to soil, crop, pest, frost/freeze and market management decisions and operations.

Figure 1. Sandy loam and clay loam soils are ideal for building and shaping the 8 – to 10- inch raised beds that are a critical component to success in the *strawberry plasticulture system.* The raised beds are 8-10 in high, and 28 – 30 in wide at the base. These beds are fumigated 2-3 weeks prior to transplanting with Methyl Bromide:Chloropicrin (67:33) at 200 lb/A in-the-row (shank injection). As the fumigant is injected, the beds are immediately "tarped" with an *embossed* 1 mil black plastic mulch film that can be "stretched" by the mulch laying/fumigation unit to give an extra tight fit over the bed. The black plastic film needs to be in direct contact with the soil (for maximum soil warming to occur in the late fall and winter months). If there are "air pockets" between the film and the soil, the black plastic will actually serve to cool the soil, and plant top-growth and root development will be significantly reduced.

In the strawberry plasticulture system berries can be harvested in just 7 to 8 months after planting in the early fall. Following harvest (early to mid-June), the strawberry plants are destroyed due to the high risk of infection with anthracnose fruit rot (*Colletotrichum acutatum*) in second-year beds. The plastic beds are sometimes re-utilized for summer/fall vegetable crops, and these crops also would benefit from pre-plant fumigation with methyl bromide for strawberries.

Yields of approximately 10 tons per acre (20,000 lbs) can be realized in this region in good weather years with "plastic mulch culture system" that involves preplant shank application of methyl bromide + chloropicrin (67% + 33%) at 200 lb/acre formulation (Fig. 1). Production costs for the system are approximately $10,000/acre (See Section on Economics). Assuming an average price of $1.03/lb (this is a blended price based on 12,000 lb/A of fruit being sold pick-your-own at $0.95/lb, and 8,000 lb/A of fruit being sold Ready-Pick at $1.15/lb), a grower producing 20,000 lb/A can potentially gross $20,600/A. Because the establishment costs for the plasticulture system are quite high, it is vital for growers to achieve yields of at least 15,000 – 18,000 lb/acre to be profitable. This works out to a minimum yield of 1 – 1.2 lb per plant (assuming 15,000 plants/acre).

There is a relatively high level of risk associated with strawberry plasticulture production – erratic weather patterns in some years (e.g. early spring heat wave in April 2002) as well as unpredictable nursery plant quality (the main concern is with anthracnose infection) can dramatically reduce marketable yields and profit potential.

Most growers in our region do not qualify for any form of crop insurance to protect against losses associated with events such as the heat wave in mid-April 2002 that scorched the crops of growers in North Carolina's Coastal Plain and Sandhills (http://intra.ces.ncsu.edu/depts/hort/berrydoc/may12/index.htm). A positive factor in our region is the increasing demand for locally grown, farm fresh strawberries. The real challenge for the strawberry producer is to try to be consistent in his/her production from one year to the next.

Important trends:

In the last few years there have been several developments in the strawberry plasticulture industry that have caused considerable concern. New and potential growers need to be aware of these problems:

1. Highly erratic weather patterns, such as the fall-winter-spring in 2001 and 2002.
2. Difficulties with harvest of Chandler strawberry were encountered in both the 2001 and 2002 spring season – the main problem was the extremely concentrated crop that made it very difficult to locate enough pickers and markets during the peak production period.
3. Pick-Your-Own markets are declining as more customers demand Ready-Pick. Prospective growers need to plan for an adequate labor supply to pick these berries.
4. Increasing problems with anthracnose in plant supplies. The best way to minimize this problem is to use plants from an anthracnose free nursery.
5. Impending cancellation of methyl bromide in 2005 – this fumigant is used by nearly 100% of all commercial strawberry plasticulture in the Mid-South.

Fig. 2. Increasingly erratic weather patterns have caused many producers to make a fairly expensive investment in row covers for additional protection against advective freezes as well for added floral development in colder than normal falls.

Section 2 – Annual Hill Culture

As stated in the introductory section, *strawberry plasticulture* is technically the annual hill training system. The term *hill culture* refers to a type of strawberry training system where the runners are either manually or mechanically removed (in summer), or don't develop at all (fall-winter season). It is a training system that allows only for the growth and development of the mother plant. Hill system transplants are normally set in double rows with plants spaced 12-14 inches in-the-row by 12-14 inches between the row – this is variety-dependent as some varieties like Sweet Charlie benefit from closer spacing than more vigorous varieties like Chandler. Plants are normally set in a staggered pattern (alternate) with the adjacent row as indicated by the illustration in Fig. 3-H. The training systems shown in Figs. 3-D and 3-E are modifications of the older matted row system where mother plants are set in the early spring and allowed to "runner". In contrast, any runners that form in the hill system are removed. In actuality, by the time growers in the southeastern Coastal Plain plant in mid-October, there is no runnering at all.

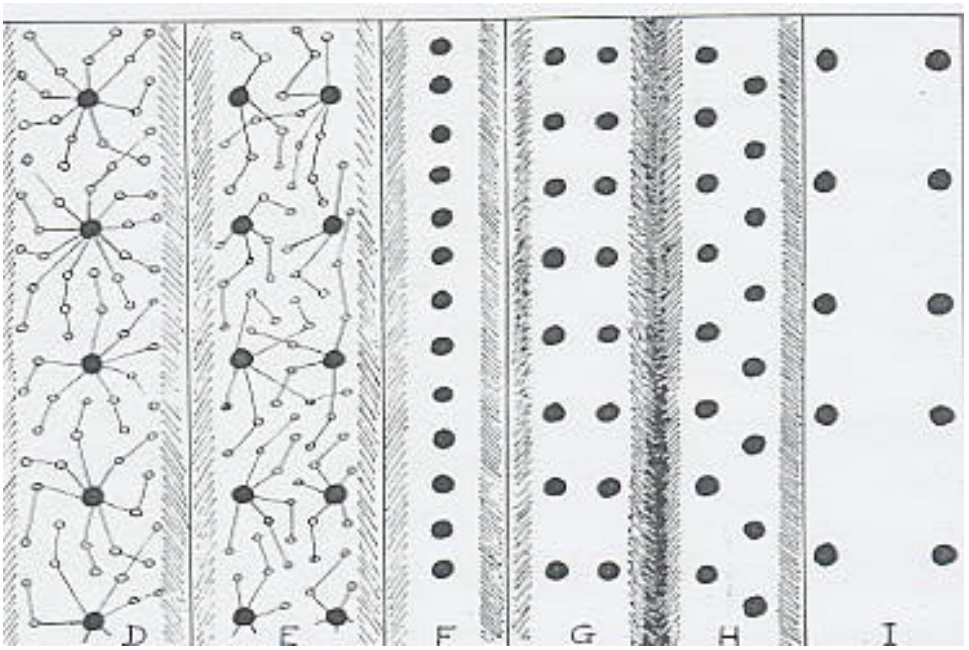

Fig. 3. Systems of training strawberries: D. Spaced Row (allows daughter plant development with mother plants set in center); E. Spaced Row (mother plants set near edge of raised bed); F. Single Row Hills; G. Double-Row Hills (opposite); H. Double-Row Hills (alternate); I. Stool Hills (Older European System).

We attach the word ***annual*** to ***hill culture*** to describe a training system where new strawberry plants are set out *each year* for fruit production as opposed to training systems that take advantage of the perennial growth habit of the strawberry (e.g. matted row, spaced row, and ribbon row). The first and perhaps most important principle of annual hill can simply be stated as follows: *Achieving large fruit size and excellent quality on a regular basis can only be achieved with first-year plants*. If you carry over a first-year planting, be prepared for smaller berries that are much more time-consuming to

harvest. In a second or third year bed there is no practicable way to control plant density. And, without that control, you cannot regulate fruit size. *The best "grower control" for optimizing fruit quality and size is to stick with the younger first-year plants.*

Raised beds are another crucial "ingredient" to success with the *strawberry plasticulture system.* In reality, most of the strawberry beds in North Carolina are 10-inch high "super beds" (not 12-inch as shown in Fig. 4), and the 10-inch high beds are typically 32 inches wide at the base and 30 inches wide on the top. The beds are slightly crowned so water will run off and not rest on the plastic (a bed with a 30-inch top should slope from the center to the edge with a drop of 1.25 inches). Beds are on 5-ft centers in North Carolina (not 52-inch as shown in Fig. 3). There are 8,712 linear ft of row per acre with the 5 ft center. Most growers use either a 54-inch or 60-inch wide plastic film roll.

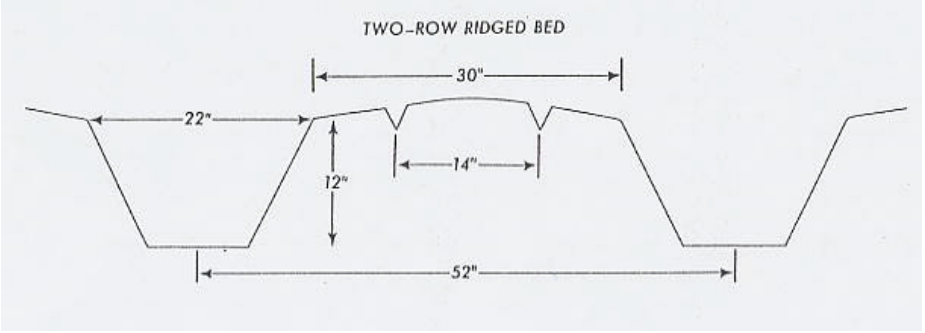

Fig. 4. Schematic of older two-row ridged bed used in California.

Fig. 5. A North Carolina raised bed covered with embossed black plastic mulch – 5 ft centers.

