Plasticulture for Michigan Vegetable Production
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# Plasticulture For Michigan Vegetable Production

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# Plasticulture For Michigan Vegetable Production

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## Introduction

Modern production of several fresh vegetable crops is conducted with high inputs and high potential dollar returns per unit of land area. Vegetable growers continually look for ways to grow high-quality produce more economically, improve yields and extend the growing cycle. The value of many vegetables is high enough to justify microclimate modification through use of polyethylene film mulch. Commercial use of plastic mulch in combination with plastic drip tape began in the early 1960s and has since been termed plasticulture (Fig. 1).

Successful plasticulture depends on understanding how plastic mulch affects the microclimate and how this microclimate affects the crop, weeds, insects, diseases and other organisms. Plasticulture also implies significant changes in the production system, including specialized equipment, adoption of new fertilization (fertigation) and pest management technologies, selection of suitable crops and adoption of new cropping systems. Growers with a good record of growing vegetables on bare ground will have potential for greater success in plasticulture. Growers with no experience should start small and increase skills, acreage and equipment over time.

Plastic mulches contribute to reduced pesticide inputs by providing non-chemical alternatives to pest control. Other benefits include soil warming, reduced evaporation, increased yield and earliness, improved nutrient application and uptake, and reduced nutrient leaching. Benefits can be grouped into the following categories:

### *Crop benefits*

- Earliness: Plasticulture-grown crops can be harvested 7 to 21 days earlier and get better prices.
- Greater yields: Marketable yield may be up to three times greater.
- Higher quality: Produce is cleaner and has increased size and fewer culls.
- Higher economic returns: Earliness, high yields and high produce quality improve the economic return to the farmer.

### *Pest management benefits*

- Reduced weed infestation: Certain plastics prevent light penetration and weed seed germination/growth, and serve as a physical barrier to weed seedlings.

Fig. 1. A commercial vegetable farm using plasticulture.

- Better insect management: Reflective mulches repel insects such as aphids and thrips.
- Potential decrease in disease incidence: As a consequence of better water drainage, incidence of soil-borne diseases may be reduced. Many foliage and fruit diseases overwinter in soil and splash onto the plant during rain events. Plastic mulch acts as a barrier, limiting the number of spores reaching the plant. Virus diseases are reduced in plasticulture when reflective mulches are used to repel vectors (aphids/thrips).

### *Production management benefits*

- More efficient use of fertilizers: Through fertigation, fertilizers are delivered directly to the root zone and on an as-needed basis, decreasing fertilizer use by as much as 50 percent.
- More efficient use of water: There is reduced evaporation from the soil surface, and delivering water directly to the root zone uses much less water than overhead irrigation.
- Possibility to double-crop: The same plastic can be used to grow a second or third crop with minimum inputs.

### *Environmental benefits*

- Reduced fertilizer leaching: Lower water rates, especially in light soils, reduce risk of fertilizer leaching and groundwater contamination.
- Reduced soil erosion: Plastic mulch protects soil from being eroded by wind or rain.

## How Do Plastic Mulches Affect Crop Microclimate?

The major reason for using plastic mulches in vegetable production is their ability to modify crop microclimate. Plastic serves as a physical barrier limiting moisture loss, and it changes the solar and thermal radiation balance affecting above- and belowground temperatures. When solar radiation reaches the mulch surface, it is reflected, absorbed or transmitted through the plastic to the soil. Reflected radiation may increase photosynthesis but will not be converted to heat. Transmitted radiation will warm the soil; absorbed radiation increases plastic temperature and heats the soil and/or air. The modified microclimate affects weed seed germination and development, crop growth and development, and populations of other organisms, including nematodes, insects and soil-borne diseases.

## How Do Plastic Mulches Affect Plants?

Plastic mulches affect plants indirectly by changing water, heat and light balances.

### *Changes in Water Balance*

Plastic mulches constitute physical barriers to water evaporation at the soil surface, potentially reducing drought effects. During rainfall, most water in a plasticulture system is channeled between mulch strips. Drainage area is therefore limited, which may lead to flooding between rows when heavy rain occurs on poorly drained sites.

### *Changes in Light Balance*

Light modification is a factor of the quantity and quality of light passing through the plastic. For that reason, the planted crop is less affected than weed species. Light is necessary for photosynthesis. The fate of weed seeds depends on the amount of light they receive. Film properties such as thickness, color and opacity determine the amount of light reaching the soil. Low light prevents weed seed germination, and high light leads to high weed populations underneath the plastic. Clear plastic (high light transmittance), therefore, is associated with high weed populations; black plastic (low light transmittance) controls most weeds.

### *Changes in Heat Balance*

Light wavelengths absorbed or transmitted through plastic increase soil temperature. When light is absorbed prior to being released in the soil as heat (example: black mulch), close contact between plastic and soil is important because heat is not transmitted well through air. Effects on soil temperature are greatest under clear plastic because clear plastic transmits over 85 percent of the incident light. White plastic reflects most light, resulting in cooler soils. Because root zone soil temperature is critical for plant growth and development, soil temperature increase early in the season is one of the most important factors contributing to improved crop growth and development, growing season extension and earlier harvest. Optimum root zone temperature is species-dependent, and temperatures below or above optimum are detrimental.

## Components of a Plasticulture Irrigation System

Components of a plasticulture irrigation system vary from simple to complex, but all systems consist of a pump, filter, chemical back-flow preventer, pressure regulator, fertilizer injector, header lines, drip tape, plastic mulch, and the components needed to connect the irrigation and lay tape and plastic (Table 1). Small systems utilizing a well or municipal water can be quite simple. Larger, automated systems utilizing surface water requiring sand filters and equipped with timers or radio controllers for operation are more complex.

Site preparation is achieved using equipment already available on a commercial operation. The first specialized implement is the plastic layer/bed shaper, which also inserts the drip tape (Fig. 2). If raised beds are being used in heavy loam or clay/silt soils, a preshaper may be beneficial. This implement shapes and presses the soil into a firm bed; the plastic layer then follows closely behind. If fumigation is done with the preshaping process, the plastic layer needs to follow

