VEGETABLE PRODUCTION USING PLASTICULTURE

William James Lamont, Jr.
Department of Horticulture
114 Tyson Building
The Pennsylvania State University
University Park, Pennsylvania 16802-4200
USA

ABSTRACT

Plasticulture is a system of growing crops in a way so that a significant benefit is derived from using plastic polymers. The discovery and development of polyethylene polymer in the late 1930s, and its subsequent introduction in the early 1950s in the form of plastic films, mulches, and drip-irrigation tubing and tape, revolutionized the commercial production of several vegetable crops and gave rise to plasticulture. The later discovery of other polymers such as polyvinyl chloride, polyproplene, and polyesters, and their use in pipes, fertigation equipment, filters, fittings and connectors, and row covers further extended the use of plastic components in this production system. The plasticulture system consists of plastic and non-plastic components: Plastic mulches, drip irrigation, fertigation/chemigation, fumigation and solarization, windbreaks, stand establishment technology, seasonal-extending technology, pest management, cropping strategies, postharvest handling and marketing.

INTRODUCTION

To be competitive in today's marketplace, vegetable growers must strive continually for high quality, superior yields, and extended production cycles that include spring and autumn crops. Plasticulture is a management tool that enables vegetable producers to realize greater returns per unit of land.

Such a system may offer many benefits:

- Earlier crop production (7 to 21 days earlier);
- Higher yields per hectare (two to three times higher);
- Cleaner and higher quality produce;
- More efficient use of water resources;
- Reduced leaching of fertilizers, especially on light, sandy soils;
- More efficient use of fertilizer inputs through fertigation technology;
- Reduced soil and wind erosion;
- Potential decrease in the incidence of disease;
- Better management of certain insect pests;
- Fewer weed problems;
- Reduced soil compaction and elimination of root pruning; *and*
- Opportunity to double- or triple-crop with maximum efficiency.

To realize these benefits, the grower needs to integrate the various components of a plasticulture system. The components include plastic mulches, drip irrigation, chemigation/fertigation and soil fumigation or solarization (which may or may not be needed depending on the location). Other components are wind-breaks, stand establishment technology, season-extending technology, pest management, cropping strategies, and marketing. The plasticulture system can be used effectively by growers with a small or large land holding. The basic principles and intensive management required to operate a plasticulture system successfully are similar, regardless of the size of the operation. A component list for a ten hectare plastic mulch/drip irrigation system is presented in Table 1. The crops

Keywords: drip irrigation, fertigatiion, plastic mulches, season extension technology

that have shown significant increases in earliness, yield, and/or fruit quality with the use of plasticulture include muskmelon, tomato, pepper, cucumber, squash, eggplant, watermelon and okra. Other crops such as sweet corn, snap bean, pumpkin, decorative gourds, crucifer crops and herbs have shown similar responses and may lend themselves to double- or triple-cropping strategies.

PLASTIC MULCHES

Plastic mulches have been used commercially on vegetables since the early 1960s. Much of the early university research before 1960 was conducted on the impact of color (black or clear plastic film) on soil and air temperature, moisture retention and vegetable yields (Emmert 1957). Most plastic mulches used in the United States are made of linear low- or high-density polyethylene. They are .012 to .031 mm thick, 122 to 152 cm wide, and on rolls 607 to 1463 m long, depending on the thickness of the mulch. Linear high-density polyethylene is used to reduce weight and cost, and is stronger than the same thickness of low-density polyethylene. The plastic mulch is either slick (smooth), or embossed with a diamond-shaped pattern. This pattern helps reduce