The "super-beds" provide a nearly ideal air-soil-water environment for vigorous strawberry root development. The beneficial effect of these beds on root growth is easily observed by excavating the soil beneath the plastic mulch film at the end of the season. George Darrow (1966) also identified the importance of raised beds for healthy root development:

> "Roots of the strawberry grow chiefly downward in well-drained sandy soils and a few roots maybe found as deep as 24 inches. In clay soils they spread more horizontally. In late fall when the water table rises and the oxygen in the deeper layers becomes low, root growth is shallow. *The oxygen content of the air in the soil where root growth is active is nearly that of the air above the soil,* but where soil is water, it may be as little as 1/10,000 the normal."

Black plastic. Late fall and early winter field conditions in North Carolina and the mid-South are actually *too cold* for the strawberry annual hill, raised bed system to be economical without the addition of *black plastic mulch*. The black plastic film must be in direct contact with the soil beneath to achieve the desired soil-warming effect needed for rapid plant establishment in the fall. With the plastic mulch, heat does not radiate so rapidly off the soil under the plastic, so that with several degrees warmer soil for several months, more extensive root and crown development occurs.

With the addition of raised beds and black plastic mulch to the total package, you can better see why the name ***strawberry plasticulture***, is preferred to the *annual hill, raised bed, black plastic mulch system*!

Section 3. Strawberry Plant Structure and Growth Habit

The strawberry plant has a short thickened stem (called a "crown") which has a growing point at the upper end and which forms roots at its base (Fig. 6). New leaves and flower clusters emerge from "fleshy buds" in the crown in the early spring. From a cultural viewpoint, it is desirable in our region to have the formation of 1-2 "side stems" called **branch crowns** form during the late fall (Fig. 7). Each branch crown will add to the yield of the main crown by producing its own "flower cluster" or what is technically called an *inflorescence*. Branch crowns and main crowns are structurally identical, and an inflorescence develops at the terminal growing point of each crown (Fig. 8).

Crown growth and development occur when temperatures are above 50^{o} F (mainly in the month of October). Average daily temperatures in November below this temperature will slow branch crown formation and floral development. Row covers may be a good option in November for Camarosa to help stimulate further reproductive development. A well-balanced Camarosa strawberry plant will form 3-5 branch crowns by the time fruiting season begins in the spring.

There is excellent potential for a 2^{+} lb crop per plant (> 15 tons per acre) when you can see the formation of 1-2 side crowns in addition to the main crown (center) in late fall/early winter (Fig. 7). In Chandler and Camarosa it is critical *not to plant too early in the fall* and run the risk of having too many crowns form (try to avoid the development of more than 6 crowns per plant). There is an important "balance" to keep in mind when growing strawberries on plastic, and this has to do with managing to get

enough plant growth for adequate cropping (minimum of 3-4 crowns per plant), but if you go to the other extreme (> 6 crowns) fruit size will potentially *decrease* to the point where small fruit size becomes a marketing problem. Significant fruit size depression occurs on 8-10 crown plants.

When planting in the fall it is important to set the plants so that the **midpoint of the crown is level with the soil surface.** If the plant is set too deep, the plant may die as the "growing point" (at the tip of the crown) may have been covered in soil. If the plant is set too shallow, the root system of a bare-root fresh dug plant will be exposed.

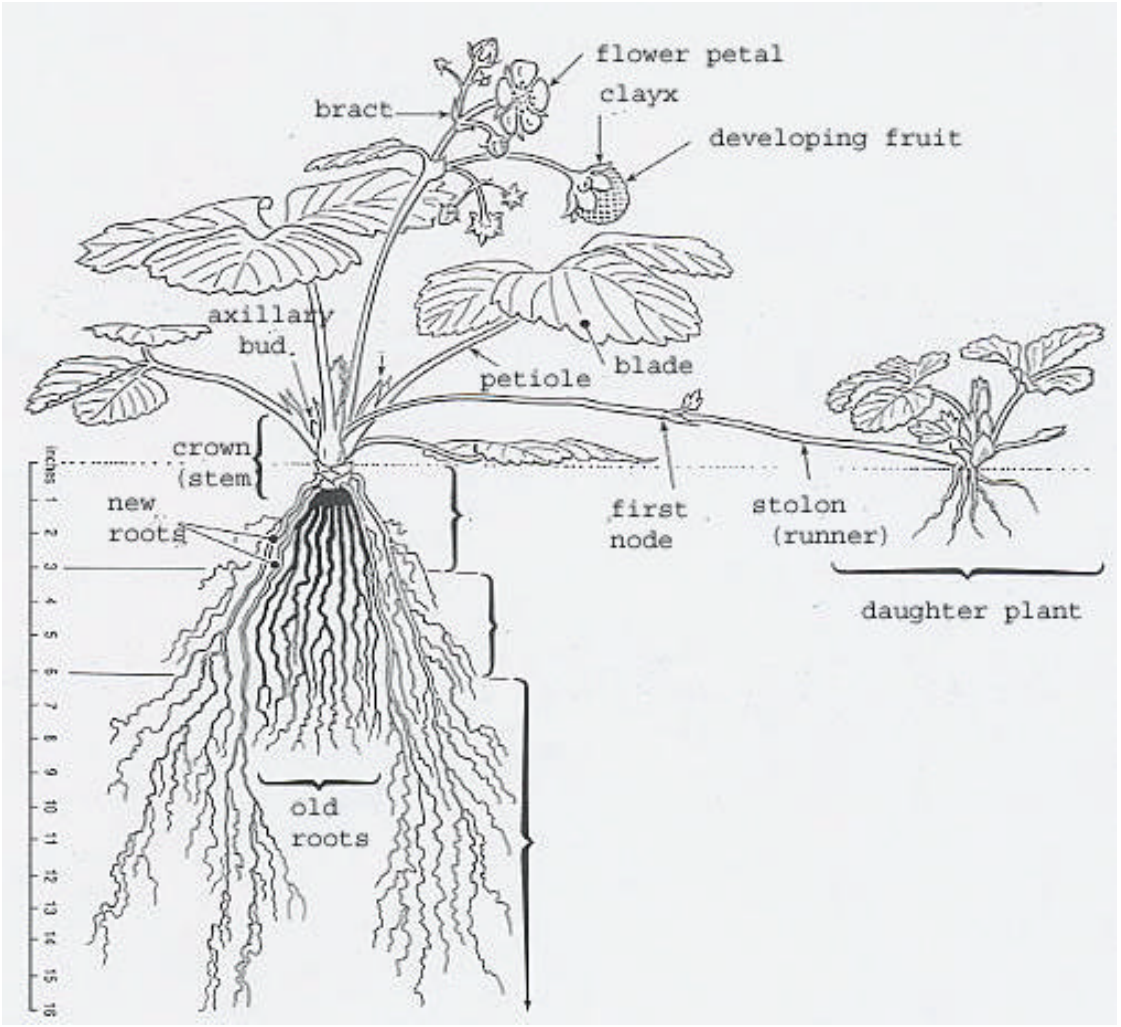

Fig. 6. Strawberry Plant Structure (from Integrated Pest Management for Strawberries, Publication 3351, Univ. Calif., 1994).

Fig. 7. The "growing point" of the strawberry (center). Note the new side stem, or branch crown, that has begun to form in late December (24-Dec-02, Clayton).

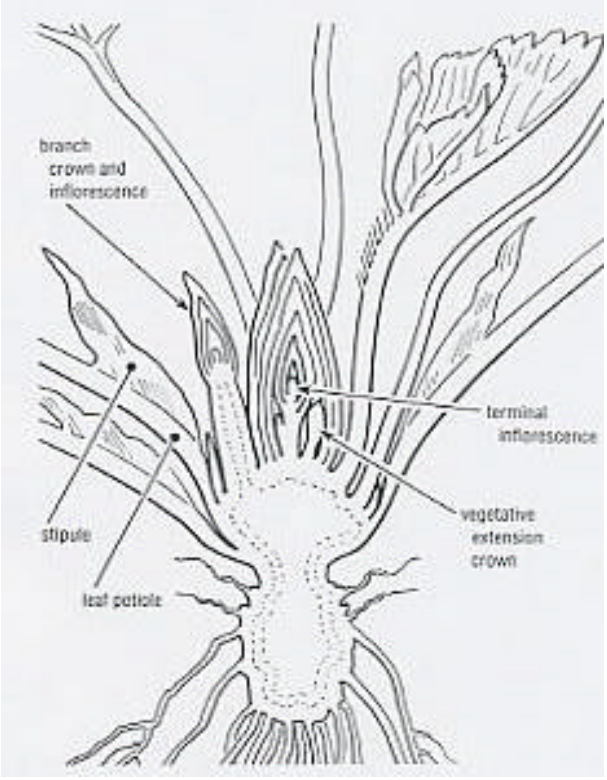

Fig. 8. The crown of the strawberry plant (from Integrated Pest Management for Strawberries, Publication 3351, Univ. Calif., 1994).

Leaves. The leaves are borne along the crown on petioles (leafstalks) arranged in spiral fashion around the crown. Strawberries have compound leaves in which the blade (flattened part of the leaf) is divided into 3 separate leaflets, called a "trifoliate" (Fig. 9). The strawberry leaf captures light, the source of energy used by plants for food

manufacture in photosynthesis. This process requires water and carbon dioxide and involves the movement (translocation) of metabolic products (sugars) from sites of manufacture (in the leaves) to sites of utilization or storage. Sugars are translocated to maturing fruits and other parts of the plant to sustain growth. Late in the fall, sugar is converted to starch in root tissue for winter storage. The number of leaves and total plant leaf area in the late fall/early winter can be correlated with fruit production the following spring.