**Table 1. Needed components and estimated 2005 costs for a 20-acre, two-zone plasticulture drip irrigation system.**

| Component description | Quantity | Unit | Unit price($) | Total price($) |
|---|---|---|---|---|
| Pump (14-hp engine) | 1 | 1 | 4,000.00 | 4,000.00 |
| 24-inch media filter and fertilizer injector | 1 | pair | 3,200.00 | 3,200.00 |
| Oval header pipe, 4 inches | 1,800 | ft | 1.04 | 1,872.00 |
| Oval header pipe, 3 inches | 1,500 | ft | 0.50 | 750.00 |
| One-row bed shaper | 1 | ea. | 4,800.00 | 4,800.00 |
| Drip tape (7500 feet per roll) | 20 | roll | 110.00 | 2,200.00 |
| Plastic mulch | 40 | roll | 80.00 | 3,200.00 |
| Zone control (3-inch pressure regulation valve) | 2 | ea. | 150.00 | 300.00 |
| 4-inch insert "T" | 1 | ea. | 32.00 | 32.00 |
| PVC "T" (S x T), 4 by 3 inches | 4 | ea. | 15.00 | 60.00 |
| 4-inch insert "L" | 2 | ea. | 22.00 | 44.00 |
| 4-foot insert x slip adapter | 6 | ea. | 12.00 | 72.00 |
| PVC bushing, 4 by 2 inches | 2 | ea. | 6.00 | 12.00 |
| 3-inch PVC "T" (S x T) | 4 | ea. | 11.00 | 44.00 |
| PVC nipple, 3 by 4 inches | 8 | ea. | 6.00 | 48.00 |
| 3-inch insert x slip adapter | 8 | ea. | 9.00 | 72.00 |
| 3-inch insert male adapter | 8 | ea. | 6.00 | 48.00 |
| 3-inch PVC "L" (S x T) | 8 | ea. | 7.00 | 56.00 |
| PVC bushing, 3 by 2 inches | 8 | ea. | 3.00 | 24.00 |
| PVC nipple, 2 by 4 inches | 10 | ea. | 2.00 | 20.00 |
| 2-inch air release valve | 10 | ea. | 27.00 | 270.00 |
| 2-inch PVC "L" | 2 | ea. | 2.00 | 4.00 |
| 4-inch hose clamp | 14 | ea. | 0.75 | 10.50 |
| 3-inch hose clamp | 16 | ea. | 0.75 | 12.00 |
| Tape x barb connections | 480 | ea. | 0.55 | 264.00 |
| Cordless electric drill (1/4-inch bit) | 1 | ea. | 150.00 | 150.00 |
| **Total** | | | | **21,564.50** |

Adapted from Lamont, Production of vegetables, strawberries, and cut flowers using plasticulture (2004).
A diagram of a drip irrigation setup is shown in Fig. 3.

Fig. 2. A bed shaper that also inserts the drip tape, fumigates and lays the plastic in one pass.

immediately to cover soil and retain the fumigant. To prevent soil drying, this should also be done quickly if weather is hot and dry. A preshaper can be a specialized piece of equipment or as simple as two disk blades mounted on a tool bar on the back of a small tractor with the blades set to throw soil to the center. In sandy soil, it is possible to shape the bed, lay plastic, insert drip tape and fumigate all in one pass.

Bed shapers can be purchased that will shape one or several beds at a time. Matching tractor size to the shaper is critical. Bed shapers are heavy because of the gauge of steel used in their construction. There is also the weight of the plastic mulch, drip tape and fumigant/propellant tanks. The fact that shapers are also long shifts the center of gravity to the rear of the tractor. All this makes tractor selection important. Single-bed shapers should have a four-wheel-drive tractor with a minimum of 60 horsepower; more if the site is hilly. The four-wheel-drive aspect prevents slippage, and the extra forward weight also lends stability. Two-wheel-drive tractors can be used but should have 15 to 20 percent more horsepower. Because of lower stability, narrow gauge tractors are difficult to use, especially on hilly sites. Front-mounted fumigant tanks improve weight distribution.

Many components listed in Table 1 can be used more than one year. The only components renewed annually are plastic mulch, drip tape, and possibly some clamps and drip tape connectors. Set-up costs for the components of a 20-acre system as listed are around $1,100 per acre (2005 costs). Continuing annual costs for the components are heavily dependent on the price of oil but were near $250 per acre in 2005. Initial costs include a pump, filter and bed shaper. These expenses can be spread over more than 20 acres because each item is capable of servicing more acreage. This lowers the initial per acre cost. Also, bed shapers could be shared among small growers if an appropriate schedule could be arranged. Components listed in Table 1 are for a simple system with no automation, and it does not include a pre-shaper or any equipment for plastic removal.

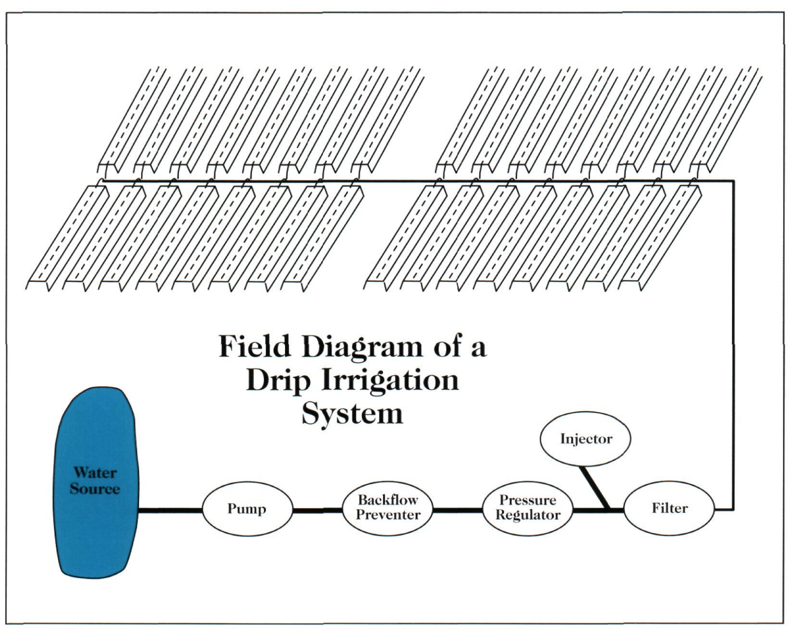
# Choosing the Type of Plastic

Plastics chemistry has provided growers with films possessing a large range of physical and optical properties.

## Physical properties: type of surface, thickness, width and length

Plastic mulches are either slick (smooth surface) or embossed (with a diamond-shaped pattern on the surface). Embossed films are preferred because they have reduced expansion and contraction under fluctuating temperatures, which can loosen plastic from the bed.

**Fig. 3. Field diagram of a drip irrigation system.**



Plastic mulches range in thickness (gauges) from 0.6 to 2.0 mils (0.0152 to 0.0508 mm). Commercially available plastic mulches are 36 to 90 inches wide (91 to 229 cm), but films routinely used in agriculture are 48 to 60 inches wide (122 to 152 cm). Plastic mulches are sold in lengths ranging from 2,000 to 4,800 feet (610 to 1,463 m). For ease in handling, thin films generally come on long rolls and thicker films on shorter rolls.

## Optical properties: colors, light transmission and reflection

Plastics are available in several colors, but black has so far been the primary color used in agriculture. Black films have so far not proven to be much different in performance than other colors, and they are the most economical (Fig. 4). Plastic mulches can be grouped into four major categories: conventional plastics, photoselective or wavelength-selective plastics, highly reflective plastics and degradable plastics.