Table 1. Components for a nine-hectare plasticulture vegetable production system

Component description	Quantity	Unit	Unit price (US$)	Total price (US$)
Engine and pump (14-hp engine and Berkley pump)	1	1s	4,000.00	4000.00
24" media filter and fertilizer injector		pr	3200.00	3200.00
Layflat, 4"	1800	ft.	1.01	1818.00
Layflat, 3"	1500	ft.	0.81	1215.00
Drip tape (7500'/roll)	20	ea.	135.00	2700.00
Plastic mulch (1.0 mil black embossed 4000'/roll)	40	rl	80.00	3200.00
Zone control/PRV valve, 3"	4	ea.	180.00	720.00
Insert tee, 4"	1	ea.	131.62	31.62
PVC tee (Sxt), 4" x 3"	4	ea.	14.34	57.36
Insert ELL, 4"	2	ea.	21.25	42.50
Insert x slip adapter - 4"	6	ea.	11.26	67.56
PVC bush, 4" x 2"	2	ea.	5.35	10.70
PVC tee (S x T) - 3"	4	ea.	10.87	43.48
PVC nipple, 3" x 4"	8	ea.	5.52	44.16
Insert x slip adapter, 3"	8	ea.	8.92	72.36
Insert male adapter, 3"	8	ea.	5.30	42.40
PVC ELL (S x T), 3"	8	ea.	6.80	54.40
PVC bush, 3" x 2"	8	ea.	2.28	18.24
PVC nipple, 2" x 4"	10	ea.	1.49	14.90
Air relase valve, 2"	10	ea.	27.00	270.00
PVC ELL, 2"	2	ea.	1.38	2.76
Hose clamp, 4"	14	ea.	1.72	24.08
Hose clamp, 3"	16	ea.	1.47	23.52
Tape x layflat connectors	480	ea.	0.95	456.00
Layflat holepunch	2	ea.	75.00	150.00
Subtotal				18,278.04
Tax 1%				182.78
Total				18,460.82

* Only plastic mulch and drip irrigation components are included. The plan assumes the field to be level, with a supply of surface water (pond) adjacent to the field. This system is basic, with media filters, venturi injector, and 14-hp engine and pump. Additional equipment that should be considered includes secondary filters, additional pressure regulators, pressure gauges, and water meters. Water samples and field topography should be analyzed before actual drip design. No sales tax. freight, or field labor were included in the estimate.

expansion and contraction, which results in the loosening of the mulch from the raised bed. The raised bed is generally 10 - 15 cm high and 75 cm wide, and has a slope of 3 cm from the center to the edge. Soil under a raised bed will warm up more quickly in the spring, and will also shed excess water from the middle of the bed, thus keeping the crop plants drier and preventing deterioration in the quality of the product.

Plastic mulches directly affect the microclimate around the plant by modifying the radiation budget (absorbitivity vs. reflectivity) of the surface and decreasing the soil water loss (Liakatas *et al.* 1986, Tanner 1974). The color of a mulch largely determines its energy-radiating behavior and its influence on the microclimate around a vegetable plant. Color affects the surface temperature of the mulch and the underlying soil temperature. Ham and Kluitenberg (1994) found that the degree of contact between the mulch and soil, often quantified as a thermal contact resistance, can affect greatly the performance of a mulch. If an air space is created between the plastic mulch and the soil by a rough soil surface, soil warming can be less effective than expected.

The soil temperature under a plastic mulch depends on the thermal properties (reflectivity, absorbitivity or transmittancy) of a particular material in relation to incoming solar radiation (Schales and Sheldrake 1963). Black plastic mulch, the predominate color used in vegetable production, is an opaque blackbody absorber and radiator. Black mulch absorbs most ultraviolet (UV) visible and infrared wavelengths of incoming solar radiation, and re-radiates absorbed energy in the form of thermal radiation or long-wavelength infrared radiation. Much of the solar energy absorbed by black plastic mulch is lost to the atmosphere through radiation and forced convection. The efficiency with which black mulch increases soil temperature can be improved by optimizing conditions for transferring heat from the mulch to the soil. Because thermal conductivity of the soil is high relative to that of air, much of the energy absorbed by black plastic can be transferred to the soil by conduction, if contact is good between the plastic mulch and the soil surface. Soil temperatures under black plastic mulch during the daytime are generally 2.8°C higher at a 5 cm depth, and 1.7°C higher at a 10 cm depth, compared to those of bare soil.

In contrast, clear plastic mulch absorbs little solar radiation but transmits 85-95%, the extent of transmission depending on the thickness and degree of opacity of the polyethylene. The under surface of clear plastic mulch is usually covered with condensed water droplets. This water is transparent to incoming shortwave radiation but is opaque to outgoing longwave infrared radiation, so much of the heat lost to the atmosphere from a bare soil by infrared radiation is retained by clear plastic mulch. Thus, daytime soil temperatures under clear plastic mulch are generally 4-8°C higher at a 5 cm depth, and 3-5°C higher at a 10 cm depth, compared to bare soil. Clear plastic mulches are generally used in the cooler regions of the United States such as the New England states. Using clear plastic mulch will require the use of a herbicide, soil fumigant or solarization to control weeds.