Individual strawberry leaves live from 1-3 months; however, an untimely early fall freeze, or poor irrigation practices during plant establishment will cause leaves to die sooner. The primary purpose of overhead irrigations following transplanting in the fall is is to prevent foliage loss until the root system can develop and absorb sufficient moisture to sustain the plant. Plants should have *three or more fully green leaves* remaining at the end of the initial3-4 week establishment period, regardless of whether they are fresh dugs or plugs. To achieve this outcome, far greater volumes of overhead irrigation are needed for fresh dug bare-root plants than plugs. If the "original" leaves on a fresh dug or plug are lost to drought stress, plant establishment is significantly delayed or "setback" and spring yields will be significantly reduced. The number of leaves and total plant leaf area in the late fall/early winter can be correlated with fruit production the following spring. It is also very important to achieve an adequate plant canopy by late fall as a good leaf canopy acts as an important crown insulator, and is the "cheapest" winter protection you can buy (Figs.10 & 11). An 8-in. plant diameter is about ideal in mid-December.

Most of the water taken up by the plant evaporates through pores called *stomata* in the leaves and stems. The grower must be sure to provide adequate drip irrigations in the spring to replenish water that is taken up by the plant during periods when the stomata are open – strawberry leaves have large numbers of stomata, and water consumption can be very high in warm periods in April and May.

For tissue sampling in late winter and early spring, fully expanded, recently mature trifoliates are selected for tissue sampling starting in early March. The petioles are sampled separately for nitrate nitrogen. Regular tissue sampling in the spring (about every 2-weeks starting after "new leaf" growth in March) and prudent use of N fertilizer and drip irrigation are critical to managing plant size and ultimately fruit quality.

If plant growth is over-stimulated with excess N and watering, the resulting larger plant size and heavy leaf canopy will:

1. Hinder picking – it becomes difficult to "find the fruit" with large "bushes";
2. There will be an increase disease incidence (mainly botrytis); and,
3. Fruit quality and flavor will be negatively influenced by extra thick plant canopies – if the leaves nearest the berries are well-exposed to light (not shaded by other leaves), you can anticipate higher fruit sugars and more favorable remarks from your customers!

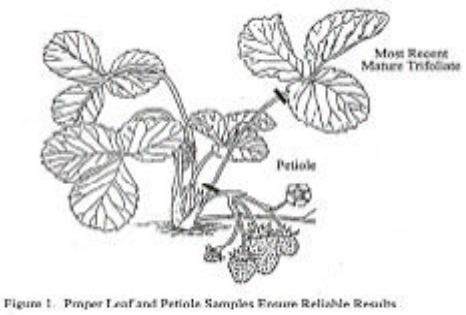

Figure 1. Proper Leaf and Petiole Samples Ensure Reliable Results

Figure 9. Proper leaf and petiole samples ensure reliable results from tissue sampling in the late winter and early spring.

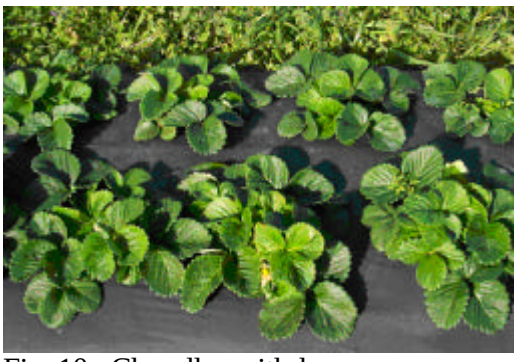

Fig. 10. Chandler with large canopy size on 16-Dec-02 (less was needed).

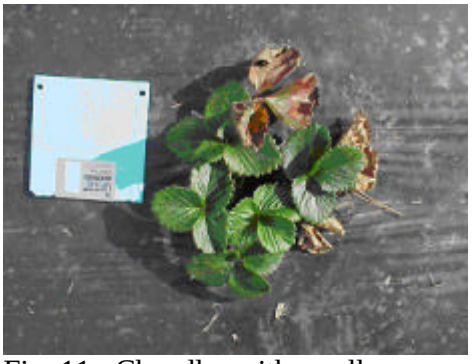

Fig. 11. Chandler with small canopy size on 16-Dec-02. Floppy is 3 ½ in.

Roots. The underground parts of the strawberry may be easily ignored – "out of sight out of mind" – but they do: 1) **anchor the plant, 2) capture water** and 3) **capture nutrients** from the soil that are necessary for growth and fruit production. In well-drained, fumigated beds, strawberry roots will penetrate the full depth of the bed. There are usually 20 to 35 primary roots and thousands of small rootlets in a good strawberry root system (Fig. 12). Roots grow most rapidly when the soil is about 55° F. Rooting is active as long as soil temperature is above 45° F. The secondary roots live for a period of days or a few weeks, and are constantly being replaced. They are easily killed by waterlogged soil in winter, or early spring during frost/freeze protections. Also, soil pests like nematodes and root-pathogenic fungi (e.g. *Phytophthora cactorum* – Crown Rot) can severely limit root development.

Water and nutrient uptake. Besides giving structural support, the roots also serve to capture water and nutrients from the soil. The water and nutrients taken up by the roots are distributed throughout the plant in its vascular system. Soil mineral nutrients needed in the largest supply by the strawberry plant include nitrogen (N), phosphorus (P), calcium (Ca) , potassium (K), sulfur (S) and magnesium (Mg). Iron (Fe), manganese (Mn), boron (B), zinc (Zn), and copper (Cu) are nutrients required in trace amounts, and are called micronutrients. Natural soil levels of most micronutrients are usually adequate; however, B injection through the drip system in late winter/early spring in very small amounts is routine practice.

Starch reserves in winter. The roots also serve as storage sites for starch reserves during winter. Growers who "push" fall top-growth with extra nitrogen feeding may be doing so at the expense of starch accumulation in the roots. The stored starch is needed for vigorous growth and flowering the following spring and will enhance berry size. When Sweet Charlie strawberries are "forced" in the late fall for fruiting, it is often the case that fruit size and plant vigor will be adversely impacted in spring (Fig. 12).

Fig. 12. Strawberry plugs that have been growing for 5 days (left) and 12 days (right). You can see the formation of primary roots in the photo (long and stringy appearance) small white secondary roots (rootlets) that make up the bulk of the strawberry root system.

Fig. 13. Sweet Charlie in December! Photo taken on December 8, 2001 (Trenton, SC). This variety is easily fooled into early blooming and fruiting in the Mid-South in a mild fall. Premature cropping will reduce fruit size and the following spring.

Flowers. The principal parts of the strawberry flower are shown in Fig. 14. Sepals are the small green leaflike structures below the white petals – they enclose the flower at the bud stage, and later on this leaflike tissue is referred to as the berry's calyx, or "cap." The strawberry flower has 5 sepals. The stamens are the "male" parts of the flower that discharge pollen to fertilize the "female" parts of the flower, called the pistils. The numerous pistils are borne on a roundish or conic-shaled flower-supporting stem called the "receptacle." At maturity, the receptacle becomes the enlarged, juicy "berry."

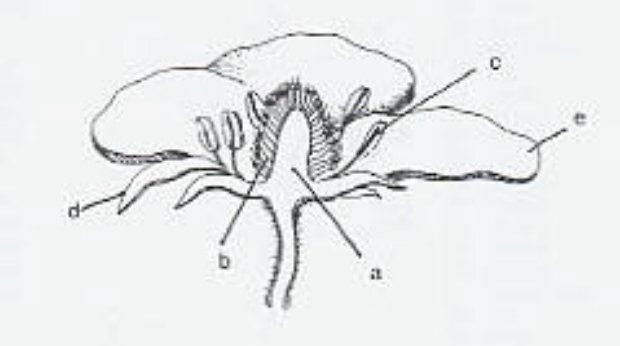

Figure. 14. Principal parts of the strawberry flower: (a) receptacle; (b) pistil and fruit wall; (c) anther; (d) sepal; (e) petal.

Botanically, the red fruit we call the "berry" is an enlarged flower stem (receptacle) with many seeds imbedded in the surface. Actually, what looks like seeds really are the "true fruits," properly referred to as achenes (Fig. 15). Inside the dry ovary walll of each achene is a real seed (ovule) with the potential of becoming a unique strawberry plant (seedling). This offspring is not likely to have any of the desirable horticultural characteristics of the parent strawberry. To preserve strawberry varieties which yield superior fruit, strawberry propagation is generally accomplished by taking runner plants that are identical in genetic makeup to the "mother plant."

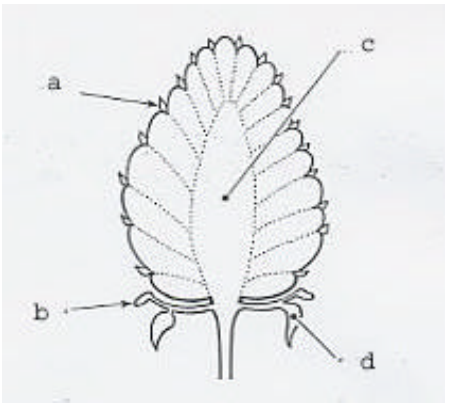

Figure 15. Structural features of the strawberry fruit: (a) achene; (b) stamen; (c) receptacle; (d) sepal (cap).

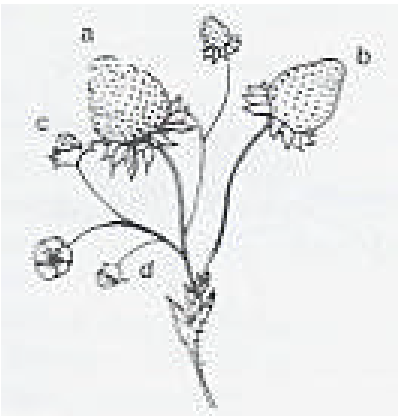

Fig. 16. Fruit cluster: (a) primary fruit; (b) secondary fruit; (c) tertiary fruit; and (d) quaternary berries.