- **Conventional plastics:** These include clear, black, white, red, yellow and co-extruded white-on-black (Fig. 5). **Clear plastics** transmit 85 to 95 percent of the incident solar radiation, resulting in the greatest soil temperature. Because they create a greenhouse effect, they are usually associated with weed problems. Use of clear plastic should be combined with an adequate weed management program. With **black plastics**, solar radiation is first absorbed by the plastic and then transferred to the soil as heat (with significant losses to the atmosphere). Efficiency of black plastic mulches at increasing soil temperature is slightly less than that of clear mulches. However, because no light is transmitted, weed control is generally good. **White and white-on-black plastics** are among the coolest and are normally used in hot environments (tropical climate) to decrease soil temperature by reflecting most of the incident solar radiation. The level of weed control depends on the opacity of the white film.

Fig. 4. Use of colored mulch in vegetable production.

Fig. 5. Use of red mulch for tomato production in Michigan.

- **Photoselective or wavelength-selective plastics:** Photoselective films absorb light used by plants and transmit infrared radiation. They are also called IRT (infrared transmitting) mulches. The transmitted infrared radiation increases soil temperature while the absorbed light prevents weed seed germination. These films are intermediate between black and clear plastic in their effects on soil temperature and comparable to black in controlling weeds. IRT films are available in various colors and are more expensive than black mulch. The major advantage of IRT over black is that, under direct sunlight, the temperature at the surface of black film is usually higher, and in hot climates, fruit or plant parts that touch the black mulch may be scalded.

- **Highly reflective plastics:** Highly reflective plastics reflect most incident solar radiation and are used primarily as pest management tools. They repel certain insects (aphids/thrips) and may delay onset of virus diseases vectored by these insects. They are most useful in situations where a significant portion of the plastic remains exposed during the season and have limited use in crops that cover the plastic (most vine crops). Soil temperature is lower under these films than under black film. Types include **silver, aluminized** and **stripe** (aluminum stripes on black film).

- **Degradable plastics:** These are either photo- or biodegradable and are made to solve the problem of removing and disposing of conventional films. Photodegradable plastics are degraded by infrared radiation, are available in various colors and look similar to conventional plastics. The degradation rate depends on the extent to which the plastic is exposed to the sun. Degradation occurs faster in high-sun years than in low-sun years. This makes it difficult to use effectively because growers cannot predict the amount of sun that will be experienced. Buried edges or portions covered by crop canopy are also less affected. The plastics also break up into various sized pieces that are prone to being blown by wind. Biodegradable plastics are broken down by soil microbes, and soil contact and soil moisture are needed for the process to occur. Time of breakdown is difficult to predict. Both technologies are expensive and have not been used widely in production.

### Mechanical properties

Mulch films are exposed to various types of mechanical damage when exposed in the field. The film should have acceptable elongation module, tensile strength and elasticity.

Factors to be considered when choosing a plastic include desired soil temperature, weed control, field life and cost.

## *Soil temperature*

Clear plastic warms the soil the most, followed by black. IRT and white are among the coolest (Fig. 6).

## *Weed control*

Weed control is maximum with black and IRT, low with white and lowest with clear plastic. By creating a greenhouse effect, clear plastics may result in more weed infestations than the bare ground system (Figs. 6 and 7)

## *Field life*

Most plastic mulches are removed and discarded after one growing season. Some films, however, are made specifically for an extended field life of up to 24 months. Normally, thick films last longer in the field, but this is not always a rule. Consult with your sales representative for more information on field longevity of the films if you anticipate using one for more than one growing season.

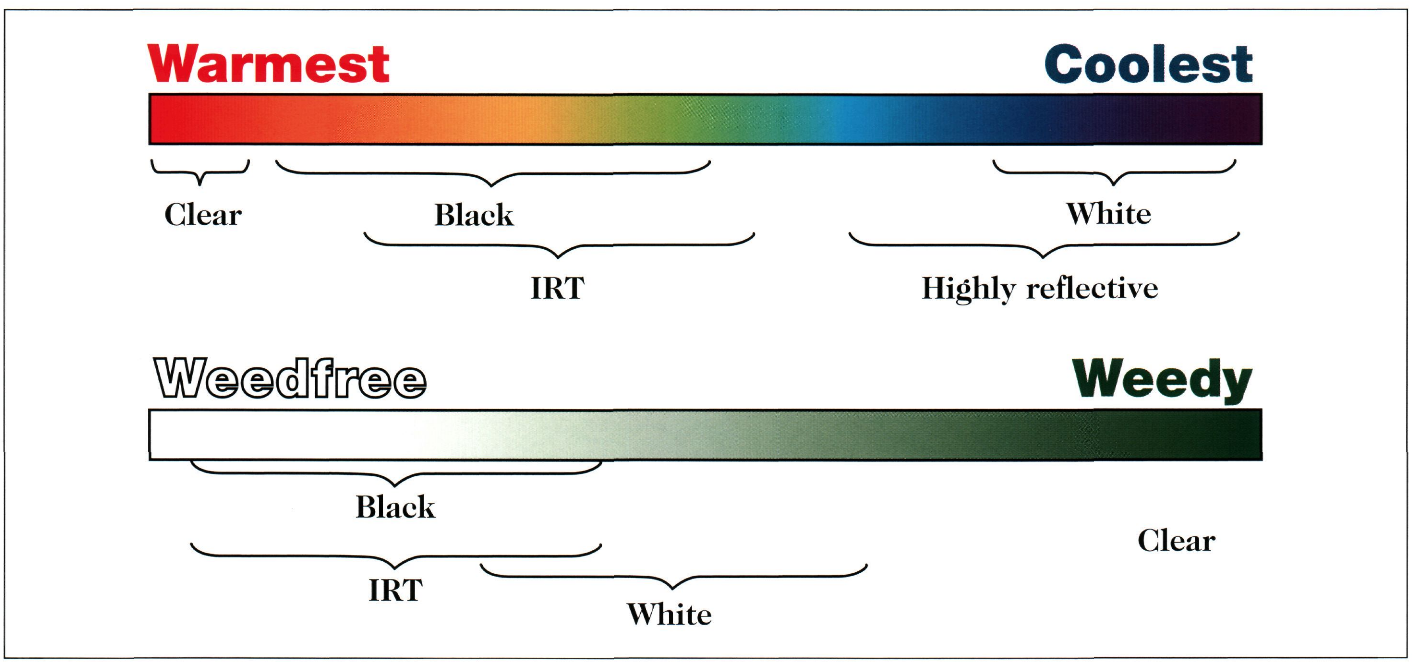



Fig. 6. Ability of various mulches to warm the soil (top graph) and to control weeds (bottom graph).

Fig. 7. Weed infestation may be a problem with clear mulch if herbicides are not applied before laying the mulch.

## *Cost*

Conventional plastic mulches generally cost less than IRT highly reflective plastics, dual colors (white-on-black) and the degradable films.

