Strawberry Plasticulture

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Introduction

Strawberry production has been a significant part of the diverse agriculture in the Northeast for u-pick, roadside, and wholesale fresh, as well as processing. There are many locations in the region which have the climate and soils desirable to produce quality berries, however, in recent years acreage devoted to matted row strawberry production has decreased. Reasons for the decrease in acreage include: decreased profitability due to high dependence on hand labor; increased pest control problems with loss of labeled pesticides; competition from western producers; and limited planting productivity and fruit shelf-life due to disease susceptibility of existing varieties. The rapidly escalating value of real estate has also put increasing development pressure on all agricultural acreage. Reduction of pesticide inputs has been possible through adoption of Integrated Crop Management (ICM) techniques, but a major overhaul of the matted row production system is necessary to improve sustainability and profitability.

The annual plasticulture strawberry system utilized in California and the Southeast U.S. has increased yield and fruit quality significantly over conventional matted row plantings, and is rapidly being adopted in the Northeast. The high density system maximizes the reproductive efficiency of the strawberry plant, requiring only 9 months from planting to harvest, compared to the matted row which requires 14 months. Late summer planting directs vegetative energy into branch crowns instead of runners, and also avoids the heat, drought, weed, and disease pressure of midsummer. The short growth period (plant Aug./Sept., harvest mid-May) allows efficient land use for double cropping and ease of rotation.

Establishment costs are higher for plasticulture than matted row, however production of higher quality and is earlier when crop value is highest. Labor costs are typically reduced as there is no need for blossom removal, setting of daughter plants, or hand weeding, and fruit is more easily and efficiently harvested from the beds. The limitation and/or risks of the system include: high establishment costs (plastic mulch, plant costs, trickle irrigation, and floating row covers), limited growth period for flower bud initiation in the fall, as well as winter injury reducing growth and fruiting. Research is being conducted to make strawberry plasticulture practical in the Northeast and dedicated growers have found high profitability utilizing the system.

Basics of System

There are many critical parameters of the system, **all** of which are important to optimal production and efficiency. Since this is an **integrated** system, **all** of the components are important, and any "weak link" or exclusion of a component can lead to failure. The late-summer planted system includes raised beds, black plastic mulch, trickle irrigation, high density planting, and floating row covers.

Meso-climate. This system has given highest yields at locations with long growing seasons, typically 190 frost free days with 3200 growing degree hours. A limitation of the system is the risk of low yield due to a restricted period available for plant growth and flower bud initiation in the fall in some locations and/or seasons. Floating row covers become even more critical as sites become more "marginal" (see discussion below). Select fields protected from westerly winds and with a southern exposure to minimize wind desiccation and maximize heat accumulation.

Pre-plant Preparation.

Soil considerations. Strawberries perform best on soils with high organic matter that have never been planted to strawberries or alternatively on land that has been in a proper crop rotation. This is best for both reducing soil pests and maintaining soil organic matter. Light to medium textured soils with medium to high organic matter are best for bed preparation, nutrition management, and plant development in strawberry plasticulture. When the soil organic matter levels are too low (<1%) a season of cover cropping is recommended before planting. Typically beds are not made until August for September planting, which allows for adequate cover crop growth in the same season prior to planting.

Management of soil pests. Since the plasticulture system incorporates ICM practices that reduce the crop's vulnerability to pest, many growers have been successful without fumigation. Plastic mulch covered raised beds reduce diseases by improving soil drainage around the plant roots and protecting the fruit from splashing water. Also, the beds are typically maintained for only one to two seasons, in contrast to 3-5 for matted row, thereby reducing the time that pests have to get established.

Fumigation is recommended where weeds and soil-borne diseases are a problem, especially where strawberries or Solanaceous crops (tomatoes, peppers, etc.) were previously planted. Fumigation may help reduce incidence and severity of red-stele (*Phytophthora*) and *Verticillium*, however problems with *Pythium*, *Rhizoctonia*, and the Black-Root Rot complex may be exacerbated. Fumigant can be broadcast or injected through the trickle irrigation under the plastic, but must be applied at least two weeks prior to planting.

Nutrition. Sample and have soil tested to determine pH and specific nutritional needs. Adjust soil pH to 6.2 with calcitic or dolomitic lime depending on Ca and Mg levels. Research in the region has shown that the plants need a total of 90-120 pounds of actual nitrogen (N) per acre per season. The high end (120 lbs. N/A) is recommended for sandy soils in warmer regions with mild winters and extended harvest seasons. In most locations in the Mid-Atlantic and north, especially areas with heavier soils and earlier fall frost dates, 90 total lbs. N/A is sufficient. The N application is typically split into pre-plant incorporation and a harvest season fertigation.

Broadcast and work into beds 2/3 of the needed N (60-70 lbs. N/A) as a 1-1-1 fertilizer, if the soil test P and K are low or medium, and apply additional P and K according to the soil test recommendations. If soil test phosphorus and potassium levels are high or very high, use a 2-1-1 or 3-1-1 ratio fertilizer or ammonium-nitrate. Many bed makers can be modified to include a dry fertilizer injector that can incorporate the desired amount of granular fertilizer directly into the bed where it is most efficiently used.

An additional 30-50 pounds of N/A should be added through the trickle in the early spring. Florida and North Carolina recommendations are for about 3.5 lbs N/A/week through the harvest season. This can be a single application or split into smaller multiple applications on a 7-10 day schedule. Plants on lighter soils benefit from split applications. Recent research has shown that it is critical to have most or all of the N in the soil by early bloom for optimal set and yield. Additional N can be fertigated later if necessary during an extended harvest season.