White, coextruded white-on-black or silver reflecting mulches can result in a slight decrease in soil temperature (-1°C at 2 cm depth, or -0.4°C at a 10 cm depth, compared to bare soil), because they reflect back into the plant canopy most of the incoming solar radiation (Ham *et al.* 1993). These mulches can be used to establish a crop when soil temperatures are high and any reduction in soil temperatures is beneficial. Depending on the degree of opacity of a white mulch, the use of a fumigant or herbicide may be needed to control weeds.

Another family of mulches includes the wave length-selective or photoselective mulches, which selectively transmit radiation in some regions of the electromagnetic spectrum but not in the photosynthetic wavelength (Loy *et al*. 1989). These mulches absorb protosynthetically active radiation (PAR) and transmit solar infrared radiation, providing a compromise between black and clear mulches. These infrared-transmitting (IRT) mulches give the weed control benefits of black mulch, but are intermediate between black and clear mulch in terms of increasing the soil temperature. The color of these mulches can be blue-green or brown. These mulches warm the soil in the same way as clear mulch, but without the accompanying weed problems.

Additional colors that are currently being investigated are red, blue, yellow, gray, and orange. All of these have distinct optical characteristics and thus reflect different radiation patterns into the canopy of a crop, thereby affecting plant growth and development (Decoteau *et al.* 1989, Orzolek and Murphy 1993). In a study by Loy *et al.* (1998) differences in reflectivity between a red, black, and red on black mulch were minimal at 40 cm above the mulch surface on the shaded side of the row. Loy *et al*. suggest that for red mulch reflectivity to have a more consistent effect on biomass accumulation and yield in tomato, the rows may need to be oriented in a north-south direction.

Light reflectivity may affect, not only crop growth but also insect response to the plants grown on the mulch. Examples are yellow, red, and blue mulches, all of which increased green peach aphid populations (Orzolek and Murphy 1993). The yellow color was especially altractive to pests, and drew increased numbers of striped and spotted cucumber beetles. Yellow has long been used in greenhouses to monitor insects. Mulches with a printed silver surface, or shiny silver coextruded mulches, have been shown to repel certain aphid species and reduce or delay the incidence of aphid-borne viruses in summer squash (Lamont *et al.* 1990). Like a white mulch, the gray mulches may transmit enough solar radiation to require a herbicide or fumigant for preventing weed growth. Some of these colored mulches (eg. the blue and the red) have a dramatic impact on soil temperatures. In one field trial, they raised soil temperatures to 75°C and 76°C, respectively, at a depth of 2 inches when the ambient air temperature was 40°C (Lamont, unpublished data). A lot of research still needs to be done on the effect which different colors have on the microclimate, crop growth and yields.

Photodegradable plastic mulch is an alternative to the conventional plastic mulches with all their retrieval and disposal problems (Ennis 1987). Although photodegradable plastic looks very much like other plastic mulches when it is installed, it can be broken down by ultraviolet sunlight. The actual rate of breakdown depends on several factors, including temperature, the extent to which the plastic is shaded by the crop, and the amount of sunlight received during the growing season. When using photodegradable plastic mulch, it is important to keep in mind that decomposition of the buried edges (commonly referred to as the "tuck") is initiated by lifting them out of the soil and exposing them to sunlight.

Research has also been conducted on a photodegradable mulch overlay system, in which the top layer of black photodegradable mulch degrades and increases the exposure of a white nondegradable layer (Graham *et al.* 1995). This particular change would lower the soil temperature later in the growing season. The potential use for this would be in a double-cropping system, in which the same mulch is used for spring and fall crops (e.g. bell peppers planted in the spring followed by squash in late summer). The concept could be pursued further with several color changes during the season. The color changes would be accomplished by having more than one coextruded layer of differently pigmented photodegradable plastic on top of the nondegradable mulch.

DRIP IRRIGATION

Drip irrigation is an important part of a plasticulture production system. It should be used with plastic mulch for the greatest benefits. Drip irrigation can save as much as 80% of the water used by other irrigation methods (Bogle and Hartz 1986). You also can double- or triple-crop by fertilizing succeeding crops through the drip irrigation tape or tubing, using a fertilizer proportioner. This allows more production for the same investment in plastic mulch and drip irrigation equipment. The major components of a drip irrigation system are

- Drip tubes or drip tapes;
- Filters—media, screen or disc;
- Pressure regulators—spring or valve;
- Valves—hand-operated, hydraulic, or electric;
- Controllers, which may range from simple time clocks to complex computer controlled units that run many zones; *and*,
- Injectors, which introduce chemicals and fertilizers into the irrigation system.