# Laying Mulch and the Drip Tape

Plastic can be laid flat to the ground or on a raised bed. In either situation, the site is first plowed and further smoothed with a disk and drag. Soil should be worked when it has the proper moisture level; if it is too wet, compaction can be a problem; if it is too dry, bed shaping and fumigation are difficult. Once sandy soils have dried, it is difficult to totally rewet a shaped bed using drip irrigation. There is not enough lateral movement of water in these soils to wet the entire soil volume under the plastic. This will limit root growth and decrease efficient use of preplant nutrients. Therefore, it is more effective to place the drip tape near the plant and to inject fertilizers during irrigation.

Raised beds warm sooner in the spring and have better water drainage than flat beds, possibly leading to reduced incidence of soil-borne diseases. In sites having shallow topsoil, raised beds also bring together more topsoil for roots to exploit. Whether plastic is on a flat or a raised bed, it is important that it have a tight fit to the soil. Most plastic layers stretch plastic over the soil to minimize air spaces, allowing for better heat transfer into the soil.

Raised beds can vary in height and width from 2 to 8 inches and 1 to 3 feet, respectively. A typical Michigan planting is on a 6-inch raised bed 2 feet wide. This system requires 4-foot-wide plastic and works well for most plantings (even double rows). Three-foot-wide plastic gives a bed width of 1 foot and can be used for single-row plantings. Some growers use 5-foot-wide plastic to produce a 3-foot bed width for double-row peppers. Raised beds are slightly crowned to help shed water rather than direct it to drain through planting holes (Fig. 8).

Bed shapers scoop the soil together and shape it, lay the plastic, insert a drip tape, open a furrow for the edges of the plastic and cover the edge with soil, all in one pass. If desired, it can also inject a fumigant. Adjusting the bed shaper is necessary for good bed formation, and all the steps mentioned require an adjustment. The manufacturer provides guidance, but some things can be learned only by experience and trial and error. However, once the shaper is adjusted, it can be set to maintain that adjustment.

A properly adjusted shaper fills the bed with soil. There should be no hollow centers. If the center is hollow, more soil needs to be pushed into the shaper, either by lowering the entire unit using the tractor hydraulics or changing the three-point hitch adjustment bar. The other critical adjustment is making sure the edges of the plastic are properly covered. If not enough soil is thrown on the edges, the plastic can work loose and be pulled off by wind. Adjusting angle and depth of the disks at the end of the shaper will change how much soil is thrown onto the edge.

Fig. 8. Raised beds covered with plastic mulch.

The speed of plastic application depends on soil type and fumigation. Lighter soils are quicker to shape than are heavier soils, and fumigation rates are affected by speed.

Drip tape is placed under the plastic through an adjustable tube. The tube can be adjusted up and down for deeper or shallower insertion. It can also be adjusted side to side, depending on where the plants will be transplanted or the seed sown. Placing the drip tape on top of the soil allows it to "snake" as it expands and contracts in response to temperature. This snaking action can cause the tape to move to one side of the bed, resulting in poor soil moisture uniformity. Inserting the tape into the soil will stop snaking.

There are up and down sides to the tape, and care should be taken to make sure it is inserted properly. Tape should be inserted so emitters face up. The tape spool will often have an arrow to indicate which direction it should spin for proper application.

Plants in single rows are planted down the middle; therefore, drip tape must be set slightly off-center so it is not damaged by the row marker, seeder or transplanter. If the planting will have double rows, the tape should be placed down the center of the row.

To begin laying plastic and tape, there has to be some resistance causing the rolls to spin. Many growers accomplish this by tying the plastic and tape to a pitchfork stuck in the ground behind the plastic layer (Fig. 9). At the end of the row, the plastic is cut with a shovel, and excess tape is pulled out and cut with a knife. If fumigant is being applied, the ends should be covered with soil before the plastic is cut.

It is rare that a roll of plastic and tape run out at the end of a row. Many plastic layers can handle a second plastic roll, and, with experience, the second roll can be fed into the first roll just before it runs out. This cannot be done with drip tape. If the drip tape is almost out at the end of a row, it is probably best to change it. If the roll runs out while laying the tape, the process will have to stop, the roll changed and the location marked so lines can be spliced.

After the drip system is installed and hooked to the water supply, it is important to flush it before closing it off. Flushing removes soil that may have gotten into the lines during installation. After the system is flushed, lines are closed off by tying a knot in the line or by taking the last 3 inches of the line and folding it twice back onto itself and inserting it into a 3-inch piece of drip tape. Once all the ends have been plugged, allow the system to pressurize, checking for proper system pressure and leaks.

Fig. 9. Starting the mulch laying process by tying the plastic and tape to a pitchfork.

# Fumigation

Many growers control weeds, diseases, insects and nematodes through soil fumigation. Fumigant options and application procedures change, so consult Extension bulletin E-312 (Insect, Disease and Nematode Control for Commercial Vegetables) for recent information. No matter what product is used, it is important to follow label recommendations and restrictions. Most soil fumigants contain chloropicrin (tear gas), which causes a severe eye and respiratory reaction. Chloropicrin was initially included as a safety precaution but has since been shown to have some pest control. Chloropicrin is an irritant; the other material is potentially fatal. Applicators experiencing eye irritation and breathing difficulty need to evacuate the area as soon as possible because it means they are breathing a highly hazardous material. Extreme care needs to be taken to protect workers with proper protective clothing and respirators.

It is important to have proper soil moisture and temperature conditions for fumigation to be effective. If soil is too wet, fumigant will not disperse, and the effect will be limited. Dry soil allows fumigant to escape too quickly, again reducing effectiveness. Fumigant volatility depends on temperature. It has its greatest effect between 60 degrees F and 80 degrees F. Cool soils reduce volatility, and warm soils enhance it. Both situations reduce effectiveness.

Fumigation in a plasticulture system is accomplished in the pre-bed-shaping procedure or in conjunction with the plastic laying. If fumigation is done while preshaping, it is important to make sure enough soil is thrown over the injection point so fumigant cannot escape, and the plastic layer must follow immediately behind, further sealing in the fumigant. Fumigants vary in required soil contact time and in how soon plants can be planted after fumigation. Once contact time is complete, beds can be vented by punching the planting holes through the plastic.

Fumigants come as liquids in tanks of various sizes (Fig. 10). Pressure in these tanks is controlled using a separate tank of pressurized nitrogen. Rate of fumigant delivery depends on ground speed, tank pressure, bed size (width) and orifice size. Information from fumigant manufacturers and suppliers is the best guide for matching all the components for efficient product delivery.

Fig. 10A and 10B. Fumigation equipment: fumigant tanks (A), fumigation knives (B).