The strawberry plasticulture system is also amenable to the use of organic sources of N. In experiments in New Jersey and Maryland, the yield of organic N nutrition treatments (Plant Tone®, corn gluten meal, poultry manure) was comparable or superior to conventional inorganic N plots. Since organic N is a slow release form that resists leaching, all of the N can be preplant incorporated, eliminating the need for the increased cost, effort, and equipment necessary for spring fertigation.

Proper N nutrition is critical for optimal quantity and quality of production. Florida and North Carolina have developed guidelines to monitor the N status of the plant at various critical stages of plant development (Table 1). These recommended levels are a good starting point for monitoring the N status in the Northeast, however keep in mind that less total N is need in this region due to the shorter growing season and harvest period.

Table 1. Sufficiency range[1] for fresh petiole sap[2] nitrogen (NO^3 - N) and potash (K^20- K) concentrations (ppm[2]) for strawberry plasticulture at specific stages.

Date - Stage	NO^3 Range	K^20 Range
mid-October	800-900	3000-3500
mid-November	600-800	3000-3500
mid-March	600-800	2500-3500
early-April (beginning of bloom)	300-500	2000-2500
5/10-6/? (harvest season)	200-500	1800-2500

[1]From Hochmuth, G. and E. Albregts. 1994. University of Florida Extension Circular 1141.
[2]Petiole sap readings with portable Cardy N and K ion meters, from spectrum technologies, Inc., 12010 S. Aero Dr., Plainfield, IL 60544.

Potassium (K) deficiency should be avoided as this will negatively influence strawberry flavor. Boron, a critical element for fruit set, can also be foliar applied or fertigated as tissue and soil samples indicate. The best way to monitor the actual status of the various nutrients is through regular tissue/petiole testing. Table 2 lists the sufficiency ranges for various nutrients for strawberry plants in a plasticulture system.

Table 2. Sufficiency range[1] (dry weight basis) for nutrients in most recently matured whole leaves (tissue analysis - blade plus petiole) for strawberry plasticulture at mid-season.

Nutrient	Adequate Range (%)	Nutrient	Adequate range (ppm)
N	2.8-3.0	Fe	50-100
P	0.2-0.4	Mn	25-100
K	1.1-2.5	Zn	20-40
Ca	0.4-1.5	B	20-40
Mg	0.2-0.4	Cu	5-10
S	0.8-1.0	Mo	0.5-0.8

[1]From Hochmuth, G. and E. Albregts. 1994. University of Florida Extension Circular 1141.

Bed preparation. Work the soil well before making the beds, as the ultimate goal for the best productivity is a center crowned, firm bed, with tight black plastic. Bed forming, fertilizer incorporation, fumigation shanking, installation of drip tubing, and plastic laying can all be done in one step with some equipment. However, in most locations in the Northeast, especially on heavier soils, it is typically better to form the beds with the fertilizer incorporated, and then come back and lay the plastic and drip tube.

Research has shown that *wider* beds (see section on plant spacing below) allow greater spacing between plant rows that promotes better sun and air penetration that translates into higher productivity and quality. High, wide, black plastic covered beds promote higher soil temperatures that induce better and more rapid plant development in the fall and spring. They improve water drainage that decreases root disease problems, improve air movement through foliage for disease prevention, and are require less effort (bending and searching) to harvest. Beds are spaced as close as possible depending on soil type, tractor size, equipment available, and space needed between rows for pickers; 4-5' row centers is common.

Plastic mulch. Black plastic mulch keeps the soil warm longer in the fall for improved growth and flower bud initiation, allows the soil to warm quickly in spring for an earlier harvest, keeps fruit clean and disease free, and controls weeds. Embossed plastic of 1.25 mil thickness is recommended as it can withstand two or even three strawberry crops under normal conditions. White-over-black plastic is equally good for retarding weed growth but does not maintain the high soils temperatures in the fall. White-over-black can be used to delay bloom which may be desirable to avoid spring frosts (and overhead frost protection) and when a later crop is preferred over earlier. Results with clear plastic have shown that weed control can be a problem, the harvest is delayed (vs. black), and there can be complications with the irrigation tubing.

Trickle irrigation. Irrigation is critical to optimal plant development, yield, fruit size, and quality (see Further Reading list). Trickle irrigation is most efficient way of supplying water to the roots without wetting leaves and exacerbating foliage diseases. Irrigation monitoring and scheduling during the critical developmental plant and fruit stages is best accomplished using tensiometer (see Further Reading list).

The trickle system can be used to directly deliver fumigant to the critical area. Applying fertilizer (fertigation) through the trickle is also the most efficient way to deliver nutrients to the plant at the proper time and in the optimal amount, all without disturbing the plastic. Environmentally friendly practices of growing as many crops as possible with the same plastic mulch and trickle tube, along with proper disposal are strongly encouraged (see double cropping section below).

Overhead irrigation. Overhead (solid set or micro-sprinklers) irrigation is critical at a few stages in the system. Overhead is helpful during planting and establishment to cool plants and plastic on hot late summer days and can also be used for evaporative cooling during the harvest season. However it is imperative to have a dependable solid set overhead system for frost protection of the early crop (see frost protection section below).

Planting Considerations

Plant types. There are currently a few plant type options available for the plasticulture system, including plugs, dormants, and fresh. A fact sheet listing of nurseries that supply plugs and runner tips is in the additional resource list. Always insist on virus tested plants from a certified nursery when purchasing plants.

Plugs. Transplant "plugs" (Figure 1) that are propagated form actively growing runner tips are the current standard for the system. Plugs can be purchased directly from nurseries as rooted plugs or one can purchase tips and root them into plugs (for directions for propagating from tips - see Further Reading list). Plugs are easy to establish and research has shown that they give the most consistent yields from season to season, however they are the most expensive option. Another benefit is that they are not planted until late-August or early-September, allowing for summer rotation or double-cropping. Besides cost, the other limiting factor with plugs has been the limited selection of varieties and date of availability. ‘Chandler’, ‘Sweet Charlie’, and ‘Camarosa’ are the only varieties currently available in commercial quantities, however two “new” nurseries in the Mid-Atlantic region are concentrating on delivering a larger choice of varieties (including many Eastern varieties) and planting dates (see section below).