Because vegetables are planted in rows, a drip tube or tape is used to wet a continuous strip along the row. Drip tape is generally 8 mm thick, and is used for one year and then discarded. Drip tube is heavier, 20 mm thick, and used repeatedly for several years. The outlet holes are spaced from 20 to 60 cm apart, although 30 cm is the most common spacing for vegetable crops.

The source of the water supply for drip irrigation is extremely important. It includes wells, ponds, lakes or municipal water systems. Well-water is generally fairly clean, and may require only a simple screen or disc filter to remove particles. It is very important to determine if precipitates or other contaminants in the water could cause a plugging problem. Water analysis is essential before installing a drip system. Municipal sources generally provide documentation of water quality, which makes it easier to spot potential problems.

Surface water such as streams, ponds, pits, or rivers contain bacteria, algae, or other aquatic life. Consequently, the use of agricultural sand media filters with surface water is necessary. These filters are generally more expensive than screen or disc filters. Assistance from an irrigation dealer or extension agent familiar with drip irrigation system design and installation is strongly recommended, and can be very helpful in avoiding problems later. Other major considerations are crop water management. This depends on soil type and the stage of crop growth.

FERTIGATION

Once a drip irrigation system has been installed, it makes economic and environmental sense to fertilize the crop via irrigation water. If done properly, this results in more efficient use of fertilizers, and probably reduces fertilizer contamination of groundwater. More nutrients are taken up by the crop, and fewer leach down below the plant root zone (Hochmuth 1992).

In its broadest sense, fertigation means feeding a crop by injecting soluble fertilizers into water in the irrigation system. There are a variety of ways to introduce chemicals into a drip system, based on different kinds of pump — small electric powered pumps or those powered by irrigation water, venturies, pressure differential tanks, bladder tanks, and gravity. Each drip system may utilize a different method or a combination of methods. If fertigation is to be successful, irrigation scheduling must be coordinated closely with the nutrient needs of the crop (Clark *et al.* 1991). **To be a good fertigator, a grower first needs to be a good irrigator.**

STRIP FUMIGATION AND SOIL SOLARIZATION

In many production areas of the United States, especially California and the Southeast, it is necessary to sanitize the soil in which greenhouse or mulched crops are grown. Plastic mulches are used with chemical fumigants, or as covers during soil solarization. In row or strip application of a fumigant, the amount of material actually applied per hectare will depend on the row width, and will be a percentage of the broadcast rate. The temperature of the soil should be at least 10°C, and soil should be well worked, free from undecomposed plant debris, and have adequate moisture for seed germination. If the weather and soil are warm, the fumigant should escape through the plastic mulch in 12-14 days. Fumigation is used primarily for nematode control, but a multipurpose fumigant can also provide good control of soil-borne diseases (Scoville and Leaman 1965). Soil solarization is another way to control soil pests. Solarization describes a hydrothermal method of cleansing soil that occurs in moist soil which is covered by mulch film (usually clear) and exposed to sunlight during the hot summer months (Stapleton 1991).

WINDBREAKS

The use of windbreaks, whether permanent (trees) or annual (grain crops), is an important part of the plasticulture system of production, but is often overlooked. In the United States, windbreaks consisting of strips of winter wheat, rye, or barley are often planted to protect young vegetable seedlings from prevailing winds. A combination of permanent and annual windbreaks can modify wind profiles and influence temperatures and other microclimate features (Hodges *et al.* 1994). Windbreaks may also serve as a habitat for both beneficial and pest insects (Dix and Leatherman 1988). For maximum effectiveness, the grain strips should be planted in the fall. Each strip of grain crop should be 3 to 3.5 m wide (the width of a sowing drill). Enough room should be left between the strips for five or six mulched beds of vegetables, each around 2 m wide. Topdressing the strips in the spring helps to ensure a dense stand of grain.

Another option is to plant a solid grain cover crop in the fall. It is important to till the crop area early in spring, so that residues from the cover crop will not interfere with application of the plastic mulch, drip irrigation and fumigation (if required). Once wind protection is no longer required, the grain strips are mowed, and used as drive rows for spraying for insect and disease control, and later for harvesting.