Fruit cluster. Primary berries are not only the largest and first to ripen; they have the most seeds. Secondary berries ripen next and are the next largest in size. Tertiary berries ripen still later and are the third largest. Quaternary berries are the smallest (generally unmarketable) and ripen last (Fig. 16). Development of the fruit from open blossom to ripeness takes 20 to 30 days, depending on weather conditions.

Section 4 – Varieties

Currently, it is possible to select 2-3 different varieties, depending on your growing region, to extend the harvest season over a six-week period. In cooler springs the season may last eight weeks. In hotter years, it can be as short as 4-5 weeks. Both Sweet Charlie (early variety) and Chandler (early midseason variety) are widely adapted throughout the Mid-South; Camarosa (midseason variety) is limited to the milder winter growing areas (Coastal North Carolina, South Carolina, Georgia, southern Alabama, and eastern and central Arkansas). A typical variety 'mix' in areas where all 3 varieties are adapted is to have 50 -60 % Chandler, 30-40% Camarosa and about 10% Sweet Charlie.

Sweet Charlie. For an early market "niche," 'Sweet Charlie' is popular, but growers do not generally plant more than 10 percent of their acreage to this cultivar. Sweet Charlie' is also suitable for carrying to a second year of cropping on plastic mulch (carryover) because of its anthracnose tolerance. The ripening season for Sweet Charlie is rather interesting – it has two weeks of very good quality early production, but then size falls off rather drastically and it does not compete well with Chandler, which is an early-

midseason variety. In some years you may experience a second crop of very large Sweet Charlie berries in the final week of the strawberry season. For all practical purposes, Sweet Charlie has only a 2-3 week season. Many consumers actually show a preference for Sweet Charlie berries, which have a high sugar to acid ratio. It is also a variety that has promise for reduced fungicide usage because of its resistance to anthracnose.

Chandler. Chandler ripens about 5-7 days after Sweet Charlie. The Chandler season will typically last 4 weeks. Chandler is still the most widely grown and adapted variety for strawberry plasticulture production in the Mid-South. It combines high productivity with good fresh eating quality (Table 2). Chandler also has a number of serious drawbacks, including:

- The first week of Chandler picking is typically very unpredictable in terms of fruit quality and shape. It is never a good idea to plan a large promotion for the first week of the Chandler season for this reason. By the second week of Chandler harvest, fruit shape and flavor is usually quite good. Maintaining two healthy hives per acre of honeybees to help with Chandler pollination in early spring is strongly recommended.
- Chandler can be very concentrated in ripening in some years. Following an exceptionally warm mid-April in spring 2002, it had an "explosion" of fruit approximately 2 weeks after the start of the season and some fields in the Raleigh area, for example, were picking as high as 4,000 – 6,000 lb/acre/picking in the first week of May. Assuming that a typical Pick-Your-Own picker will harvest 10 lb/farm visit, this means that as many as 400 to 600 pickers will be needed per picking (it is normal to harvest 2x/week) for a single acre during the peak production week
- Chandler plants and berries can become severely infected with anthracnose – there is now a fungicide that can help manage this disease (*Quadris),* but the recommended approach to managing this disease is to start with anthracnose-free, certified plant material. Chandler plants are destroyed immediately after the first season of harvest due to this variety's extreme susceptibility to anthracnose during the humid summer months in the Southeast. (A list of plant nurseries can be found in the Sources/Resources Section of this Notebook.)

Timing of Chandler Season in NC. The harvest season for Chandler can begin as early as the first week in April for southeastern NC, and good volumes of Chandler are usually available from this region by the second and third week of April. In the lower Piedmont and Sandhills of NC, Chandler begins to ripen in mid-April, and in the upper Piedmont and Foothills it starts ripening near the end of April, and the first week of May in the mountains.

Cold hardiness of Chandler. Chandler is quite cold hardy and does not *generally* require winter protection (straw or row covers) for most growing areas in North Carolina. It is known that winter temperatures below 10^{o} F will cause extensive flower and crown injury in this variety, and for this reason row covers are strongly recommended for protecting all strawberry plasticulture varieties in areas where there is a potential for periods of extreme cold in winter ($<10^{o}$ F).

Critical blossom temperatures. Extensive studies of the critical field blossom temperature (freeze injury) for Chandler were made in the late 1980s and early 1990s,

and this work suggested that there was considerable variability in the frost tolerance of open blossoms of this variety. For practical purposes, it is usually recommended that 28 F is the critical open blossom temperature, but in reality it could be closer to 27 F. More recently, it has been observed that Chandler blossoms may be extremely sensitive to heat injury, and in the early season (25 – 50% bloom) measures should be taken in periods of extreme heat (> 88 ^{o} F) to cool the blooms (see the Irrigation Section of this Notebook for further details on overhead irrigation for frost/freeze and evaporative cooling).

Camarosa. The mostly widely planted variety in the world is Camarosa, released from the University of California breeding program. The variety situation in California continues to change as several new releases have been evaluated in North Carolina (including Gaviota and Diamante), but Camarosa continues to be the "new favorite" of growers in the coastal plain regions of North Carolina, South Carolina, and Georgia. In these warmer winter areas Camarosa production now surpasses 'Chandler' in acreage. The fruit is very large and firm, and the plant is vigorous and runners well in summer nurseries. It is quite susceptible to anthracnose, and the same precautions apply as for Chandler (no carryover, use anthracnose-free nursery plants). To achieve the best Camarosa flavor, it is important to delay picking past the glossy 'bright red' stage and to train pickers to harvest Camarosa when it takes on a darker color – however, when it becomes wine-red in color, it is becoming overripe. Since Camarosa is a relatively new variety for the Mid-South, there is considerably less research information available on how to achieve optimum fruit quality and yield with this variety. More information is needed on planting dates, plant spacing, and specific seasonal requirements for N, P, K, Ca, S, and Mg, and relatively little is known about Camarosa's fall temperature requirement for optimum floral development in our region. Studies will also be needed to evaluate a fuller range of fumigants that can actually replace methyl bromide for use with Camarosa.

Other varieties worthy of consideration are noted in Table 2. Gemstar is a Florida variety from a private breeding program that may be worthy of consideration for growers in the Piedmont, Foothills, and mountains. Earlibrite is a recent University of Florida variety that may have some potential in the foothills and mountains but fresh eating quality is only fair. Bish (NCR 95-08) is a new NC State variety that was released in Nov. 2002. Bish is resistant to anthracnose and has attractive, flavorful berries.

Fig. 17. Gemstar has v. large berries.

Fig. 18. Chandler has excellent flavor.

Table 2. Performance of Short Day Strawberry Varieties and Selections in NC

Dr. James R. Ballington, Professor

Dr. E. Barclay Poling, Professor

Short Day Varieties	Coastal Plain	Pied., Sandhills	Foothills, Mountains	Yield	Fruit Size	Flavor	Comments
Chandler	3[1]	5	5	5	3	5	Industry standard, some roughness, soft berry, good quality
Camarosa	5	3-4	1-2	3-5	4	2-3	Industry standard for milder areas; firm large and v. firm, attractive
Sweet Charlie	2	2	2-3	2	3	3	Lose many primary fruits to freeze; anthracnose resistant fruit
Gemstar	2	3	4	3-4	5	3	White shoulders in CP, and soft
Earlibrite	?	?	4	4-5	4	2	Needs testing
Bish (NCR 95-08)	3	3-4	5	3-5	3-4	5	New release. Resistant to anthracnose

[1]*Ratings: 5 = excellent; 4= very good; 3=good; 2=fair; and 1=poor*

The balance of this guide highlights important preplant, planting, and postplant considerations for successfully growing strawberries in the plasticulture system in North Carolina and other regions in the Mid-South.

Section 5. Preplant Considerations

Equipment. If you are new to strawberry plasticulture, specially equipped and trained custom applicators should be considered for fumigation. They can form beds, inject fumigant, apply plastic, and lay trickle tubes in one operation. The *North Carolina Strawberry Association, Inc.*, maintains an up-to-date listing of custom fumigators. In other states where custom services are unavailable for bed-shaping, fumigation, and plastic-laying, the grower must purchase equipment costing approximately $5,500 and become certified to apply methyl bromide, or alternative fumigants such as 1,3-D (Telone C35). Telone products require the use of a full-respirator, rubber gloves, and boots and coveralls. After 2-3 years of "learning the ropes" of strawberry plasticulture, most commercial growers will buy their own fumigation and plastic-laying equipment.

Strawberry plasticulture also requires overhead irrigation for plant establishment (fresh-dugs and plugs), frost/freeze protection, *and evaporative cooling* during periods of extreme heat stress that can cause scalding of ripe berries and destroy blossoms. The expense for solid-set irrigation can run from $1,200 to $2,500/acre depending on whether more expensive aluminum or cheaper PVC pipe is used. This does not include the expense for the diesel or electric pump, or a new pond. At least 60 to 70 gal/min pumping capacity is necessary for each acre that is frost protected.

All of the approximate 1800-acre strawberry plasticulture industry in North Carolina utilizes drip irrigation. The higher 10-inch beds require drip irrigation because of poor capillary water movement. The proper use of plastic mulches and drip irrigation can provide maximum control of the environment, and the most efficient use of water and fertilizer. Drip irrigation systems can be designed by a specialist to irrigate any size strawberry production unit. A line source emitter with pre-punched holes is used to maintain a continuous moist strip along the row. Because strawberries grown on plastic mulch are considered annuals and are grown for only one season, a thin disposable tubing (4 to 8 mil thick) is commonly used. Water may come from wells, ponds, lakes, municipal lines, or pits. Water source from wells generally is fairly clean and requires only a screen filter to remove particles. However, precipitates or other contaminants in the water should be determined by a water quality test prior to considering a drip system. Any surface water such as streams, ponds, pits, or rivers will contain bacteria, algae, or other aquatic life, and sand filters are an absolute necessity.