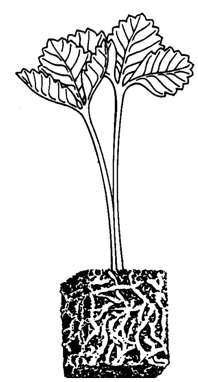

Figure 1. Plug plant

Dormant or frigo plants. Results of studies in the region show that traditional dormant plants (dormants) may be used in the system. They are less expensive than plugs, offer a larger number of variety choices, and allow for earlier planting. Establishment (planting and de-blossoming) is more expensive as it requires more hand labor. Also, there can be a decrease in plant viability with prolonged storage of the dormants at the nursery, which ultimately reduces plant stands and necessitates costly replanting. A mechanical transplanter that can be adapted to planting dormants is currently being developed. Dormants decrease plant costs and allow for early planting which reduces the overall risk of the system, and play an important role as the system is extended to more limiting northern locations.

Fresh plants. Fresh plants are the traditional plant type for this system in the Southeast. The plants are grown and shipped just prior to planting, typically mid-October in Florida. They are less expensive than plugs but since they are dug bare-root in Canada and shipped, they require special storage, rapid handling, and extended establishment overhead irrigation (a problem on heavy soils). Variety choice is limited and they are typically available too late for planting in the Northeast. An alternative, however, are the multiple crowned "mother plants" (MCF) that are a "by-product" of the digging and sorting of fresh plants. Two years of investigation revealed that the MCF plants were high yielding and superior to plugs and fresh single crown plants when planted on or after the recommended plug planting dates. This plant type can provide for late planting opportunities in northern locations but availability is limited.

<u>Planting dates</u>. Optimal planting date for individual sites must be determined to allow ample time to produce sufficient vegetative growth before flower bud initiation. This ensures development of the desired numbers of flower trusses which will result in high yields of quality fruit. Research has shown that the “optimal” planting date can vary from season to season depending on the subsequent fall growing season. However, late-August through early-September seems to be the best range for establishment of plugs in most locations in the Mid-Atlantic. FRC applied in October can increase yield and compensate for late plug planting (Table 3).

Table 3. Range of planting dates for various sites when establishing strawberry plasticulture plots with plug, dormants, and fresh plants.

Plant Types	Warmer Sites	Colder Sites
Dormant crowns	Mid-to-late July	Mid-June to Mid-July
Plugs	Early September	Mid-to-late August
Fresh single crown	Early September	plants not available
Fresh multiple crown	Early-late September	Early September available

As the system moves north, earlier planting become more critical however plug availability is currently limited. As improved tip/plug technology fosters plug availability in July or early-August, planting plugs in more limiting northern locations will become a reality (see section on future prospects). Dormants overcome planting date problems as they are available spring through summer. However, storage of the plants until the optimal planting dates (late- June through mid-July) may reduce plant viability and establishment. MCF plants can have high good yields even when planted up to 4 weeks later than recommended for plugs, but again availability is limited.

Cultivars. As with most horticultural crops, variety choice is very important for adaptation, disease resistance, season, and quality (Table 4). At the core of ICM principals is the utilization of an innate genetic resistance to pests as the most efficient means of control. Utilizing pest resistant varieties with site specific adaptation and tolerance to local stresses, including winter cold and summer heat, is always recommended. The plasticulture system is relatively new in the region, therefore, it is recommended that growers run their own trials to see what varieties perform best in their location while fitting into their marketing strategy. Varieties that have performed well in matted row and are popular in the market in the area may be worth trying on plasticulture.

‘Chandler’ is the current primary cultivar choice for this system. Developed in California, its high vigor, high productivity, extended harvest, as well as good color and shelf-life, make it well adapted to the system. ‘Sweet Charlie’ was developed in Florida as an early, large, good flavored berry for the system. It has anthracnose tolerance and is, therefore, amenable to carry-over. It is recommended for Mid-Atlantic locations from Southern New Jersey and south, but will not yield as high as ‘Chandler’. It has not sized well and blossoms are routinely killed by spring frosts in more northern sites.

Considerable research on testing Eastern-adapted varieties in plasticulture has been conducted with both dormant and plug plants. Many eastern cultivars have proven to be high yielding, large fruited, pest resistant, and offer early season extension over ‘Chandler’. ‘Earliglow’ has been extremely early in this system, with a significant portion of its fruit harvested before the other varieties started coming on. Quality has been excellent and size was good. A new release from the NJUS Breeding Program, ‘Avalon’ (NJUS8826-11 - patent pending) is early, very large, and has excellent fruit quality, however, yield can suffer when late frosts are common. ‘Noreaster’ had good productivity and very good fruit size. Flavor is generally good but it can have a “grapey” flavor under certain conditions.

Table 4. List of recommended strawberry varieties and their performance in plasticulture.

Variety	**Season**	**Yield**	**Fruit size**	**Firmness**	**Attributes**
Sweet Charlie	VE	M	M-L[1]	F	very good flavor anthracnose tolerance
Earliglow	E	M	S-M	F	very good flavor

NJ8826-11	E	M	M-L	F	very good flavor
Noreaster	E-M	M-H	M-L	M-F	productive
Chandler	M	VH	M-L	F	harvests over long season attractive berry
Allstar	M	VH	L	F	harvests over long season widely adapted good sweet flavor
Seneca	M	VH	L	VF	attractive berry very firm - good shipper
Jewel	M	H	L	F	attractive
Latestar	M-L	VH[2]	M-L	M	very productive
Marmolada	M-L	VH[3]	M-L[3]	F	very productive

[1]Sweet Charlie does not size as well in colder locations
[2]Latestar quality, productivity, and firmness have been best in mountain locations.
[3]Marmolada requires higher nitrogen input than other varieties for maximum yield, size, and symmetrical fruit.