# Irrigation

Irrigation is economically beneficial in most plasticulture systems and is done primarily through drip tape. Overhead systems have been used, but greatest benefit is limited to crops that have spreading root systems (some vine crops) with roots capable of growing beyond the plastic. Crops having downward growing root systems (tomato and pepper) will not benefit as much from overhead irrigation, especially in sandy soil. For those crops, drip systems are more appropriate. Drip systems also provide growers with the opportunity for better nutrient management. Because of this added benefit, further discussion here will be limited to drip systems.

### Regulations:

Water use for irrigation has become increasingly regulated in Michigan. Irrigators need to be aware of any permits they may need or any records they may have to maintain to be in compliance. Check with your local MSU Extension or Michigan Department of Agriculture office for the most recent requirements.

### Water source:

Water quality plays a greater role in drip irrigation than in overhead systems, and much attention needs to be paid to water source and limitations it may pose. Suitability includes adequate supply, cleanliness (suspended solids) and chemistry (primarily calcium and iron concentrations).

Drip systems water only that portion of the field where crops grow, so they use less water than overhead irrigation. The rate of recharge when using a pond or the flow rate from rivers, streams and wells is still important, however, because it determines zone size. A 1-acre field requires 10 to 40 gallons per minute (gpm), depending on tape flow rate. During peak water use, a 10-acre zone requires a water source capable of sustaining 100 to 400 gpm for at least 2 hours, potentially every day during July and August. If the water source is adequate, it can be cycled to other zones once one is finished. Municipal water may be used if accessible; however, economics for large-scale use are questionable.

Surface water and groundwater sources present their own difficulties. Surface water has more particulates (silt and clay) and other potential contaminants (bacteria, algae, plant diseases and chemicals) than groundwater. Groundwater, however, may have more dissolved minerals (calcium and iron) that have to be managed. Surface water sources require extensive filtration with sand filters (Fig. 11) to remove particulates and may need chlorination to control bacteria and algae. Groundwater will need limited filtration with disk or screen filters, which are less expensive than sand filters. Groundwater may precipitate calcium and iron into the system. Acidification may be required to keep emitters from becoming plugged.

### Drip tape:

Drip tape is available in flow rates ranging from 0.125 gpm to 0.5 gpm per 100 feet, depending on emitter spacing (4 inches to 2 feet) and diameters (5/8 inch to 1 3/8 inch). Flow rates are on a 100-foot basis regardless of emitter spacing. A shorter distance between emitters produces more uniform wetting patterns, but this has not necessarily resulted in increased yield. Modern tapes are pressure-compensating — that is, they put out just as much water on top of a hill as they do at the bottom.

Fig. 11. Sand filter for irrigation water.

Choice of tape depends on plant spacing, soil type, distance and water availability. Soils with heavy clay content should be irrigated more slowly than sandy soils, and sandy soils need to be irrigated more frequently but for shorter times. Smaller diameter tapes are suited for shorter distances (600 to 1000 feet or less), but to maintain uniformity, larger diameter tapes are used for longer runs (up to 5000 feet). Drip tape also comes in various wall thicknesses, from 4 to 15 mil. Heavier gauge material is used for systems that will be in place for more than one year. Choice of flow rate depends on pumping rate. A 10-acre zone using 0.50 gpm tape will require a 400 gpm capacity, but a 0.25 gpm tape requires only 200 gpm but will have to be operated twice as long to deliver the same amount of water. Studies in Michigan have shown few to no differences between flow rate, emitter spacing and two tapes vs. one. A common design in Michigan is an 8-mil, 5/8-inch diameter tape with a flow rate of 0.25 gpm and a 12-inch emitter spacing. Fields with distances greater than 600 feet are generally divided in the middle with a mainline with drip lines branching off the mainline.

### Pressure:

Drip irrigation operates at a pressure of 8 to 12 pounds per square inch (psi). Higher levels will cause the tape to burst or stretch emitter openings so they are not delivering similar amounts of water. Pressure-compensating valves are built into the system to keep pressure at the desired level. To maintain uniformity, be sure to standardize the pressure compensation valves with the tape.

### Irrigation amount and time:

Amount of water to apply varies with plant growth, temperature, wind and other environmental factors. It is important for soil to be moist when the bed is shaped and plastic laid. If the soil is not moist, it will be difficult to maintain bed integrity and get proper fumigation, and it can influence transplant mortality. If soil is not moist, steps should be taken, if possible, to moisten it through overhead irrigation.

Studies have shown that, when initial soil moisture is adequate at planting, there may be benefit in waiting to begin irrigation until three to four weeks after planting/transplanting. It is important to irrigate immediately after transplanting to improve root contact with the soil before delaying further irrigations. Delaying irrigation encourages deeper plant rooting and root exploration of a larger soil volume for water and nutrients. Irrigation time may range from 0.7 to 2.5 hours when using a 0.25 gpm tape. Shortest times are for vegetative and flowering plants; longest times are for mature, fruit-bearing plants during July and August.

Soil moisture monitoring and irrigation scheduling can be done through a variety of systems. Tensiometers (Fig. 12) are one means of monitoring soil moisture at the root level. Studies on tomato and cucumber have indicated that a soil moisture level between 15 and 20 centibars is adequate. Lower levels (wetter soil) do improve yield and quality but utilize more water. Levels of 25 centibars or higher (drier soil) significantly reduce fruit yield and quality.

Soil moisture in a plasticulture system has a strong daily pattern: moisture level decreases during the day and then rebounds at night. Moisture depletion begins near 9 a.m., reaching a low point at 7 p.m. Moisture then rebounds under the plastic, reaching a high point at 7 a.m. Studies on tomatoes and cucumbers have shown the best time to water is during the depletion phase (9 a.m. to 7 p.m.). This supplies water when the plants require it. Trying to "bank" water in the soil ahead of when the plants actually use it appears not to be a benefit.

# Fertilization, Fertigation

Plastic mulch provides an excellent opportunity for conservation of nutrient inputs in vegetable production. Under plastic, nutrients, especially nitrogen and potassium in sandy soils, are less subject to leaching loss. Hence, fewer total nutrient inputs may be required. Water from rainfall moves up into the raised bed under plastic rather than moving downward through the soil. Trickle irrigation tape installed under plastic mulch is an excellent system for supplying nutrients as needed by the crop. In plasticulture vegetable production systems, nutrient additions can be made to the soil before laying plastic or through the trickle irrigation system.

Fig. 12. A tensiometer used to measure soil moisture.

Sampling and testing the soil to determine the soil pH and levels of available nutrients provide the base for building a solid nutrient program. A soil pH between 6.0 and 6.5 is favorable for most vegetables grown in a plasticulture system. Where the pH is less than 5.8, it is important to raise the soil pH by applying the amount of lime indicated in the soil test. Phosphorus and potassium needs vary inversely with the amounts available in the soil. The nitrogen requirement is determined by the crop being grown.

