The Sustainable Weed Control Rag

Notes for Sustainable Weed Management for Vegetable and Row Crops, a presentation by Mark Schonbeck at the 17th Annual Southern SAWG Conference in Louisville, KY, January 16-19, 2008

Introduction: What are Weed Doing in My Field?

Weeds are Nature's way of protecting soil that has become exposed by fire, flood, landslide, clear-cutting, clean tillage or other disturbance. Bare soil is *hungry* and *at risk*. The soil life, so vital to soil fertility, goes hungry because the normal influx of nourishing organic compounds from living plant roots has been cut off for the time being. The exposed soil surface is at risk for erosion by rain or wind, especially if roots have also been removed or disrupted. Pioneer plants – what we call weeds – are those species that can rapidly occupy the open niche of bare soil, holding and protecting the surface and beginning to rebuild organic matter and soil life.

Production of annual crops disturbs the soil and creates open niches (bare soil) in time (between one harvest and establishment of the next crop) and in space (between rows or beds until the crop has closed canopy). Weeds emerge and grow in these open niches – until they are stopped by cultivation, pulling, mowing or herbicides.

The most problematic weeds are those that are not native to our region. Kudzu – those enormous vines that cover and kill large trees – is perhaps the most dramatic example in our region. However, a small (4-18 inches) perennial weed called purple nutsedge, which has invaded the Deep South, causes much greater crop losses (even in sugarcane and coffee trees), and is considered the world's worst weed.

Newly introduced plants growing in the absence of the natural enemies with which they evolved may spread unchecked and choke out crops or native vegetation. These "invasive exotic plants" often become the focus of regional coordinated eradication efforts. Musk thistle, spotted knapweed and purple loosestrife are three invasive exotics in the upper South that have been successfully managed through *classical biological control* – importation of specific insects that feed on those weeds in their areas of origin.

Weeds are the most costly pest problem on many farms in terms of crop losses and/or labor costs. In surveys by the Organic Farming Research Foundation, organic farmers cited weed control as a high research priority. Weeds hurt crops by:

- Competing directly for light, nutrients, moisture, space;
- Releasing natural substances that inhibit crop growth (allelopathy – this is how purple nutsedge hurts many crops);
- Physically hindering crop growth and development (e.g. climbing vines like morninglories and bindweeds);
- Hosting pests or pathogens that may attack crops;
- Promoting disease by restricting air circulation around the crop;
- Interfering with or contaminating crop harvest;
- Reproducing prolifically, resulting in a greater weed problem in future seasons; and
- Parasitizing crops directly (e.g. dodder, witchweed).

The key sustainable strategy for dealing with weeds is to *minimize open niches for weeds in crop production systems.* Well-managed pasture, forage, orchard or agroforestry systems can reduce weed niches virtually to zero. In annual cropping systems some open niche are unavoidable. The challenge is to eliminate as many of these open niches as practical while maintaining satisfactory crop production.

Weeds – a Working Definition

The word "weed" has been defined as a "plant out of place" or a species of plant that often becomes a pest. In practice, any vegetation that comes up in a garden or field that the grower did not plant is collectively called "weeds," whether or not it is causing a problem. Trying to eradicate all volunteer vegetation is hard on farm budgets, gardeners' backs, soils, agroecosystems, fuel supplies and the greater environment. Thus a working definition might be:

A weed is any plant not intentionally sown or propagated by the grower, which requires management to prevent it from interfering with crop or livestock production. In this context, a weed is often, but not always a pest. Weeds also perform ecosystem services such as:

- protecting exposed soil;
- adding organic matter, feeding soil life;
- enhancing ecosystem biodiversity;
- providing habitat to beneficial organisms;
- providing food or forage.

The goal of Sustainable Weed Management is to minimize the adverse impacts of weeds on crops – and sometimes to reap the benefits of weeds.

A Note on "Sustainable" and "Organic"

All the practices discussed here are "organic" in that they are allowed under the USDA Organic Standards. They are "sustainable" to the extent that they reduce crop losses to weeds while protecting or improving soil health and environmental quality. The information presented is intended to assist both organic and non-organic producers develop effective, ecologically sound weed management strategies.