‘Allstar’ has been a consistently good performer over many years and locations. It is very productive, has large size, good flavor, and is very firm. ‘Allstar’ is recommended for plasticulture production, especially where it has performed well in matted row. ‘Seneca’ has been very productive, with good fruit size, and excellent color and firmness, especially in Southern N.J. Fruit flavor, however, can be less that the high quality that is desirable if not picked red ripe. ‘Jewel’ performance has been comparable to ‘Seneca’, with slightly better flavor. ‘Latestar’ has been very high yielding with good fruit color and good firmness in mountain locations. Fruit size can fall off at the end of the season, and fruit firmness can also be limiting under warm ripening conditions. ‘Marmolada’ has consistently been among the highest yielding varieties. The fruit can be very irregular if N nutrition is insufficient, and flavor can also be limiting for direct fresh market.

Plant Spacing. Late season, high density planting (non-runnering) promotes high yields, large fruit size, and improves efficiency by promoting fruit production over runner production. The quantity of plants per acre depends on row center distance (example: 60" (5') centers x 12x12" within ‘17,400/A). Research has shown that 12 inches between plants (staggered double row) is the most efficient *in-row* spacing for most location. However, on fertile soils that induce high vigor, the spacing may be stretched to 18 inches, saving money on plants. Conversely, when planting later than the recommended planting dates, tighter density (9 inches) may compensate and maximize yield per acre. Also, expanding the *between row* spacing from 12 to 18 inches can increase yield and quality without increasing plants costs. Care must be taken, however, to insure that there is still adequate bed height and side bed area for the fruit to hang down without contacting the soil.

Figure 2. Diagram for plant spacing in a plasticulture production system.

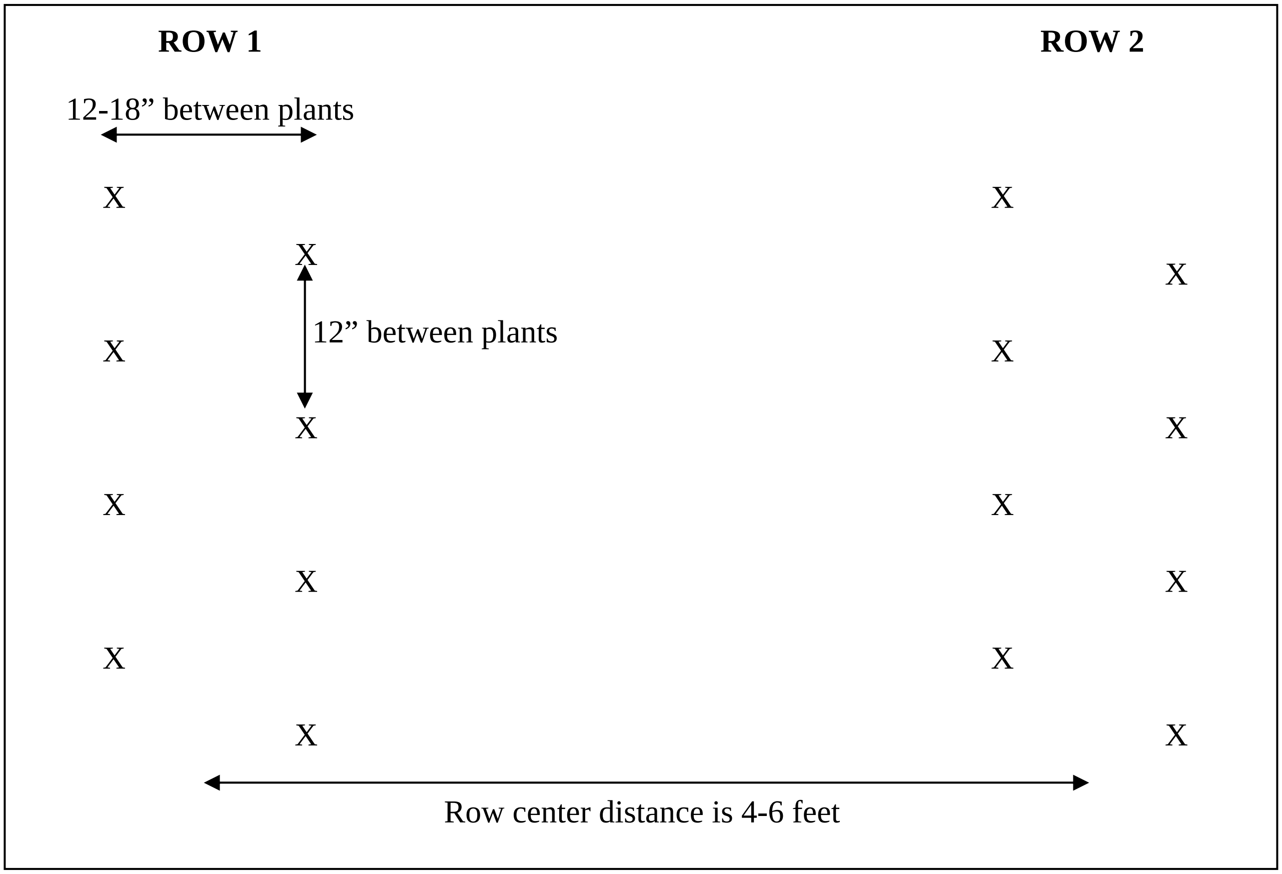

Table 5. Required plant numbers per acre for a given spacing between and within rows.