Regional adaptation. The vast majority of the strawberry farms in the Mid-South using annual cropping plasticulture production system and varieties are achieving favorable productivity in the milder winters indicated in Fig. 19 by USDA Plant Hardiness Zones 7 and 8. There is more limited strawberry plasticulture production in Zone 6, but the perennial matted row system should be considered in Zone 5 and colder. In North Carolina, strawberry plasticulture is most ideally suited to the milder coastal plain (USDA hardiness Zone 8a) and lower piedmont (Zone 7b), but growers in the upper piedmont and mountains of North Carolina (USDA zones 7a and 6b, respectively) are experiencing success with the system as well.

Site selection factors. Low lying sites can become frost pockets where cold air settles. Some of the best strawberry plasticulture sites are those with a wooded area or a windbreak on the north or northwest side of the field. This will help reduce losses associated with wind-borne freezes in late winter and early spring. Extreme wind protection and restricted airflow locations, however, often lead to increased fungal pressures. Sufficient air movement is needed so that plants dry quickly after dews and rainfall.

A. Deer control is a must! Electric fences should be put up soon after mid-October to protect succulent now strawberry plants. The yield loss associated with deer can be 50% or more of a crop.

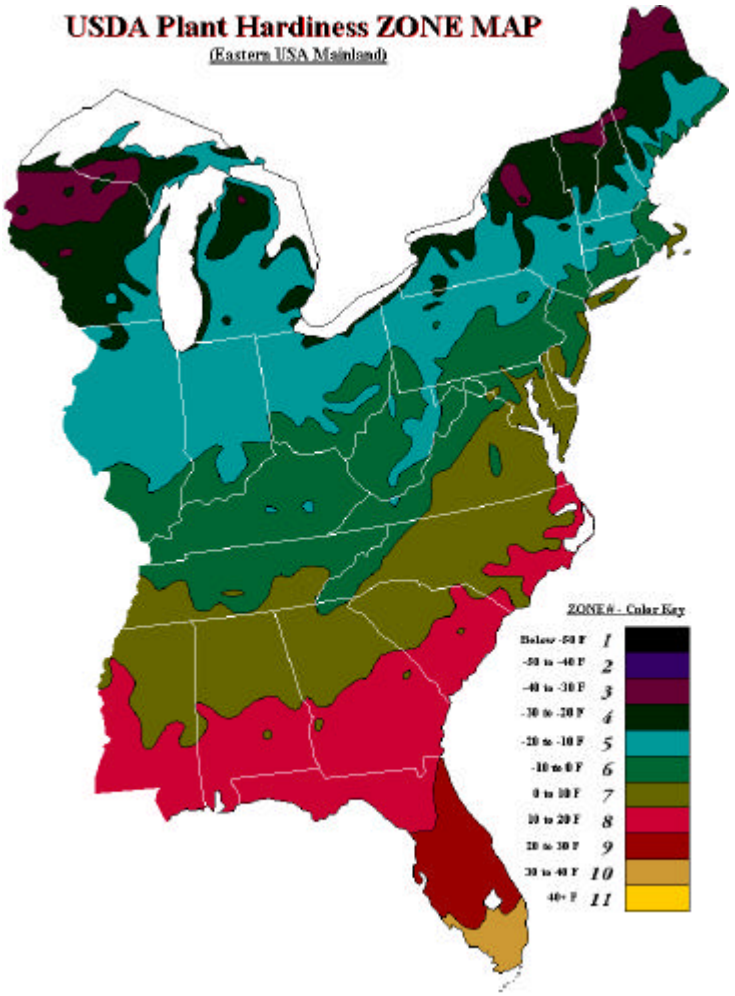

Figure 19. Strawberry plasticulture for Alabama, Arkansas, Georgia, North Carolina, South Carolina, Tennessee and Virginia is primarily concentrated in Zones 7 and 8.

B. Row orientation. A north/south orientation of strawberry beds is recommended to encourage more uniform plant development and ripening on both sides of a double-row bed. If rows are oriented east/west, plants on the north side of the bed will become partly shaded by the plants on the south side of the row during the winter season.

C. Water drainage. The raised beds enhance internal soil water drainage, but plasticulture growers frequently encounter problems with getting rid of excess "surface water." This problem occurs because 50% of a strawberry field has been covered with an impermeable plastic film. For this reason, it is desirable to have a field with enough slopes so that surface water is removed uniformly and gently from the field after periods of heavy precipitation, without causing erosion or leaving puddles. On fields with more than 2% slope (2ft. drop in 100ft), continuous overhead sprinkling for fresh dug plant establishment may cause severe soil erosion.

D. Soil type. Soil type has a decided influence on how well the planting beds are formed. Sandy loam and clay loam soils are ideal for building and shaping the 8-to-10 inch raised beds. However, soils with a high clay content, or those that are rocky or very stony are more difficult to prepare. As a general rule, the physical conditions of the soil in relation to its bed-making characteristics and internal drainage are more important considerations than soil fertility. High clay content, stones or rocks and underlying hardpan are more difficult conditions to manage than low pH or a lack of minerals which can be balanced through the applications of lime and appropriate fertilizers.

E. Rotations. Avoid rotations with soybeans, field corn, tobacco or other crops treated with herbicides and/or plant growth regulators that could carryover and cause crop losses or significant production reductions in strawberries. Read all labels carefully for rotational restrictions. Get assistance to clear up any chemical related questions before, not after planting strawberries.

Growers are encouraged to rotate strawberry field sites as often as possible, but the general practice in North Carolina is to crop strawberries continuously on the same land because of existing irrigation lines and market location considerations. If possible a grower should rotate strawberry plantings every few years for improved disease control and yields. Also, this will help with insect/mite control, and soil re-building with green manure crops can be very beneficial.

If you apply cyprodinil + fludioxonil (Switch 62.5 WG) to your strawberry crop for disease control, you cannot plant rotation crops other than strawberries or onions for 12 months following the last application of Switch.

F. Cover crops. Summer cover crops are recommended to reduce weed problems and soil erosion. Cover crops also increase organic matter and some can supply nitrogen (i.e. legumes). Cover crops should be chopped at least 1 ½ months before fumigation to allow sufficient time for decomposition.

G. Post-harvest field sanitation. It is very important for anthracnose and mite control to remove strawberry plants immediately after harvest. If plants remain after harvest diseases and mites will build up and threaten next year's planting. Carryover Chandler and Camarosa plantings are never recommended because of anthracnose potential. Other varieties like Sweet Charlie may be suited to carrying over to a second year of cropping because of their high level of anthracnose tolerance/resistance.

Soil preplant fertility. A soil test is made several months in advance of planting to provide an indication of how much dolomitic lime is needed to raise the soil pH to 6.0. For sandy soils that do not retain potassium (K) or nitrogen (N) well, the usual recommendation for a preplant fertilizer program is to broadcast 120 lbs K/acre in addition to the 60 lbs nitrogen/acre. The recommended fertilizer source for K is potassium sulfate. Usually, ammonium nitrate is the preplant N fertilizer of choice, and it is usually broadcasted, or banded 4 inches deep in the bed center. Essentially, these preplant fertilizer applications of N and K supply early nutrition to the strawberry plant in

fall and early winter, when North Carolina growers typically do not run their drip irrigation systems.

Conventional programs of applying slow release N fertilizer at rates of 100 to 150 lb of N/acre are no longer being recommended. Growers are currently advised to supply approximately two-thirds of the crops' N, or 100 to 120 lbs N/acre through drip fertigation in the prebloom, bloom, and fruiting periods. Thus, approximately 33% of the N, 50% of the K and all of the recommended P (based on soil testing) are applied preplant with the remaining N and K being applied in through the drip irrigation system.

If your field has a high soil test P index, the P recommendation may be low or even 0 lb/acre. Application of 30 to 60 fall-applied P_2O_5 at our Clayton, NC, research sites, which tests high in P (index of 90), resulted in mean market yield increase of approximately 2,500 lb/acre over a two year study. There was an early growth response to fall P on cool soils resulting in enhancement of flower production (not crowns). Consequently, for this high value crop it is recommended to apply 30 to 60 lb P_2O_5 in the fall, even on high P soils.

Other nutrients can be injected as called for (preferably as the result of tissue testing) through the drip system. On deep sandy soils, boron (B) may be needed. Wait until late winter/early spring to inject B through the drip system. It is vital to have an early tissue sample taken about 3rd week of February in Eastern NC. If the tissue sample is found to be low in boron (20 ppm is critical level), then the standard procedure is then to inject 1/8 lb of boron per acre (5/8 lb, or 10 oz. of Solubor which is 20% B) through the drip system by early March. It should only be applied once unless subsequent tests indicate another application is needed. We generally get by very well with the one application on Wagram sandy loam at Clayton. *Regarding dry fertilizer applications of boron: not recommended at all.*

Plant bedding and fumigation operations. Methyl bromide/chloropicrin fumigation has been a standard practice in California and Florida where annual hill plastic mulch culture has been practiced since the 1960's, and in North Carolina since the mid-80's. Beds are fumigated with methyl bromide for weed, nematode, disease, and insect control. Strawberry plasticulture production on the same site year after year is not advisable without pre-plant fumigation. The amount of material actually applied per acre will depend on row width and will be a percentage of the broadcast rate. The normal broadcast rate for methyl bromide + chloropicrin is 400 lb/acre broadcast, but since only ½ of an acre is being treated with the fumigant (by shank injection) and therefore the actual amount of the fumigant being applied *in-the-row* is 200 lb/acre. Methyl bromide is one of the most expensive fumigants of the currently registered materials for strawberries, but it also provides the grower with a high level of management flexibility in terms of plant-back effectiveness (Table 3).