## Fertilization before bedding and plastic laying

Plastic mulch is usually combined with trickle irrigation tubing laid under the plastic. If for some reason trickle tubing is not used, it is important to soil apply the needed nutrients before laying the plastic. The required amounts of nitrogen (N), phosphorus (P) and potassium (K) are best broadcast and incorporated, but all of the phosphorus and up to 50 pounds per acre each of N and $K_2O$ could be applied in bands 4 to 6 inches on both sides of where the row of plants will be set or seeded. This can be done before or during the plastic-laying process. Laying plastic over the soil minimizes the chance of N and K loss by leaching because rainwater soaks into the soil between the rows of plastic and moves laterally under the plastic and up into the root zone, rather than draining down through the soil and out of the root zone.

## Fertilization with irrigation

When trickle irrigation is present, much of the nitrogen and potassium can be supplied throughout the growing season during irrigation. A general guide is to apply 20 to 40 percent of the N and K and all of the P to the soil, either broadcast incorporated or in bands. Micronutrients can be included in the broadcast or band fertilizer. Band fertilizer is best placed so that the trickle tubing is between the plant and the fertilizer band. This slows the movement of salts toward the roots. If available levels of P and/or K are adequate, preplant application of these nutrients may not be necessary.

Little or no phosphorus is usually injected into trickle irrigation water because it is likely to form a precipitate with calcium in the water that may clog the emitter openings. Injecting phosphoric acid helps to lower the water pH and minimize the formation of phosphate precipitates. It is safer, however, to avoid putting phosphorus into the irrigation water. Band application is very effective.

Amounts of N and K to apply through the trickle are determined by subtracting the amounts applied to the soil from the total needed for growing the crop. The next decision is how to schedule the applications. During the early stages of growth, crop nutrient requirements are small; they increase as the plants increase in size and set fruit. These nutrients can be applied daily or weekly or at some other interval. It tends to be easiest to think of nutrient applications on a daily basis. Determine the number of days that nutrients will need to be supplied for the crop. Dividing the amounts of N and $K_2O$ to be supplied through the trickle irrigation by this number gives the average amounts to be supplied each day. The average daily need for N may range from 1.5 to 2 pounds per acre, but the rates need to be adjusted over time to give this average. A suggested program is to start with 1 lb N/acre per day, then increase it to 1.5 lb/acre per day and then to 2 or more lb/acre per day. The need is highest during the period of heaviest fruit load or most rapid growth. During the last few weeks of crop growth, reducing the rate will help minimize the amount of residual N in the soil. Depending on the growth rate of the crops grown, the rates may need to be adjusted up or down. For potassium, the rates may range from 1 to 3 lb/acre per day, depending on the crop and the amount applied to the soil up front. As with N, the rate needs to be adjusted as the crop develops.

Although some growers like to maintain a set ratio of N to $K_2O$, research has not shown this to be important. Good quality produce and yields can be produced over a range of N to $K_2O$ ratios. What is important is satisfying the nutrient needs as indicated by a soil test for the particular crop. The effectiveness of applied nutrients may be influenced by the amount of water applied. Long irrigation cycles may result in the leaching of nutrients, especially nitrogen and potassium, out of the root zone. Therefore, it is important to monitor water application and soil moisture in and below the root zone.

The following components are important for fertigation:

- A back-flow prevention valve.
- An injector.
- A soluble fertilizer.

### Backflow prevention valve:

This device is used to prevent contamination of the water source by fertilizers and pesticides. The device is normally installed between the injection system and the water source.

### Injectors:

Injectors available for application of fertilizers through irrigation systems include positive displacement pump injectors (powered by electricity or water) and venturi injectors (powered by pressure differential). Choice of injector depends on the desired need for accuracy of the injection (water-powered injectors are more accurate than venturi injectors) and the desired injection rate (a large area requires high rates of injection and powerful injectors).

### Soluble fertilizers:

The solubility of fertilizers is usually given as the amount (in pounds) that can be dissolved in 100 gallons of water. Solubility varies with the type of fertilizer, water temperature and water pH. Always make sure the fertilizer used is appropriate for fertigation and it is used properly. Some growers prefer to buy ready-to-use injectable liquid fertilizer formulations to avoid all problems and risks associated with on-farm mixes. Only completely soluble fertilizers should be used. Additional information on fertilizer rates, sources and application frequency are available in Hochmuth et al. (Chapter 4 in W.J. Lamont Jr. [ed.], 2004). Also consult with the fertilizer company for information on specific fertilizers and growing conditions.

## Weed Control in Vegetable Plasticulture Systems

Weed control is more complex and often more difficult in plasticulture production systems than in bare ground production. Plastic mulch laid on the soil surface is the most common use of plastic in vegetable production. Other uses include plastic or fabric row covers, mini-tunnels, high tunnels and hotcaps.

Black mulch is the most common type used for vegetable production, though some growers trying to obtain early harvests may use clear plastic for its slight heat advantage. A major drawback of clear mulch is that it promotes accelerated growth of weeds. For some crops, growers use clear plastic because they plant seeds and then lay the plastic, thus using it as an incubator for quick germination and a mini-greenhouse to get the crop up and growing. Without effective weed control under the plastic, however, weeds quickly take over and outcompete the crop. Therefore, growers need to use herbicides under clear plastics to avoid a solid mass of weeds.

Other colored mulches are intermediate between black and clear in their weed suppression effectiveness. White or milk-colored mulch is translucent and allows good heat penetration with moderate weed growth. Plastic in various shades of green, red, brown, yellow and other colors generally are opaque enough to suppress most weed growth. They theoretically allow passage of certain wavelengths of light, which warm the soil while limiting weed germination and growth. Their higher expense and lack of obvious advantage have limited their widespread use.

Several weed problems affect vegetable production in or under plastic mulch. With clear plastic, the major problem is germination of annual weeds under the plastic. With black and other opaque mulches, the major problems are annual weeds germinating under the plastic and growing up through the plant holes, and annual weeds in the row middles between rows of plastic. Yellow nutsedge germinating under and growing through the plastic may also be a problem. Each situation and crop needs a specific solution; no herbicide will solve all the weed problems in a crop.

Soft, young plants growing in the warm, damp conditions under mulch are very susceptible to herbicide toxicity. Under these conditions, herbicides tend to be more volatile and some will move off of soil particles and migrate to the holes in the plastic, where there is more air movement. This volatilization may result in increased crop exposure and possible phytotoxicity or death.

Sweet corn may be seeded in the field and covered with clear plastic to obtain quick germination and growth early in the season. The sweet corn grows under the plastic until it is about 12 inches tall, then the plastic is cut open to allow the sweet corn to expand beyond the plastic. Weeds also germinate under the plastic and can reduce sweet corn growth substantially if not controlled. Therefore, a preemergence herbicide is needed under the plastic that will not injure sweet corn but suppresses the weeds. Other crops that may be seeded before laying plastic include cucumbers, melons and summer squash.

Some crops may be grown in mini-tunnels or high tunnels, which create a similar weed situation. Salad greens, leaf lettuce, mustards and spinach may be grown in tunnels to extend the season in spring or fall. Weed removal is a major production expense.