Spacing within row (in.)	**Spacing between rows (ft.)**		
	4	**5**	**6**
9	32,670	26,136	21,780
12	21,780	17,424	14,520
18	14,520	11,616	9,680

Planting procedure. Much of the planting of plugs can be mechanized. The plastic can be cut, starter fertilizer injected, the hole made, and the plant placed with a mechanical water-wheel transplanter. The water wheel can also be used for the initial procedures when planting fresh and dormant plants, except that the actual planting must be done by hand to insure proper planting depth. There is currently research being conducted to create a mechanical transplanter that will accommodate dormant plants.

Overhead irrigation at planting is desirable to cool plants and plastic in warm weather. Irrigate through trickle to continue establishment and maintenance. Be careful not to over-irrigate through the trickle before there is adequate root growth for absorption, as this will lead to wasteful leaching of incorporated nutrients.

Maintenance and Post-Planting Procedures

Maintenance between rows. The plastic mulch provides an effective barrier against weeds on the raised beds. Some hand weeding may be needed in the planting holes, especially on non-fumigated beds. Clean cultivation or turf can be used for between-the-row maintenance, however the overwhelming majority in the mid-Atlantic use clean cultivation. Herbicides, straw mulch, and/or cultivation can be used to maintain the vegetation free strip. Please contact your Agricultural Extension Office for local Commercial Strawberry Weed Management Recommendations. When cultivating, care must be taken not to hit the plastic bed sides or pull up the plastic that is under the soil to hold it in place. Many growers in the Southeast choose to establish a sod strip in between rows. This can be advantageous for erosion control and provides a stable base during wet springs.

Row covers. Spunbonded polyester or polypropylene floating row covers (FRC) are an integral part of the strawberry plasticulture system and a necessity for optimal production in the Mid-Atlantic region. FRC increase establishment costs but serve multiple beneficial roles in development and production which more than covers the added costs. FRC increase the temperatures under the covers, which is desirable for many reasons. When applied in mid-October (average daily air temps in low 70's) the elevated temperatures continue plant development and branch crown formation, and promote flower bud initiation, resulting in higher yields. The FRC warm the beds early in the spring, inducing earlier fruiting when the value of the crop is typically the highest (see Harvest Considerations below). Also in the spring, row covers maintain higher temperatures during the day and night which in many cases is adequate to protect from frost without overhead sprinklers (see frost protection below). The planting can be uncovered/recovered depending on the specific temperatures expected.

FRC reduce wind desiccation and protect the plantings from rapid changes in temperature, as well buffering from extremes in temperature. Uncovered plantings have experienced extensive deer predation in the fall and winter. Covers over the green plants tend to deter the deer. FRC also seem to allow the planting to escape tarnished plant bug and strawberry clipper damage through earlier bloom and physical exclusion.

The covers may be utilized a second and even third season when heavier materials (0.9 - 1.4 oz.) are purchased initially. The heavier materials are more expensive initially, but are more efficient and can be utilized for multiple years, reducing overall annual cost/acre. When applying the covers, it is preferable to hold down one side permanently with soil, etc., and the opposite side with something more temporary (irrigation pipe, bricks, UV stable sand bags, etc.) so that the field can be uncovered/recovered in the spring if there are late-frost warnings. Remove the FRC at the first signs of bloom to allow for bee pollination. Leaving on the covers on for too long into bloom may reduce fruit size and reduce light transmission to the leaves.

Straw mulch. As the system has moved north into climates with colder winters (Massachusetts to Ontario), growers have found success with straw mulch as winter protection instead of FRC. The straw is applied when the plants are dormant, as with the traditional matted row. Advantages of using straw are the low cost compared to FRC and the additional winter cold insulation. Straw covered beds are not subjected to the extensive fluctuations in temperature that can occur with FRC during warm sunny days in January and February. Drawbacks of using straw instead of FRC is the loss of the additional growth and flower bud initiation in the fall, the induction of the earlier crop in the spring, and late frost protection provided by the option of recovering with the FRC. It is also sometimes difficult to keep a thick enough straw layer on the plastic mulch covered raised beds.

The crop can still be staggered somewhat when using straw. To induce an earlier bloom, the straw is removed completely from the plants and bed in the early spring to expose the black plastic and warm the bed. If the bloom is to be delayed, the straw is removed only from above the plant itself and left on the bed to prevent sun penetration to the black plastic.

Frost Protection

Strawberry flower buds are susceptible to frost injury anytime after bud break, and must be protected if the fruit is to develop. Open strawberry flowers are more prone to freeze damage than green fruit that, in turn, are more sensitive than ripe fruit (Table 6). There are *many* factors that influence the actual damage, including the stage of development, position of blossom, severity/duration of the freeze, wind speed, cloud cover, and surface moisture.

Table 6. Critical Temperatures (air) for strawberry buds, flowers, and fruit[1]

Buds emerge	Buds Closed	Flowers Open	Small Green Fruit
10°F	22-27°F	30°F	28°F

Funt et al., 1985 [1]Duration of temperature for damage can be 20 minutes to 2 hours, depending on wind, humidity, and cultivar.

Irrigation. Overhead irrigation is the usual method for freeze protection. The irrigation water provides 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 31 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 (Table 7). However if wind speed is 10-15 mph or greater, water application with this technique can be erratic, and plants can be severely damaged. **WARNING: The use of overhead irrigation for frost protection is a sensitive procedure which result in MAJOR PLANT DAMAGE if not handled properly.** See Further Reading List for more details.

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 plants). The most accurate way to monitor temperatures under the covers and/or ice is to install thermocouples into the flowers that can be read externally with a digital thermometer without disturbing the cover. This way one can monitor more accurately when to turn the water on as the temperature drops and when to turn the water off when the ice is melting.