Table3. Plant-back effectiveness – How "In Kind Alternatives"[1] Under Varying Weather Conditions Can Impact Coastal NC, SC, GA & AL Strawberry Growers.

Alternatives	Normal Late Aug./Early Sept. – no delay	Wetter than Normal = 1 week delay [3]	Extremely Wet Weather = 2 week delay [4]	Managerial Flexibility Rating [5]
1,3-D (Telone)	*(2)	**	***	1-2
1,3-D, Chloropicrin	*	**	***	1-2
1,3-D, Chlor., Metam-Na	*	**	***	
Chloropicrin	*	**	***	1-2
Metam-Na	*	**	**	2-3
Metam-Na, Chloropicrin	*	**	***	2
Standards				
MBC 98:2	*	*	*	5
MBC 67:33	*	*	**	3
Future [6]				
IM 98:2	*	* (?)	* (?)	?
IM 50:50	*	* (?)	** (?)	?

[1] These alternatives were identified by the U.S. EPA and the technical advisory committee to the Parties of the Montreal Protocol and published in the Federal Register Notice announcing the Critical Use Exemption Process (FR:67. 31798 – 31801, May 10, 2002). The list of alternative materials identified as technically feasible for strawberries by international technical advisory group to the Montreal Protocol was further refined to be chemical treatments registered in the U.S.

[2] A single * indicates no issue with plant phytotoxicity and/or planting delay; a double ** indicates some concern with plant phytotoxicity and/or planting delay; a triple * ** indicates great concern with plant phytotoxicity and/or planting delay.

[3] This condition would cause 1 added week of weather-related delay in field operations related to preplant fumigation, or could be ascribed to a condition where fumigated beds have become saturated by a tropical storm.

[4] This condition of very extended delay is one that has been experienced in NC in recent years - Hurricane Floyd in September 1999 caused extensive phytotoxicity in 1,3-D, Chloropicrin (Telone C35) research plots in Plymouth, NC], and also in an On-farm trial in Bunn, NC.

[5] Overall management rating: 5 = very flexible product; 4 = good flexibility; 3 = adequate flexibility; 2 = poor flexibility; 1 = completely inadequate.

6 Future research and grower experience is needed with these 2 new Iodomethane + chloropicrin formulations (98:2, and 50:50) to determine preplant period and overall management rating

Steps in scheduling late summer soil fumigation

1. Decide which fumigant you will be using. Telone C-35, stand-alone Chloropicrin, Metam-Na and Metam-Na + chloropicrin combination products have a minimum of 21 days for plant-back compared to 14 days for methyl bromide + chloropicrin, 67% + 33%. In seasons of Tropical Storms or Hurricanes, such as *Floyd* in September 1999, fumigants with no more than a 2-week waiting period are essential to "making your planting dates." The use of an alternative in one of these seasons with a more extended plant-back could delay fall planting past an optimum window and lead to yield reduction in the range of 20% or more. This is one of the main reasons most commercial growers in the Mid-South do not use alternative fumigants requiring 21-days for plant-back compared to 14-days for methyl bromide + chloropicrin, 67% + 33%.

2. Next, decide your optimum planting window. This window primarily varies with location and variety, and to a lesser extent year to year seasonal effects. In other words, there is a relatively narrow planting window for each variety for your location. For example, in the upper piedmont North Carolina area of Winston-Salem, the optimum planting window is around 25-Sept every year.

3. You are now ready to develop your soil fumigation schedule (this schedule assumes methyl bromide + chloropicrin as the fumigant):

Example Schedule, Winston-Salem, NC

Early to mid-August – whenever there is adequate soil moisture, begin soil preparations in anticipation of bed-making and fumigation towards the end of August. In an unusually dry July/early August, you may be forced to overhead irrigate to get the land ready for chisel plowing, and possibly sub-soiling. Sub-soiling is needed every few years on heavy soils. This needs to be done in N-S, and E-W (both directions). Sub-soiling needs to be done deeply to loosen the soil and break up the plow layer (at 10-12 in.) Breaking up this layer will require setting the draft control so the V-ripper doesn't come up easily when it hits the hard spots. This operation requires extra hp! Be sure to incorporate your lime at this juncture (ideally the lime should be spread in June, just after the plastic is pulled and the beds are knocked down).

Third week of August - make broadcast application of N-P-K, and then incorporate with disk - this prevents nitrogen loss. The disking is to a depth of 6-inches and should get the soil "fluffy" (breaking up clods). Don't use equipment that will compact the soil (a rotary hoe or rototiller may cause compaction).

Fourth week of August - pull beds, fumigate with methyl bromide + chloropicrin and lay plastic and drip tape. Also, stick tips (if you are rooting your own plugs). This is also the time to seed annual ryegrass.

Third week of September - set your Sweet Charlies first (we like to set these 5 days ahead of Chandler). *Always try to allow 3 weeks from fumigation to planting*, even though methyl bromide is a 2-week plant-back material. This extra week allowance is a "cushion" for possible weather delays that may occur. Likewise, for a 21-day plant-back

fumigant, you really need to allow a one month waiting period from fumigation to planting (thus, fumigation with Telone C-35 should be done in the Third Week of August for a Third Week of September planting area).

Fourth week of September - transplant Chander (need 4 workers for water wheel transplanting of plugs and 10-12 workers to set an acre of fresh dusgs in 45 minutes or less)

Special bed-making, fumigation and plastic mulch notes:

1. Soil temperature. The air temperature should be at least 50^{o}F.

2. Soil tilth and condition. The soil should be well worked, free from plant debris and have adequate moisture (for weed seed germination). Most problems associate with poor strawberry plasticulture crops are due to poor soil and bed preparation for fumigation and bed-making. The soil needs to be free of clods, stones, and undecomposed plant residue. Also, sharp stones and sticks will puncture the mulch film and allow the fumigant to escape. If the summer cover crop is not plowed down early enough, you will have a plant residue problem and this will greatly reduce the effectiveness of the fumigant (these residues will serve to trap the fumigant).

3. Soil moisture. Having the proper soil moisture is of critical importance for bed-making and fumigation operations. In order to have good soil moisture for forming the beds, it is frequently necessary to wet up the sprinkler irrigation system and apply approximately ½ inch one to two days in advance of bed-making and fumigation. If both weather and soil are warm, it should be safe following fumigation with 67% methyl bromide + 33 % chloropicrin (at recommended rates) to transplant in 14 days. Never plant earlier than 14 days with this formulation of methyl bromide (67% methyl bromide + 33 % chloropicrin).

4. Plasticulture beds and bed-making. Do not use a vegetable bed-maker! Stick with the bed-making equipment that is specifically designed for higher strawberry plasticulture beds (Reddick and Kennco are two of the leading suppliers). The 10-inch high plastic mulch beds are typically 32 inches wide at the base, and 30 inches wide on top. Beds are slightly crowned so water will run off and not rest on the plastic (a bed with a 30 inch top should slope from the center to the edge with a drop of 1.25 inches). With lower bed height, the long fruit trusses of Chandler or Camarosa come in direct contact with the soil in the row aisles. Thus, it becomes necessary to apply straw mulch to the aisles to keep the berries clean -- this is not necessary with 10-inch high beds. Bed centers are usually 5 feet. Most machines have some fine points which make them worth your time to investigate these differences. Almost all of the machines sold will form the bed, fumigate, and lay plastic and drip tape all in one operation. In general, the single-row bed-making and plastic-laying machines are appropriate for most strawberry operations.

5. Pre-bedding? Be sure that enough soil is pulled up so that the bed has good, sharp corners (it is not usually possible to get these sharp corners on clay soils). You may find it beneficial to pre-bed the rows to make sure that enough soil will be pulled up for the bed-shaper – the same plows used for making tobacco beds work nicely for strawberry pre-bedding.

6. Disking ahead of fumigation? A real good idea is to disk the soil just ahead of fumigation. Some growers will lightly disk an acre, and then fumigate it immediately. If you disk all of your plasticulture acreage early on a hot sunny day, chances are that it will be too dry for fumigation and bed-making. Leave that moisture trapped beneath the soil's upper crust until you need it.

7. Red-clay. Some of the low organic matter, red clay soils are aptly described as "dinner-time soils" – they can be too wet to fumigate before lunch, and too dry after lunch to make a good bed where the shoulders do not begin to crack and come apart. The real difficulty with red clay is getting this type of soil properly conditioned for good fumigation and bed-making. Compaction and clods are the net result of working the land when it is too wet. Thus, for 'red clay' plasticulture growers there can be some very important advantages to owning your own fumigation rig as far as being able to schedule fumigation operations when the land is ready (which is not necessarily the case when the custom fumigator is ready to come to your farm).

8. Plastic mulch. Embossed 1 – 1.25 mil black plastic mulch film is recommended. For 5-foot row centers there are 8,712 linear feet of row per acre, so you will need about 3.5 rolls (2,4000 ft) of plastic mulch per acre. For 6-foot centers, three rolls of plastic mulch will be required per acre. It is important that the plastic fit tightly on the bed and that the edge of the plastic, or the tuck, be held firmly in the soil. These measures reduce the chance of wind getting under the plastic and causing it to blow off or float up and down, which injures plants.