STAND ESTABLISHMENT TECHNOLOGY

Crop establishment in a vegetable plasticulture production system involves either transplanting or direct seeding. Well-grow vegetable transplants in suitable containers are an integral part of this production system. For early harvests of pepper and tomato, large seedlings in large individual containers (cells) of 9-10 cm across are recommended. For other vegetable crops, a cell size around 5 cm in diameter is a good general recommendation. Transplants can be set by hand or machine. The following vegetables have been transplanted successfully: Tomato, pepper, eggplant, watermelon, muskmelon, honeydew, summer squash, cucumber, onion, and okra. In specialty or niche marketing situations, other crops such as sweet corn, herbs, leaf lettuce, and cole crops can also be transplanted. Mechanical seeders are available in single or multirow models that will plant directly through the plastic mulch. This equipment is good for direct-seeded crops of sweet corn and cucumber, as well as other crops. Some spacing recommendations are shown in Table 2.

TECHNOLOGY FOR EXTENDING THE HARVEST TECHNOLOGY

Row covers, high tunnels and low tunnels can make possible earlier crops of vegetables by creating a mini-greenhouse effect. The first row covers used were solid polyethylene sheeting that needed support and required venting during the day (Hall and Besemer 1972).

To eliminate the need for venting by hand, a variety of materials have been developed, including slitted polyethylene covers that require wire hoops; floating nonwoven sheets; a white point-bonded, polypropylene material; a spunbonded polyester fabric; and a polyethylene sheet with tiny pores (Wells and Loy 1985).

Row covers also help keep out insect pests (Natwick and Durazo 1985).

High tunnels are another option for producing vegetables in a plasticulture system. They can be used to extend the spring and fall growing seasons. High tunnels are covered with a single layer of polyethylene film (Wells 1991). The use of high tunnels is widespread in many parts of the world, especially in Asia and the countries of Spain and Italy.

PEST MANAGEMENT

Plasticulture system must have a good integrated program for insect, disease, and weed control. To obtain good insect and disease control, it is important to use a sprayer that generates sufficient pressure so that pesticide sprays penetrate to, and cover, the whole crop. This means using sprayers with pumps capable of generating over 200 psi, with appropriately sized nozzles. It is important to use chemical sprays efficiently, to control the targeted pest without damaging the environment. The use of an integrated pest management (IPM) approach, which combines the use of disease-resistant varieties with chemical and biological control practices, crop rotation, and effective monitoring, is recommended. Only approved herbicides for the vegetable being grown should be used between rows of mulched vegetable beds, because this should not be considered a fallow area. The use of low-pressure sprayers, coupled with shielded application of herbicides, is recommended for spaces between vegetable beds. This approach will protect the mulched crop from herbicide, so it will not be damaged by any concentration of herbicide in the planting hole (Bonnano 1996).

Reflective plastic mulches such as silver mulch have been shown to interfere with the movement of aphids. Aphids are common vectors of virus diseases on various vegetable crops (e.g., watermelon mosaic virus II, which causes green streaks in summer squash (Lamont *et al.* 1990) and mottling and green streaks in yellow squash, melons and pumpkins).

CROPPING STRATEGIES

Double- or Triple-Cropping

Double- or triple-cropping is another important component of the vegetable crop plasticulture system. One cropping scheme that has been investigated in the United States is broccoli or cabbage followed by yellow summer squash, which is then followed by broccoli, cabbage or Chinese cabbage (Marr and Lamont 1992). Another cropping scheme is strawberry followed by muskmelon (Lamont and Poling 1986).

In the event that the first crop is a failure, double- or triple-cropping is a way of recovering investment into plastic mulch, drip tape or tubing, and fertilizer. Fertigating through a drip system makes it relatively easy to supply sufficient nutrients for a second or third crop.

MARKETING

Although plasticulture makes possible higher yields of vegetables, beginning earlier in the season, growers should organize their marketing strategies and outlets before planting any crop. A large amount of an early crop could present a marketing problem if there is not good advance planning of where to market it.

Plasticulture production may be an asset in marketing. For example, muskmelons grown in Texas are marketed in advertisements and on individual melon boxes: "These melons grown using plastic mulch and drip irrigation". Growers feel that this advertisement gives buyers an impression of product quality and environmental awareness.