Some crops are direct-seeded through black plastic mulch with a seeder specifically designed to plant the seeds alone or with some planting mix. Weeds may germinate and grow up through the holes along with the crop plants. If herbicides are used in this production system, the crop must be tolerant of the herbicide.

The most common method of crop establishment in plasticulture is transplanting. If clear or translucent plastic is used, a herbicide usually is applied to the soil before laying the plastic. After plastic is laid, the crop is established by punching holes through the plastic and planting the seedlings in the soil. The plants are usually started in peat pots or soil cells, which help protect them from herbicides in the soil. Weeds soon emerge from the holes in the plastic. It is critical to remove these weeds because their roots are intertwined with the crop roots, and pulling them often results in removal of the crop plants. The options for control of these weeds are preemergence herbicides applied under the plastic and postemergence herbicides applied over the top of the crop and weeds. Grasses usually are easy to control with postemergence graminicides, but broadleaves may be more problematic, depending on the crop and weed species.

The row middles, the bare soil between the strips of plastic, may be relatively narrow and include the 6 inches of soil-covered plastic on the sides of each row. Thus, in a 2-foot row middle, about half of the area is soil over plastic. Row middles may be cultivated shallowly, but great care must be taken to avoid hooking and tearing the plastic mulch. Making new holes in the plastic allows more weed growth and may reduce the warming effects of the plastic. Holes at the edge of the plastic also may allow wind to get under the plastic and tear it or pull it out of the ground. For cultivation, use a device that moves the surface soil and does not dig deeply into the soil. Cultivate when the weeds are small.

Row middles should be treated with preemergence herbicides after laying the plastic if no preemergence herbicide was broadcast over the field. Later in the season, another preemergence treatment may be applied, and emerged weeds may be controlled with shielded postemergence herbicide applications. Even though the herbicide is not applied directly to the crop plants, it needs to be labeled for use on that crop. When making postemergence shielded applications, read labels carefully for warnings on herbicide drift or volatilization. Paraquat, glyphosate and carfentrazone are effective for this type of application, but all of them can cause serious crop injury if they contact the crop. It normally is safer to use a herbicide for which the crop has some tolerance for row middle applications. For instance, halosulfuron may be applied between rows of summer squash on plastic as a directed spray without causing serious crop injury. Slight crop contact does not cause serious yield reduction. If paraquat or glyphosate is used, it must be shielded completely to avoid serious injury of any crop.

Weed control recommendations for crops grown on or under plastic mulch can be found in Zandstra (2006), Extension bulletin E-433, Weed Control Guide for Vegetable Crops.

# Double-Cropping Plastic Mulches

One of the major advantages of plasticulture is the ability to produce more than one crop using the same plastic and drip irrigation system. In many parts of the United States, two crops can be grown the same year, allowing growers to virtually double their acreage. In Michigan, however, the growing season is relatively short, and crop selection and timing are important to obtain two crops the same year. Plastic can also be cropped over two years by simply leaving the plastic in the field after harvest and planting a second crop the next summer (Fig. 13). This does not increase acreage but does reduce production costs. Growers in southwestern Michigan have used this strategy successfully. The cropping scheme is usually **fresh market tomatoes** the first year and **slicing cucumbers** the next. Before planting the cucumbers, growers usually apply a non-selective herbicide to control weeds between mulch strips and those that germinated in the holes.

Fig. 13. Double-cropping cucumber on old plastic previously used for tomato production.

When more than one crop is grown on the same plastic, the following suggestions may be helpful:

- Select plastic mulch and drip tape (if necessary) with a long field life.
- Grow a high-value crop the first season and a low-value crop the second season.
- High deer traffic may be a limiting factor.
- Avoid planting related crops back to back to reduce disease problems.
- Avoid applying any herbicide with residual effects on plastic mulch.
- Allow the required number of days between non-selective herbicide application and planting.
- Rainfall will help wash herbicides from the plastic mulch.

Plastic can be reused the same year if harvest of the first crop is complete soon enough. Many early-planted squash and cucumber fields are finished in mid- to late July. This provides the opportunity for replanting with summer squash, zucchini or cucumbers or an unrelated crop such as cabbage, bok choy or lettuce.

# Heat Injury With Plastic Mulches

When the weather favors a clear and sunny sky, maximum temperatures can exceed 90 degrees F. These conditions in early season are conducive to heat injury with plastic mulches because the crop canopy is not yet large enough to cover an important portion of the mulch. Black plastic mulches are widely use in vegetable production to control weeds and to warm the soil in early season. Under hot and sunny conditions, however, they can cause significant injury to the crop. The injury is usually related to heat and may be direct or indirect or both.

## *Direct crop injury*

Black mulches allow little light to pass through. They first absorb the light, which is then converted into heat. The heat is finally transferred to the soil. For greatest efficiency, it is usually recommended to have close contact between plastic and soil. On a clear and sunny day, the black mulch surface temperature can exceed 130 degrees F. This may result in injury or desiccation of most plant parts — roots, stems, leaves and fruits — in direct contact with the mulch.

## *Indirect crop injury*

Crop injury can occur even if the crop is not in direct contact with hot plastic mulch. On a sunny day, hot air builds up between the plastic and the soil. If the plastic is loose, its flapping (even under a light wind) funnels hot air through crop holes. This causes stem girdling and transplant desiccation, a problem commonly observed with young pepper transplants.

## *Implications for crop management*

### 1. Before the injury: reduce the risk.

The risk of heat injury from plastic mulch can be minimized by improving the contact between the mulch and the soil. Plastic mulches are either slick (smooth surface) or embossed (with a diamond-shaped pattern on the surface). Embossed films are preferred because they expand and contract less under fluctuating temperatures that can loosen plastic from the bed.

Hardened transplants will tolerate heat injury better than young and tender ones. Crop holes in the plastic should be round, cut evenly and large enough that there is no direct contact between the plant and the plastic. The transplant should be centered in the hole.

Infrared-transmitting (IRT) mulches maintain a cooler surface temperature than black mulches on hot, sunny days. But they are also more expensive than black mulches.

### 2. After the injury: minimize the effects.

Depending on the importance of the injury, growers might consider replanting. If injury is extensive and occurs when the transplant is very young, replanting might be a good option. When replanting is not possible, it is better to minimize the effects of other stresses (drought, diseases and nutrients) on the plant. Pepper plants become very susceptible to wind damage and should be staked and tied as early as possible.

# Row Covers and Windbreaks

Row covers are used for many reasons, including season extension (frost protection), insect exclusion, and heavy rain and hail protection. When the main objective of row covers is to increase temperature, it is important to understand several factors: row cover type, material used, level of temperature increase and frost protection ability.