An excellent strawberry bed has the plastic mulch in direct contact with the soil beneath – you get this by going to these extra pains. If there are air pockets beneath the plastic, plant growth will be slow in the fall and winter (heat from the black plastic will not be conducted into the soil if there are air pockets – in fact, the black plastic will have a cooling effect if it is not in good contact with the soil beneath).

*9. Drip tubing installation***.** Install drip tubing with the orifices facing upwards. The tubing is typically buried 1-2 inches deep in the bed center. During installation several workers should be watching to insure that the tubing maintains its orifice-upwards orientation, to assist if the tubing becomes tangled in the injector, and to signal when the drip tape reel is empty. Tubing ends should be closed off by kinking or knotting, until the tubes are hooked up to the system. Generally, growers do not use the drip system until late winter/early spring, and fall irrigation is applied by overhead sprinklers.

10. Cover crops on sloping terrain. As soon as the land is fumigated and mulched, it is often a good idea to broadcast approximately 50 lbs per acre of annual ryegrass over the entire field. Annual ryegrass can be spread the same day you finish fumigating. Ryegrass will reduce soil washing in the aisles after heavy rains or irrigation for plant establishment (fresh dugs) on sloping terrain. There are chemical controls for killing the annual ryegrass in late winter before it grows above the plastic mulched beds. The annual ryegrass can provide an inexpensive alternative to applying wheat straw to the aisles in the spring, if it is not killed prematurely. It is too late to dress up the ends of the fumigated rows once you have applied the ryegrass. It is vital to dress the land immediately after fumigating, so that surface water can flow easily out of the rows. It is much more difficult to deal with surface drainage problems once the ryegrass is established. Obviously, you do not wish to apply any pre-emergent herbicide to the aisles if you decide to grow a "living mulch" for the fall and winter season. In fact, very few herbicides are labeled for strawberry plasticulture, and you should check with the Cooperative Extension Service or your consultant if you have questions about available herbicides, rates, and timing of application.

11. Herbicides. For information on weed control in the aisles see the Weed Management Section of this Notebook. Never apply *Roundup* to the tops of the plastic mulch bed before planting – the residue left by *Roundup* on the film will severely injure/kill strawberry transplants.

12. Punch holes. An additional precaution to reduce the likelihood of methyl bromide injury to the strawberry transplant would be *to cut or punch plant holes through the plastic mulch a day or two prior to planting.* NEVER SEED ANNUAL RYEGRASS AFTER HOLES HAVE BEEN PUNCHED!

Section 6. Planting Considerations

Plant quality. The success of a strawberry plasticulture planting, in large part, depends on the health and vigor of the planting stock. Purchase your plants from a reputable nursery. Plants should be true-to-variety, and free of insects, diseases, nematodes, and viruses. The North Carolina Strawberry Association, Inc. 1138 Rock Rest Rd., Pittsboro, NC 27312, www.ncstrawberry.org) maintains a current listing of 'Chandler', 'Camarosa', 'Sweet Charlie', and 'Gem' nursery plant sources in the United States and Canada for interested growers.

Plant type. Plug plants are generally more expensive to purchase than fresh dug strawberry plants, but they do have the advantage of being suitable for mechanical transplanting with a water-wheel or disposable pot mulch planter; whereas fresh dug plants are most often transplanted by hand. The establishment procedure for highly perishable fresh dug transplants depends on intense overhead sprinkling for 1-2 weeks, depending on weather. Commercial grower experiences in North Carolina with plug plants indicate that these do require overhead sprinklings for the first, second and possibly third day following transplanting for approximately 5 hrs, 3 hrs and 2 hrs, per

day, respectively. Plugs are definitely recommended over fresh dugs for part-time growers who do not have the time to oversee the continuous overhead watering of fresh dug plants during the first week following field transplanting. Also, less experienced growers are encouraged to consider planting plugs because they are more "mistake-proof" than highly perishable fresh dug plants. Transplanting dates for plugs can also be slightly later than for fresh dugs without as great a yield reduction. This is because plugs establish more quickly than fresh dugs after transplanting. Plug plants have been found to be comparable to fresh dug plants in both marketable yield and fruit size in studies conducted in North Carolina.

Section 7. Storage, Handling and Transplanting Procedures

Fresh dugs. Freshly dug plants may be stored in a cold room at 40°F for 1-2 days before setting. Storage for a longer period can make the plants more difficult to establish. Plants in a nursery box or crate are packed tightly enough (typically packed 500-100 plants per crate) to make them prone to what is called a "heat" -- rendering them unfit for subsequent planting in the field. *It is very important to cool the plants prior to transit*. During hot weather it may be necessary to run water through the crates to keep plants cool.

The fresh dug strawberry plant is hand-transplanted through the plastic mulch in 2 ½ inch slits cut by specially constructed spacing wheels that also open a narrow hole for planting. This equipment can reduce substantially the number of hours required to set one acre of fresh dug strawberries (approximately 40 hours per acre). Some root pruning may be needed to shorten roots to 5 to 6 inches prior to transplanting. Set the plants so that the midpoint of the crown is level with the soil surface. If plants are set too deep, the plants are unthrifty and crowns may rot and plants die. If planted too shallow, the root system is exposed, which can result in poor rooting and shifting of the plants. Often plants may be set at the right depth, but may either be in a small depression or have soil ridged around the crown. When irrigation is started to establish plants, the depression can fill and bury the crown or the ridge may erode and expose roots. A *firm plant* bed well assist in preventing the bed from settling or eroding.

Start overhead irrigation as soon as plants are set -- no more than 1 hour should elapse. These plants will require irrigation varying from 7-12 days after transplanting. Each morning start irrigation when plants show moderate wilt and continue to irrigate until the hot part of the day has passed. After a few days, irrigation can be initiated a little later in the morning and can be discontinued earlier in the afternoon. The primary purpose of these irrigations is to prevent foliage loss until the root system can develop and absorb sufficient moisture to sustain the plant. Plants should have *three or more fully green leaves* remaining at the end of the establishment period. Only a relatively small volume of water is required for mist cooling -- we have been successful using 1/10 inch per hour.

Plugs. Extended storage of the plantlets or tips is generally not needed. Commercial tip nurseries can harvest fresh tips weekly from late July through mid-October. The tips are shipped by refrigerated truck to the grower's farm for delivery approximately 35 days prior to field transplanting. Tips can be stored up to 2 weeks at 34

to 40°F without deterioration in quality. The boxes containing approximately 1000 plantlets must be stacked "loose" so that the cool air can circulate freely around the boxes. The strawberry tips are a living, respiring plant and must be kept cool until the grower is ready to root them under mist. The humidity in the cooler should be kept around 75 to 80 percent relative humidity.

Prior to rooting, additional plantlet preparation is needed to trim away excess runner-cords. An approximate 3/8 to ½ inch runner "stub" serves to anchor the plantlet until new roots develop. Fresh strawberry tips are best rooted under a fine mist that will wet the foliage yet put very little excess water on the soil. The goal is to keep moisture on the leaves until the plant is well rooted, about 7 to 10 days. As the roots form, the plants can be weaned from the mist and allowed to get their moisture from the soil. This is a gradual reduction over 2 to 5 days. Two weeks after sticking, you should be able to pull most plants from the cell and the root ball will remain intact. When that occurs, misting can be terminated.

Strawberry plants raised in containers are grown in specially prepared media. Many different media are available but a soil-less media based on peat, sand, grit, vermiculite, perlite, polystyrene or other materials is recommended. You will need about 4 cubic feet of media for approximately 1000 tips, in 50-cell rigid plastic trays 2 3/8 x 12 x 20 inches. The 50-cell tray is suggested for small and medium size strawberry tips. If the tips you receive from your supplier are quite variable in plantlet length, it is well worth the extra step to grade the tips into large, medium and small-sized lots. The large tips should be rooted in 38-cell trays, the medium tips rooted in 50-cell trays, and the smaller tips rooted in 60-cell trays. Sticking large tips (more than 5 inches) in the same tray with small tips (2 to 3 inches) will result in light competition and irregular root growth of the smaller, shaded tip plants. During misting, shaded tips are susceptible to botrytis infection.

After the misting cycle is complete, trays are moved to a fully exposed gravel pad for another 2 to 3 weeks of growth and acclimation before field transplanting. During this final field-conditioning phase, a single daily watering is suggested along with a weekly supplemental drench of a complete fertilizer material. A root-bound plug is desirable for mechanical transplanting; plugs for hand transplanting can be set before this stage is reached. In transplanting plugs, the plant crown (bud) should be just above the soil line, and *not buried*.

Plug plants pose less serious problems than fresh dugs for field transplanting. Pot mulch planters or vegetable water wheels can be used to mechanically transplant and water strawberry plugs. Careful size-grading of tip plants will produce more uniform plugs for efficient machine transplanting. A few hours of overhead sprinkler irrigation after transplanting plugs is recommended.

Planting dates. Until more recent years, plasticulture growers could not obtain fresh dug (green) plants until sometime in very late September or early October from northern United States and Canadian nurseries. This happens to be the best time of year for transplanting in the lower piedmont and southeastern North Carolina, but earlier transplanting dates are needed to achieve full crops in colder climatic areas such as the upper piedmont and mountains of North Carolina (USDA zones 7a and 6b, respectively), Virginia, Delaware, Maryland, and New Jersey. Growers in Western North Carolina and

more northern areas are now able to achieve target planting dates in mid-September by using fresh 'container-grown' strawberry plug plants.

North Carolina – planting dates:

Standard varieties

1. Sweet Charlie - set 5 days ahead of Chandler (see Chandler dates next).

2. Chandler - WNC high elevation (2nd-3rd week Sep); WNC lower elevation and foothills (3rd week Sep); Upper Pied. and Tidewater (4th week Sep); Piedmont transition to CP (1st week Oct- like Clayton); Sandhills (first week Oct, but the last week of Sept is also fine for "colder locations", especially for fresh dugs); lower CP (2nd week Oct 3rd week for the "warmer sites"); and, for our most southeastern counties like Brunswick, it is fine to go as late as the fourth week of October.