In general, when used without FRC, sprinklers are turned on at 34 F (higher temperature if very low dew point) and not turned off until the ice begins to melt and continues to melt when no additional irrigation is applied. Remember, turning off the sprinklers too early can result in evaporative ***cooling*** that can cause severe damage to the planting.

Table 7. Inches of water/hour to apply with wind speed (mph) and air temperature considered.

Air Temp., ^{o}F at canopy	Wind Speed, (mph)				
	0-1	2-4	5-8	10-14	18-22
27	0.10	0.10	0.10	0.10	0.20
24	0.10	0.16	0.30	0.40	0.80
20	0.16	0.30	0.60	0.80	--
18	0.20	0.40	0.70	1.00	--

Martsoff and Gerber, Penn State University

Row Covers. As mentioned previously, spunbonded floating row covers offer two major benefits in frost protection. Growers utilizing FRC will realize several (2-5) degrees of protection just from the covers, especially with residual heat built up under the covers. Row covers should be reapplied early in the day to trap latent ground heat whenever an overnight frost/freeze is anticipated.

When more severe frost/freezes are anticipated, supplemental overhead irrigation can be applied directly *over* the covers. Irrigation applied over the covers is more effective and less risky than irrigation on exposed plants, as it is easier to maintain an even ice coating over the FRC. When using irrigation over FRC with thermocouples to monitor, the sprinklers do not need to be turned on until *the blossom* temperatures under the cover have dropped to 31 F. On many nights these few extra degrees can be enough to avoid the need for irrigation. And the water can be turned off as soon as the blossom temperature under the cover rises to 31 F again. If temperatures permit, remove the FRC soon after irrigation to allow for drying and pollination.

Pest Control

The plasticulture system is based on integrated crop management (ICM) practices that avoid and/or reduce pest pressure. Late summer planting affords relief from the heat, drought, weed and disease pressure of mid-summer. The system decreases the dependency on chemical pesticides by maintaining a microclimate that is not conducive to pest development, and by physically excluding pests from the susceptible plant material.

Black plastic mulch can eliminate or reduce the need for herbicides and fumigation against weeds, since it blocks the light needed for weed seed germination and development. The raised bed and black plastic mulch decrease disease pressure by keeping the fruit cleaner and dryer, decreasing *Botrytis* fruit rot and leather rot and increasing shelf life. The raised bed allows greater air movement through the vegetative canopy, promoting quicker drying of morning dew and rainfall, thereby reducing the duration of disease promoting conditions on leaves and fruit. The beds also allow the soil to drain more efficiently, reducing or eliminating root diseases such as red stele, black root rot, and *Verticillium* wilt.

Plants are only in the field for a short period of time in the annual system, thereby avoiding many pest problems, since they have fewer chances to be exposed to pests. Plant trash is greatly reduced as leaves are much younger, greatly decreasing the inoculum source for grey mold (*Botrytis*), other fruit rots, and leaf spots. Leaf spot cover sprays in the fall are eliminated as the growth is much younger and has not been exposed to inoculum during the heat of the summer.

Root weevils have not been a pest in this system since plants are only in the field for one or two seasons. Sap beetles are very rarely found in first year beds and greatly reduced relative to matted row in second year fields. Floating row covers (FRC) aid in avoiding insect infestations, by physically excluding pests, such as tarnished plant bug. Since the FRC promote an earlier crop, they also serve to accelerate plant development past the susceptible stage before the pests such as the strawberry clipper emerge. However, the increased heat under the FRC in the dormant season has increased aphid and mite pressure. It is important to scout for mites and aphids and treat when necessary before applying the cover. Please contact your local Extension Office for Commercial Strawberry Pest Management Recommendations for your area.

Pithium and *Rhizoctonia*, which can come in on transplants, can be more of a problem on fumigated soils, possibly due to lack of competing microorganisms. Starting with healthy transplants from a reputable certified nursery is of great importance to avoid problems. When rooting tips to make plugs, care must be taken to avoid overwatering in the propagation bed.

If beds are carried over for a second growing season the traditional strawberry pests can become more of a problem. Anthracnose, which is typically a problem in warmer southern climates, can be a major disease problem in this system, especially in carry-over beds. Again, always start with disease free tips and plugs, preferably greenhouse produced or from a northern nursery. Also, care must be taken during renovation to remove the old leaves *and fruit* from the field to reduce disease inoculum.

Deer. The fresh tender green leaves present fall through spring make deer grazing a major problem in this system. If the leaves are mowed off by deer in the fall/winter, yield will be reduced the following season. Many of the techniques used to protect other crops, including fencing (exclusion and electrified), fenced in dogs, audio scare devices, repellants, and harvest are viable options.

Harvest Considerations

The raised bed, black plastic, and FRC all work together to advance bloom and harvest. Warm sunny springs can induce up to one month earlier harvest than traditional matted row. This can be advantageous since the early fruit can typically command the highest value at the market. Since strawberries are one of the earliest crops of the season, an early harvest can be used to get early cash flow. The down side is that early bloom means increased risk of frost damage and greater need for frost protection.

Conversely, when the early crop is not desired, to avoid irrigation for frost protection, or if a later harvest is desired, the FRC can be removed early (just as growth begins in the spring). Research in Northern New Jersey has shown that bloom and harvest can be delayed up to two weeks by removing the FRC early. However, yield was also down when the covers were removed early. Care must be taken to put the cover back on if the temperatures are going to dip low enough to cause damage to vegetative parts of the plants (see Table 6 in frost protection section). This early cover removal technique can also be used to stagger the harvest by removing the cover from a portion of the field.

Total production, timing of first harvest, and length of harvest can vary from season to season, depending on the growing conditions from planting until bloom. Also, it is sometimes desirable to estimate the timing and amount of harvest for marking purposes. By monitoring plant development it is possible to estimate yield and date of first harvest to notify potential markets and maximize profits (see Further Reading list).