The Organic Grower's Dilemma

Organic farmers and gardeners seek to maintain crop yields by building and maintaining a healthy, living soil rich in organic matter. Because they do not use herbicides, organic growers rely more heavily on tillage and cultivation for weed control, especially in annual vegetable and row crops. This tillage accelerates the breakdown of soil organic matter and soil structure, and may leave the soil more prone to erosion, compaction and crusting. Thus the organic grower's dilemma:

How can I control weeds without tilling the soil to death?

An ecological approach to organic weed management takes into account the need to conserve and improve soil health while keeping weed pressure below the "economic threshold" – the level at which significant crop losses become likely.

Beyond Tillage and Cultivation

Controlling weeds in annual cropping systems without herbicides means some tillage and cultivation. However, organic weed control does not simply substitute steel for herbicides. Cultivation is just one of a multitude of vital components in any farm's weed management strategy. Experienced growers develop site-specific systems for their farms, selecting materials and tactics from a large weed-management toolbox, which continues to expand with ongoing research and experimentation by farmers and scientists.

A Sustainable Weed Management Toolbox

Major Tools:

- The **Grower's Mind** – observation and ingenuity.
- **Vigorous Cash Crops**
- **Crop Rotation**
- **Cover Crops**
- **Mulches** – organic and black plastic film
- **Indigenous Biocontrols** – weed consumers already present on the farm
- **Livestock** – graze weeds after crop harvest
- **Tillage and Cultivation Tools and Implements**
- **Mowers and other Cutting Tools**
- **Rollers and Roll-crimpers** – for no-till cover crop management
- **Flame Weeders**

Minor and Experimental tools:

- OMRI certified organic herbicides
- Bioherbicides – specific fungal pathogens
- Soil microflora
- Specific crop-weed allelopathic interactions
- Classical biological controls for specific weeds
- Clear plastic mulch - soil solarization

Eight Steps to Sustainable Weed Management

1. Plan Cropping Systems to Minimize Open Niches

Keep the soil covered with desired vegetation or organic mulch as much of the season as possible. Schedule plantings of each cash or cover crop as soon as practical after the preceding crop is finished – or sooner! Eliot Coleman, Maine farmer and author of *The New Organic Grower*, has developed an eight-year crop rotation for vegetable production in northern New England, in which clovers or other cover crops are interplanted between rows of established vegetable crops. When the vegetable is harvested, the cover crop is already established and rapidly covers the ground. This eliminates the open niche at the vegetable → cover crop transition.

No-till planting of vegetables or row crops into mowed, rolled or winterkilled cover crops eliminates the open niche at the cover crop → vegetable transition. Whereas *continuous* no-till is not currently feasible in annual cropping systems without herbicides, tillage can be greatly reduced, thereby minimizing soil degradation and flushes of weed germination.

Intercropping (companion planting), relay cropping, alley cropping, agroferstry systems, strip tillage and living mulches are all strategies to reduce weed niches in space. Some indigenous cultures in Mexico and other developing countries maintain multi-tier food gardens with tree, shrub and annual herb canopies containing as many as 75 useful plant species (including a few that American farmers call "weeds") growing together, leaving little room for noxious, invasive weeds.

Organic mulches such as straw, old hay (preferably seed-free) or chipped brush restrict niches for weed growth by blocking light stimuli and offering physical hindrance to emerging weed seedlings. However, established perennial weeds arising from rootstocks, rhizomes or tubers can penetrate organic mulch, and a black plastic mulch or landscape fabric may be needed to block their emergence.

With the exception of the synthetic mulches, *all* of these strategies to prevent weed growth also add organic matter, build soil quality and enhance farm biodiversity.

Bio-Intensive and Bio-Extensive Organic Weed Management Systems

Gardeners and growers with limited land area usually implement *bio-intensive* methods to close off weed niches in their crop rotations. Vegetables are spaced close together for rapid canopy closure, cover crops are used intensively and cut to generate mulch or composting materials, and each crop is planted immediately after the preceding crop is harvested.

Farmers with more land area often alternate several years in cultivated annual vegetable crops with several years in a perennial grass-legume sod, often managed as pasture or hay land. At Elmwood Stock Farm in central Kentucky, growers John Bell, Ann Bell Stone and Mac Stone grow vegetables for three years, then rotate to pasture for five years. These rotations help limit the buildup of annual "weeds of cultivation" such as pigweed, lambsquarters, galinsoga, crabgrass and foxtails.