Table 2. Plant spacing for plasticulture

Crop	In-row spacing (cm) single row	double row	Between-row spacing on plastic beds (cm)
Common with plastic mulch			
Cucumber ((fresh)	30-45	22-45	30-35
Cucumber (pickles)	30-45	22-45	30-35
Eggplant	45-60	45-76	35-40
Honeydew	45-60	...	...
Lettuce (leaf)	...	...	...
Muskmelon	45-60	...	...
Okra	30-45	45	35-40
Pepper	30-40	30-40	30-35
Pumpkin	60-122	...	...
Squash			
Summer	30-45	40-60	35-40
Winter	45-122	...	...
Tomato	45-60	...	...
Watermelon	60-122	...	...
Less common with plastic mulch*			
Broccoli	...	20-30	22-30
Cabbage	...	22-30	30-40
Cauliflower	45	45-60	35-45
Chinese cabbage	30	22-30	30-35
Collard	22-30	30-45	30-45
Sweet corn	15	15-30	30-45
Greens	...	15-30	22-30 (2-3 rows)
Onion	...	10-15	10-25 (3-6 rows)

*Used in double- or triple-cropping

DISPOSAL OF THE USED PLASTICS FROM PLASTICULTURE

The main question asked by growers who are interested in using plastics for the production of vegetables is: “What do I do with the plastics when I have finished with them?" This is certainly a worldwide problem. There have been many attempts to solve if, including the development and use of photodegradable or biodegradable materials (which just disappear), using the plastics several times (delaying the problem), reducing the weight of films (less material to deal with), recycling (making the material into other products) and incineration (for a discussion of various disposal methods, see Hemphill 1993). Plastic mulches and drip irrigation tapes are the hardest to deal with. After a season in the field, these materials are dirty and often wet, which makes them difficult to recycle. One option is to incinerate them to recover their very substantial fuel value. A pound of plastic has as many BTU’s (thermal units) as an equivalent amount of fuel oil. Used plastics have been burned in waste-to-energy plants, but one problem is that they create “hot spots” in the waste stream. Another incineration option being explored by a team of researchers at Pennsylvania State University is to create a “fuel nugget” that can be burned to supplement coal or other waste products, or used alone to heat various kinds of structures. More research needs to be done on the proper collection, preparation and transportation of the plastics from the site of use to the point where it is processed, and then to the point of incineration. Incineration may be the answer to the disposal problem, but much more work is needed.

CONCLUSION

The production of vegetable crops using plasticulture is a certainly a production system that involves high input costs and levels of management and is subject to mismanagement and risk, just like any other production system. With proper planning, attention to details, and dedication to all aspects of the plasticulture system, the opportunity exists to reduce the acreage of an existing operation and possibly increase profits using efficient production techniques. Some yields of various vegetable crops using plasticulture are presented in Table 4.

REFERENCES

Bogle, O. and T.K. Hartz. 1986. Comparison of drip and furrow irrigation for muskmelon production. *HortScience* 21: 242-244.

Bonnano, R.A. 1996. Weed Management in Plasticulture. *HortTechnology*, 6, 3: 186-189.

Clark, G.A., C.D. Stanley, D.N. Maynard, G.J. Hochmuth, E.A. Hanlon, and D.Z. Haman. 1991. Water and fertilizer management microirrigated fresh market tomatoes. *Transactions of the American Society of Agricultural Engineering* 34: 429-435.

Decoteau, D.R., M.J. Kasperbauer, and P.G. Hunt. 1989. Mulch surface color affects yield of fresh-market tomatoes. Jour. American Society of Horticultural Sciences 114: 216-219.

Dix, M.E. and D. Leatherman. 1988. Insect management in windbreaks, p. 501-502. In: J.R. Brandle, D.L. Hintz, and J.W. Sturrock (Eds.). *Windbreak Technology: Proceedings of an International Symposium on Windbreak Technology.* Elsevier, New York, USA.

Emmert, E.M. 1957. Black polyethylene for mulching vegetables. *Proceedings of the American Society of Horticultural Sciences* 69: 464-469.

Ennis, R.S. 1987. *Plastigone™ a new, time-controlled photodegradable plastic mulch film.* Proceedings, 20th National Agricultural Plastics Congress, pp. 83-90.