Harvest begins earlier on plasticulture than matted row, and staggering the harvest with a succession of varieties is possible. ‘Sweet Charlie’ is the earliest of the varieties and ‘Earliglow’ and ‘Avalon’ (NJ8826-11) are also very early on plastic. The relative harvest season for varieties on matted row is the about the same in plasticulture.

An interesting difference between matted row and plasticulture is the duration of harvest. ‘Chandler’ on plastic will typically be harvested for about four to five weeks; six weeks is possible in cool seasons. ‘Chandler’ and ‘Sweet Charlie’ are also prone to Asecond flushes@ of harvest, where just about a week after the bulk of the harvest is over there is an additional flush of large ripe fruit from secondary branch crowns that extends the harvest.

The early, large, clean, high quality, local fruit has commanded premium prices at the wholesale and direct market level. This high return has been helpful to cover not only the high establishment costs, but to give a significant return per acre (see Economic consideration section). Ease of harvest of the individual plants on high plastic beds reduces harvest costs and improves efficiency. This also allows the harvest to take place early in the morning when temperatures are still cool, which is best for quality and shelf life. Harvesting shortly after a rain is feasible with plasticulture, as the beds and fruit dry out quickly.

Harvesting early when the fruit is still cool coupled with rapid removal of field heat will maximize the shelf-life of strawberries. Forced air cooling is the quickest and most efficient way of removing the majority of the field heat (see Further Reading). Once cooled, the flats can be stacked until the fruit is marketed. If the fruit is to be sold direct retail, it is best to only pick what is to be sold that day. Again, if the fruit is picked while still cool, it does not need to be refrigerated, as the fruit may loose their sheen if cooled and warmed.

The high yields also make u-pick a lucrative option, however once customers get accustomed to the ease of harvesting on raised beds with plastic, it is difficult to get them to pick on the matted row. Many growers are using their first year fields for wholesale or direct retail and allowing u-pick on the renovated second year fields.

Renovation and Vegetable Double-Cropping

Plasticulture establishment costs are high, so research has been conducted to investigate options for a second year of strawberry production and/or double cropping with vegetables. These options make optimal use of the beds, plastic, fertility, and trickle by producing a second crop reusing all of the original inputs. Triple cropping experiments are also being investigated. The following are considerations and techniques for the various alternatives.

<u>Considerations</u>. University research as well as commercial grower experience has shown that both second year cropping of berries and vegetable double cropping can be profitable if handled properly. Which option employed should be determined by the overall crop production and marketing strategies employed in the operation.

Renovated "carry-over" strawberry beds can be very high yielding, however, there is a decrease in average fruit size that may limit marketing options. First year beds that have not produced yields that are expected for the system are best suited for second year production, since the plants are not as dense. Second year beds, however, have an increased risk of diseases and pests, including Anthracnose and sap beetles. ‘Sweet Charlie' is a better choice for renovation than ‘Chandler' because of the risk of Anthracnose.

Double-cropping of vegetables in the same season as the strawberry harvest can be very profitable, as long as the proper choice of crops is made as determined by the remaining length and conditions of the growing season. As always, one should always know the specific cultural practices and market demand before planting any crop.

<u>Renovation techniques for second year production.</u> Soon after strawberry harvest has ended, mow the leaves to stimulate healthy new growth. Cut the leaves as low as possible without damaging or pulling up the crowns. It is important to remove the old leaves *and fruit* from the field to reduce disease inoculum.

Fields that have had high production during the first fruiting season tend to have high branch crown numbers (5-8) and will benefit from crown thinning. Crown thinning is accomplished after mowing by inserting an asparagus knife or sharp object through the center of the crown and removing about half, being careful to avoid damaging the remaining section.

It is important that beds are trickle irrigated throughout the heat of the summer, however, it is best to hold back fertilizer unless plants show stress or deficiency. Fertigation of 20-30 lbs of actual N is applied in late-August or early-September.

The plastic mulch will continue to provide an effective barrier from weeds on the raised beds for the second season providing that it was not substantially damaged during the first harvest. For between-row weed control, roto-tilling, straw, or herbicides can be used; please contact your local cooperative extension office for commercial strawberry pest control recommendations. Remember, **herbicides should *never* be sprayed *over* the mulched beds, as runoff into holes will greatly increase the actual application rate.**

Second year beds do not need early applied floating row covers as do first year plantings. To keep costs down, many commercial growers in Southern New Jersey do not cover the renovated plantings at all over the second winter, while others utilize the "used" covers from the previous season. The high first year inputs coupled with very little input necessary for a second year of harvest has prompted many growers to carry over their beds. Some growers have even been successful in keeping the fields for a third season.

Techniques for vegetable double-cropping. Soon after fruiting, the strawberry plants are killed with a contact herbicide. Dead plants are left in place to retard weed growth in the holes and keep the bed intact. It is best to wait for some rain before planting to prevent problems from herbicide residue on the plastic bed.

Plant choices. The timing of the strawberry harvest can be important when deciding which vegetable to double-crop, especially in locations with short growing seasons. In seasons when the strawberry harvest finishes early, long season crops such as tomatoes, peppers, melons, and pumpkins are a viable option. In seasons when the strawberry harvest ends late, short and/or cool season crops such as squashes, beans, greens, and Cole crops (broccoli, cauliflower, cabbage, collards, and brussel sprouts as transplants) are the preferred candidates. Herbs and cut flowers could also be viable options. Success with each crop requires care as to the specific requirements for water, nutrients, and pest control for that crop. Again, see the local commercial production recommendations for details.