3. Camarosa - Normally, the same time as Chandler, but at the Summer Preplant Meetings in 2001 and 2002, it was felt that several days of "backing up" with Camarosa may be appropriate. *Thus, a producer accustomed to setting Chandler on Oct 5th, should think about setting on Oct. 1st or 2nd.*

New varieties (we still need lots more information on these 2 new varieties on planting dates):

1. *Gemstar (JP 2)* - set with Sweet Charlie.
2. *Gaviota* - set with Sweet Charlie (or earlier?). Still not sure on this one.
3. *Bish* (NCR 95-08) – one week earlier than Chandler.

Additional comments: Very few growers are growing Gaviota, but it may be worth doing some experimenting with planting dates for this newer California variety. Sweet Charlie needs to be set 5-7 days earlier than Chandler - always! Also, the 12 inch in-row spacing is best for Sweet Charlie (17,500 plants/A at 5 ft center). Camarosa and Chandler are commonly set at 14 inch in-row spacing (15,000 plants/A) because of their extra plant vigor (see next section).

Plant spacing. There are two plant rows per bed ("double row hill"). Plants between rows are generally offset for improved light and air circulation. There is usually 12 to 14 inches between the plant rows, and 12 to 16 inches between plants in the row. With 5 ft between bed centers, 17,500 plants per acre will be required at the 12 inch x 12 inch spacing; 15,000 plants per acre at the 14 inch x 12 inch spacing; and 13,000 plants per acre at the 16 inch x 12 inch spacing (Table 4).

In North Carolina, the influence of Chandler in-row plant spacing on marketable yield and fruit quality has not been adequately investigated. The 12-inch in-row plant spacing is often too close and many growers have adopted a wider in-row spacing of 14-inch because of problems with excess Chandler plant vigor. Some growers have adopted a 16-inch in-row spacing for even easier picking, improved spray penetration and less botrytis fruit rot than with closer plant spacings. In mild falls and/or winters in which plants develop more branch crowns and flowers than normal, the wider in-row spacings are advantageous. But, the opposite can also hold true in colder fall/winter seasons, and

then the grower faces the prospect of a significant reduction in per acre yields because of lower planting densities at the 14-inch and 16-inch in-row spacing (assuming 5 ft bed centers). Many growers are inadvertently creating a plant "spacing-problem" (and experience lower fruit quality) by planting too early, applying excessive amounts of N and K preplant fertilizer and by over watering with drip irrigation system.

Table 4. Plant requirements for various row centers and in-row spacings (assume double-row planting; some rounding of plant numbers has been done).

	12 inch (in-row)	***14 inch (in-row)***	***16 inch (in-row)***
5 ft. row center	*17,500 plants*	*15,000 plants*	*13,000 plants*
6 ft. row center[1]	*14,500 plants*	*12,500 plants*	*10,890 plants*

[1] *A 6 ft. row center is not usually recommended.*

Section 8. Postplant Care

Postplant fertility. In southeastern North Carolina, drip irrigation applications begin at first bloom (late February) and continue through harvest (ending in late May or early June). In conjunction with a plant analysis program, drip fertigation has the potential to improve N and K efficiency and possibly berry firmness and quality. Over an approximate 100-day period from late February through late May or early June, N and K-maintenance drip applications are made daily, or weekly, at the equivalent of 0.75 - 1.0 lb/acre/day (1.12 kg/ha/day) of N, along with 0.75 - 1.0 lb/acre/day (1.12 kg/ha/day) of K20. We have not been able to observe yield or fruit quality benefits in Chandler by injecting higher amounts of K relative to N in this maintenance program.

Bi-weekly plant analysis is used in the late winter and early spring to make more precise determinations of nutrients that may become limiting for optimum plant growth and fruit production. Most recent, fully expanded leaves are selected and analyzed to identify nutritional problems. The following sufficiency ranges are used for 'Chandler' strawberry in North Carolina (from most recent fully expanded leaves): N 3.0-4.0%; P 0.2-0.4%; K 1.1-2.5%; Ca 0.5-1.5%; Mg 0.25-0.45%; Fe 50-150 ppm; Mn 30-100 ppm; Zn 15-50 ppm; Cu 4-15 ppm; and B 25-50 ppm. Petioles are detached and analyzed for nitrate nitrogen concentration. Experience to date indicates that highest yields are obtained when petiole nitrate nitrogen ranges from 5,500 - 6,000 ppm early in the season to 800-1200 ppm at the end of the season.

Water management and operation. As the strawberry plant grows, larger quantities of water are needed, because root systems become more extensive and more foliage is present. In the fall, other than for plant establishment in the first two weeks after planting, relatively little water is needed. In the late winter, you will begin your drip fertigation program (late February/early March), and water will be furnished to the plants in this period when you drip fertigate. But, as foliage and blossoms begin to develop rapidly in March and early April, more water is needed. Peak water use occurs in May

during harvest and; obviously, more water is needed under hot, dry conditions to replace evaporative loss.

Measuring water loss. Water loss by evaporation can be measured by an open pan and is usually quoted by agricultural weather reports as pan evaporation. A far easier method of determining daily water need for crops on drip irrigation system is the use of tensiometers. A tensiometer consists of a porous, porcelain-tipped tube containing water with a vacuum gauge at the top. The tensiometer is placed at root-zone depth with the porous tip buried in the soil. As water moves from the porous tip, a vacuum reading (in centibars of soil suction) indicates the moisture status of soils. Tensiometers work well for the sandy soils commonly found in many vegetable and strawberry growing areas. A value of 0 means the soil is completely saturated with water. A reading of 10 represents a normal field capacity soil water status. Irrigation should be turned on when a reading of 20-30 appears on the gauge.

Tensiometers are usually installed in pairs, called a "station," one at a 6-inch depth and one at a 12-inch depth. Turn on the system when the deep 12-inch tensiometer reads 20-30, and turn off the system when the shallow (6 inch) tensiometer drops to 10 or below. Tensiometers can be purchased with solenoid switches to completely automate the turn-on and turn-off processes.

Spring frost/freeze control. Overhead sprinkler irrigation is still the best and most reliable means for protecting strawberry blossoms from cold injury in March and April. In North Carolina, it is a common practice to pump ten or more nights each spring for as many as 8 to 10 h each night. If, for example, the pump is used four consecutive nights, for an average of 10 h each night at the rate of 1/8 inch/h.

Approximately 136,000 gal of water will be needed for protecting just one acre. The irrigation water gives off heat to the plant as the temperature of the water drops to 32°F, and especially as it freezes. As long as the temperature of the flower or fruit stays above 30°F, no damage results. The lower the air temperature the greater the amount of water needed to maintain the temperature of the flowers and fruit above the damaging level. Open strawberry flowers are more prone to freeze damage than green fruit, which, in turn, are more sensitive than ripe fruit. If wind speed is 10 to 15 mph or greater, the result of water application with this technique is erratic, and plants as well as flowers and fruit can be severely damaged. With little or no wind, about 0.15 inch/h of irrigation is required for frost protection down to a temperature of 22°F, and about 0.25 inch/h from 22°F - 18°F. Turn sprinklers on at 34°F and do not turn them off until the ice begins to melt, and continues to melt when no additional irrigation is applied. Thermometers should be calibrated in an ice bath and placed in the lowest spot(s) in the field, fully exposed to the sky, and just above the mulch (be sure they are not protected by nearby plants).

Row covers. It should be realized that row covers should not be regarded as frost protection systems. For total frost protection, bona fide sprinkler irrigation systems are needed. Row covers do provide temperature modification, and crops may be slightly early, if covers are applied in winter. Overwintering covers (strips or floating) may be justified in Western North Carolina and more northern climates.

We have observed that floating covers do provide economic benefits in late winter and early spring during advective or windborne freezes. During such freezes sprinkler irrigation cannot be used to protect the crop because of high winds. The floating covers can be deployed for short durations. The covers can be returned to storage once field conditions have moderated. This will help to extend the life of the covers -- 2 or 3 years is typical.

Conclusion:

Consistent profitability in southeastern strawberry plasticulture is associated with these BMPs (best management practices):

2. Annual late summer fumigation for weeds, nematode and disease control before fall planting – starting fresh each season with a pre-plant treatment of methyl bromide + chloropicrin is especially important for controlling nut sedge, which infests much of the prime cropland in our region where strawberries are grown.

3. Timely planting of well-adapted varieties – there is about a 5-day optimum window in the fall season for timely planting of the three main direct-market varieties: Chandler, Camarosa, and Sweet Charlie, in each growing region. Missing the optimum planting window for your growing region can cause substantial yield reductions.

3. Healthy, mite- and disease-free nursery transplants.

4. Well-formed raised beds in which the plastic mulch has a tight fit to the soil and there are no air pockets. Fumigated beds must be well aerated before planting to avoid potentially devastating plant phytotoxicity problems.

5. Timely and adequate irrigations for plant establishment, fall plant development, spring frost/freeze control, and management of spring heat waves (evaporative cooling of blossoms and fruit).

6. Scouting and timely management of insect, mite and disease pests (especially 2-spotted spider mites, botrytis and anthracnose), and use of chemical and biological controls in accordance with established procedures and label restrictions.

Literature citations:

Darrow, George M. The Strawberry, History, Breeding and Physiology, Holt, Rinehart and Winston, Chicago (1966).

Additional information:

BerryAgent Electronic advisories: http://intra.ces.ncsu.edu/depts/hort/berrydoc/