Graham, H.A., D.R. Decoteau, and D.E. Linvill. 1995. Development of a polyethylene mulch system that changes color in the field. *HortScience* 30: 265-269.

Hall, B.J. and S.T. Besemer. 1972. Agricultural plastics in California. *HortScience* 7: 373-378.

Ham, J.M., G.J. Kluitenberg, and W.J. Lamont. 1993. Optical properties of plastic mulches affect the field temperature regime. *Jour. American Society of Horticultural Sciences* 228,2: 188-193.

Ham, J.M. and G.J. Kluitenberg. 1994. Modeling the effect of mulch optical properties and mulch-soil contact resistance on soil heating under plastic mulch culture. Agriculture for Meteorology 71: 403-424.

Hemphill, D.D. 1993. Agricultural plastics as solid waste: what are the options for disposal? *HortTechnology* 3, 1: 70-73.

Hochmuth, G.J. 1992. Fertilizer management for drip irrigated vegetable in Florida. *Hort Technology* 2: 27-32.

Hodges, L., M.E. Dix, J. Brandle, R. Wright, and M. Harrell. 1994. Effects of shelterbelts on insect pests in muskmelon. *Proc. Nebraska Fruit and Vegetable Growers Conference,* pp. 19-18.

Lamont, W.J., K.A. Sorensen, and C.W. Averre. 1990. Painting aluminum strips on black plastic mulch reduces mosaic

Table 3. Yields of selected vegetables using plasticulture

Crop	Yields per hectare
Eastern muskmelon	20,000-22,000 fruit at 2-3 kg/fruit
Western muskmelon	29,000-37,000 fruit at 1-2 kg/fruit
Cucumber	74 mt
Pepper	44 mt
Squash	40 mt
Tomato	71 mt
Watermelon	7200 fruit

symptoms on summer squash. *HortScience* 25: 1305.

Lamont, W.J. and E.B. Poling. 1986. A fresh way of looking for profits: double-cropping strawberries, muskmelons. *Fruit South* 7, 4: 8-11.

Liakatas, A., J.A. Clark, and J.L. Monteith. 1986. Measurements of the heat balance under plastic mulches. Part I. Radiation balance and soil heat flux. Agriculture for Meteorology 36: 227-239.

Loy, B., J. Lindstrom, S. Gordon, D. Rudd, and O. Wells. 1989. Theory and development of wavelength selective mulches. *Proceedings, 21st National Agricultural Plastics Congress,* pp. 193-197.

Loy, B., O.S. Wells, N. Karakoudas, and K. Mibert. 1998. Comparative effects of red and black polyethylene mulch on growth, assimilate partitioning, and yield in trellised tomato. *Proceedings, 27th National Agricultural Plastics Congress,* pp. 188-197.

Marr, C.W. and W.J. Lamont. 1992. Profits, profits, profits—three good reasons to try triple cropping. *American Vegetable Grower* 40: 18, 20.

Natwick, E.T. and A. Durazo, III. 1985. Polyester covers protect vegetables from whiteflied and virus disease. California Agriculture 39(7+8): 21-22.

Orzolek, M. D. and J.H. Murphy. 1993. The effect of colored polyethylene mulch on the yield of squash and pepper. *Proceedings 24th National Agricultural Plastics Congress*, pp. 157-161.

Schales, F.D. and R. Sheldrake. 1963. Mulch effects on soil conditions and tomato plant esponse. *Proceedings 4th National Agricultural Plastic Congress*, pp. 78-90.

Scoville, R.H. and D. Leaman. 1965. Polyethylene uses in soil fumigation. *Proceedings 6th National Agricultural Plastics Congress,* pp. 98-99.

Stapleton, J.J. 1991. Use of soil solarization for the control of soil pests. *Proceedings 23rd National Agricultural Plastics Congress*, pp. 266-271.

Tanner, C.B. 1974. Microclimate modification: Basic concepts. *HortScience* 9: 555-560.

Wells, O.S. and J.B. Loy. 1985. Intensive vegetable production with rowcovers. *HortScience* 20: 822-826.

Wells, O.S. 1991. High tunnels shelter early crops. American Vegetable Grower 39, 2: 44,46-47.

For additional information on plasticulture, contact the following websites:

American Society for Plasticulture: http://www.plasticulture.org

Center for Plasticulture, Pennsylvania State University: http://hortweb.cas.psu.edu/plastic