Economics

The plasticulture strawberry production system has shown consistently high commercial profitability in the South and Mid-Atlantic (Table 7). The system costs more up-front and overall than the traditional matted row system, however, bottom-line profitability has been higher. Plasticulture establishment inputs range from $5-7000/A while matted row costs are typically $2,500-4,500/A. Commercial yields are ranging from 10-22,000 lbs/A for plasticulture (4-12,000 lbs/A for matted row). In addition, the excellent fruit size, and very high quality plasticulture fruit commands a higher price. The plasticulture berries are being sold for $1.75 to $3.75/quart; on the average this is 25-40% higher than matted row berries. If a commercial grower harvests 15,000 lbs/A, sells the fruit for $2.00/lb, with $13,362 expenses (including harvest), ***the net is about $16,638/A***. An average matted row scenario of 10,000 lbs/A at $1.33 with $7,811 in expenses equals ***$5,489/A net*** (see detailed economic summary in attached supplements). ***Plasticulture profitability is 300% higher*** ($16,637-$5,489), not including the potential profits from vegetable double cropping. This profitability makes strawberry plasticulture one of the most profitable crops on a per acre basis.

Although the majority of the fruit is sold direct retail for the highest margin, a few commercial growers have worked their fruit into the large commercial supermarket chains in the area. They are successfully competing with California berries due to the superior quality and the high demand and margin for local produce. The value of the fruit has been even higher in the more northern locations, and that has helped to more rapidly spread the system to those areas. There are also a few organic growers in the region who are using the plasticulture system and marketing the fruit for between $2.00 to $3.75/***pint***. This system has great potential for organic production, as described in the nutrition and pest management sections.

Table 7. Economic summary of plasticulture production and marketing.

Operation - Year 1	Amt		Cost
Plow			35.00
Disk/Harrow			15.00
Lime	2	tn	50.00
Fertilizer			
10-10-10	300	lb	39.00
Ammonium Nitrate	100	lb	10.00
Labor/Machine	0.3	hr	7.46
Form Beds	2	hr	82.92
Herbicide (@planting)			
Sinbar 80WP	4	oz	6.40
Devrinol 50WP	3	lb	27.00
Labor/Machine	1	hr	25.75
Plastic			174.24
Drip Tube			191.66
Fumigation			
Vapam thru Drip	50	g	500.00
Custom			
Labor/Machine	2.5	hr	40.30
Planting			
Plants	17424		2613.60
Labor/Machine	8	hr	244.16
Irrigation	8	hr	128.96
Install Rowcover			
Material			1089.00
Labor	4	hr	24.00
Fertilizer			
Liquid Fertilizer	10	g	12.50
Labor/Machine	2.5	hr	40.30
Hand Weeding - Labor	2	hr	12.00
Pesticides (5x)			
Thiodan 3EC	1.3	qt	11.70
Captan 50WP	9	lb	22.50
Benlate 50WP	1	lb	16.00
Rovral 50WP	2	lb	40.00
Kelthane 4EC	1	qt	50.00
Labor/Machine	2.5	hr	64.38
Frost Protect (Water)		hr	0.00
Frost Protect (FRC)	6	hr	36.00
Remove FRC & Store	4	hr	24.00
Irrigation	20	hr	322.40
Harv. Labor (lbs/hr) *	30		3000.00
Quart/16oz Cont.**	15000		3000.00
8 Qt Carriers	1875		1406.25
Yield (lbs)			15000
Total Expenses			13362.48
Avg Price/lb			2.00
Total Income			30000
Net Income			16637.52

* Harvest costs assume 40% increase in picking efficiency with plasticulture system.

** Matted Row marketed in pulp qts, Plasticulture in 16oz clamshells.

Future prospects

Development of a local tip nursery industry to support plasticulture. The demand for plugs of the Eastern varieties has fostered the development of a “new” nursery industry in the Mid-Atlantic region, including both field and greenhouse tip production. Production of tips for plugs in the greenhouse will permit better control of production, allow earlier planting for northern locations, and almost unlimited choices of varieties. Establishing a plug nursery (to go along with the strong existing dormant industry) that can “insure” plant/variety availability in the region will expedite the expansion of the production system within the region.

Breeding specifically for plasticulture. Development of varieties which are regionally adapted and have the vegetative and reproductive traits that are optimal for the production in the system is the next step to increase production efficiency. A new cooperative breeding program has been established between the University of Maryland and Rutgers University to breed strawberry varieties specifically for the system. Unique and diverse germplasm has been obtained that contain traits to be incorporated that could make the system completely pesticide free and significantly extend the geographic range and seasons of production. Existing programs in Florida and North Carolina are currently breeding specifically for plasticulture and the USDA Strawberry Breeding Program in Beltsville, Maryland also tests many of selections on plastic.

Additional R&E. The plasticulture system has shown good profitability and great potential in many sections of the region. Research and extension programs have opened the door to new and exciting opportunities to improve productivity and decrease costs. Preliminary results with dormant plants ($90/1000 plants) instead of plug plants ($140/1000 plants) have been promising. Preliminary studies with hoops over the beds with FRC and or plastic offers multiple advantages: Uniform plant development and fruiting; extension of the flower bud initiation period in the fall; added protection from the adverse winter environment; greater protection against frost/freeze damage, and season extension through earlier fruiting when the prices are the best. High tunnels take that concept even further for season extension. Also, as more commercial growers are maintaining planting for a second fruiting season, research is needed for determining the best renovation practices, including mowing, crown thinning, fertilization, and disease monitoring/control.

Conclusions

High density strawberry plasticulture production systems can have increased profitability over conventional matted row plantings. This system is rapidly expanding in the Mid-Atlantic and Northeast, however it is best to start with small acreage and increase as knowledge and experience increases. Additional investigations into varieties, planting dates, microclimate, etc., are being conducted to broaden the adaptation and decrease the potential "risk" of the system.

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