### Types of row covers:

Most row covers are either floating row covers or supported by hoops. Floating row covers are supported by the plant canopy. Therefore, for use on crops with a sensitive growing point (e.g., tomato) or a frail structure, they must be made of a lightweight material. Floating row covers can be installed over multiple crop rows. Hoop-supported row covers, also referred to as low tunnels, are installed on individual crop rows or beds (Fig. 14). The height can vary from 18 to 36 inches

Fig. 14. Low tunnels.

from the soil surface. They are more expensive to install than floating row covers.

### Types of materials used:

Most row covers are made with polyethylene plastic or spunbonded fabrics (polyester or polypropylene). Polyethylene covers are used for low tunnels. They are lightweight and come in either solid or perforated sheets. Holes in perforated covers are important for gas and water exchange with the outside environment. Spunbonded fabrics allow for ventilation and water to pass between the fibers. Polyethylene materials are available in various thicknesses; spunbonded fabrics are available in various weights.

### Temperature increase and frost protection:

When using row covers, always keep in mind that they are more efficient at increasing temperature, especially on a sunny day, than at protecting against frost. Even in the absence of a frost risk, some growers may consider using row covers because most warm-season vegetables stop growing at temperatures below 40 to 50 degrees F. A row cover may increase the temperature enough to promote the growth of these warm-season vegetables. In general:

- Polyethylene plastic materials build more heat than woven fabric (spunbonded). Timing of removal or ventilation is important.
- Clear plastics increase temperatures more efficiently than white or colored plastics.
- Plastic tunnels with holes magnify heat better than slitted tunnels.

The increase in temperature under the cover during daytime may vary greatly, depending on the material used. For frost protection, however, differences among materials used are minimal. Most woven fabrics and polyethylene materials used in agriculture can protect the crop only down to 28 degrees F. Optimum frost protection is achieved when the wind is calm.

Some growers have combined row covers with plastic mulch beds; others also add cover crop windbreaks. Finally, some growers have attempted to improve the level of frost protection by installing double or multiple layers of cover. The potential for those systems to protect against a hard frost has not been documented.

When the outside temperature is high enough, it is recommended to remove row covers so that high temperatures inside the covers do not injure the crop. It is also important to remove the cover at flowering for pollination.

Plastic mulches are routinely used by vegetable growers to protect the crop from wind damage. Wind damage can be either direct or indirect. Direct effects include lodging, slow growth and root exposure due to soil erosion. Indirect effects include injury caused by soil particles, especially sands, spread of soil-borne diseases and increased incidence of diseases due to plant abrasion. In addition to row covers, plastic mulch strips (1 to 3 feet tall) are used as windbreaks in vegetable production in Michigan (Fig. 15). Some growers also use cereal rye cover crops as windbreak (Fig. 16).

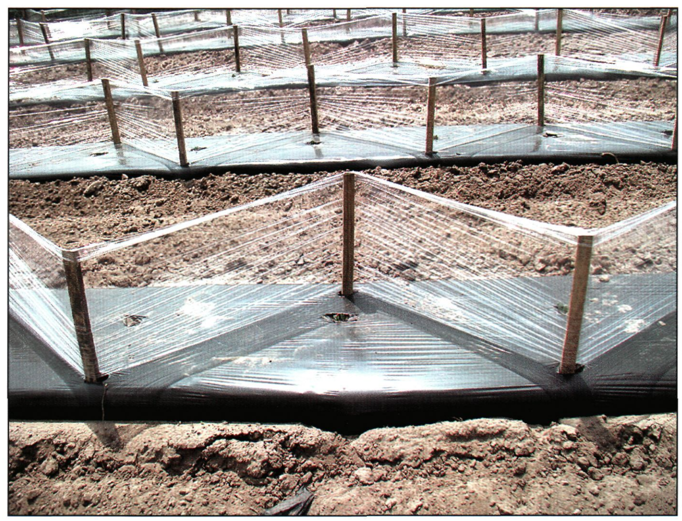


Fig. 15. Plastic mulch used as windbreak.

Fig. 16. Cereal rye cover crop used as windbreak.

# Removal and Disposal of Agricultural Plastic

Removing mulch and drip tape is necessary at the end of the production season. If plants have been staked and tied, stakes and strings are removed and plants mowed. Plastic is then slit down the middle using a coulter mounted to a tool bar behind a tractor or a four-wheel ATV. After slicing, plastic is hand pulled off the bed and placed in the alleyway. To make the lifting process easier in heavy soil, a lifter attached to a tractor can be used to remove soil from the edges of the plastic.

Once in the alleyway, plastic may be picked up in several ways. Some growers have workers place it in piles and pick it up with a front-end loader, placing it into a large container. Or it is placed in smaller piles, where workers pick it up with pitchforks and then place it in 20-bushel bins that are emptied into a large construction refuse container. Once in the container, it is compacted as much as possible with a front-end loader. About 20 acres of plastic and drip tape can be put into a 30-cubic-yard container. The construction bin is then taken to a landfill at a cost of $330 to $350 (2005 dollars).

Plastic can also be picked up using round hay balers (Fig. 17) with minimal modifications. Using balers saves labor and makes plastic easier to handle, transport and recycle. Balers having a chamber that starts off large and compresses the bale only at the end of the process have worked well. Best results have come from 4-foot by 4-foot or 4-foot by 5-foot bales. Larger chambered balers require more material to initiate the bale and should be avoided.

Fig. 17. Use of a hay baler to pick up plastic mulch can minimize volume and disposal cost.

Growers have found that removing the pickup head on the baler is beneficial. The pickup head is needed only to start the plastic into the baler; once plastic is in the chamber, the spinning of the bale pulls the plastic in. The pickup head has a tendency to snag plastic and wrap it in the mechanism. Removing the head eliminates this but requires a worker to feed plastic into the chamber at the beginning of each row.

The bale is spun using belts or chains with cross-connecting metal bars. Belt balers occasionally catch plastic between the belt and the roller, tearing off pieces that trail behind the baler. Chain balers are like a hinged can and will not tear plastic as readily as belt balers. Plastic weighs more than hay or straw, so expect to replace at least the bottom belts on used balers. To reduce stress on the machine, the baler needs to be set to make the lightest bale possible.

Before baling, the plastic and drip tape are hand removed from the rows and placed in the alleyway in long strips. Several rows of loose plastic can be placed in the same alley. The alleyway should not be newly mowed or the baler will pick up a fair amount of plant material. To start a bale requires enough material in the chamber to start tumbling. The first 50 to 75 feet of plastic in a row are generally enough. Coordinating ground speed and power takeoff (PTO) speed is important. Ground speed should be a fast walk (4 to 5 mph), and PTO speed should be set to pull in the plastic at the same or a slightly faster rate than ground speed.

Once in bales, plastic can be trucked to a landfill at a reduced cost because it is more highly compressed than it would be in a construction bin. It is also in a form that can be easily used by recyclers. It can be unwound and put through a washing line to get it ready for reprocessing.

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