Eric and Anne Nordell of Trout Run, PA have developed a *bio-extensive* approach to weed management in their organic vegetables. Their motto is *weed the soil, not the crop.* In each rotation block, they grow only one production crop every two years. The rest of the rotation schedule consists of high-biomass cover crops, and a short (6 week) fallow period during the summer of the non-production year. Frequent, shallow tillage during the fallow period draws down the weed seed bank, while the heavy cover crops on either side of the fallow choke out emerging perennial and annual weeds, and provide plenty of organic matter to compensate for the 6 weeks of soil disturbance and replenish organic matter. The result? Their crops require very little cultivation or manual weeding; in the Nordells' words, "We substitute land for labor."

2. Know Your Weeds

Get correct identification of the weeds in your fields or gardens. This is important, because two weeds that look similar may have very different life cycles and growth habits, and may respond very differently to weed control measures. For example, giant foxtail and Johnsongrass are two tall, vigorous summer grasses with large, fairly wide leaves. However, while the foxtail is an annual whose reproduction can be stopped by a single mowing soon after head

emergence, Johnsongrass is a perennial that reproduces through heavy, winter-hardy rhizomes that will survive the effects of one mowing and regenerate the weed. Aggressive tillage followed by vigorous cover crops, or running hogs in the field to root out the rhizomes, can control Johnsongrass.

Use a good field guide or taxonomic key to identify the *major* weeds in your fields and learn about their life cycles. Weed identification resources are listed in the Resources section. It is not necessary to identify *all* the weeds, especially those that aren't causing a problem. However, it pays to identify a *new* weed that appears on your farm, to help spot and eliminate noxious invaders before they multiply. If you get stuck trying to identify a new or major weed, contact your Extension agent or a university weed scientist for help.

3. Grow Vigorous, Healthy Crops

This is one of the most important weed management strategies. Vigorous crops can get ahead of the weeds, suffering less yield loss, and smothering weeds to some extent. Choose vigorous, locally adapted crops and varieties, use high quality seed, plant at or near optimum dates for rapid crop establishment, and use optimal row and plant spacings. Provide favorable growing conditions throughout the cropping cycle by maintaining healthy, living, fertile soils with sufficient but not excessive nutrient levels and suitable pH for the crop. Manage insect pests and maintain optimum moisture through irrigation and/or mulching.

Use plant and row spacings that promote prompt canopy closure without excessively crowding the crop. Arranging crops in double or multiple rows on raised beds can speed crop canopy closure and facilitate between-bed cultivation. Use in-row drip irrigation or fertigation to water and feed the crop but not the weeds.

Trying to stretch the season for a given crop by planting earlier or later than usual can make the crop less vigorous and thus more prone to weed pressure. Utilize season extension techniques to maintain more favorable temperatures for the crop, and plan on a little extra labor for diligent weed management during crop establishment.

Grow the least competitive crops on fields with a recent history of effective weed control, and plant weedier fields in competitive, dense-canopy crops like potato, sweet potato, sunflower, winter squash or cowpeas.

Discard old, slow-germinating, partially-viable seed unless you are salvaging a hard-to-replace heirloom variety or breeding line. Although those seeds that sprout retain the genetic potential to produce a crop, thin, slow-starting stands may require several time the normal weed control labor!

4. Knock the Weeds Back at Critical Times.

Timely cultivation, flame weeding, mowing, manual pulling and/or mulching can make the difference between success and failure. Early in the season, when the crop is just getting established, *get the weeds while they are small.* Many growers do a very shallow cultivation while the weeds are in the "white thread stage" – just emerging, and perhaps not even visible unless you look closely or lightly stir the soil surface. Timely shallow cultivation makes lighter work for the gardener, saves fuel for the farmer, and destroys millions of weeds per acre before they cause trouble.

Knowing the Weeds: Some Major Weed Categories

Summer Annual Weeds such as pigweeds, smartweeds, cockleburs, morningglories, sicklepod, crabgrasses, foxtails and goosegrass, typically grow rapidly during the frost-free season, reproduce through prolific seed production (thousands to hundreds of thousands per plant), and usually die with the first fall frost. Their seeds usually germinate in response to a light stimulus, and come up in "flushes" after tillage or cultivation. They can usually be managed by: timely *shallow* cultivation (the shallower the disturbance, the fewer additional seeds are stimulated to germinate); mulching (more effective on small seeded broadleaf weeds than on grasses or larger seeded broadleaf weeds like velvetleaf and morningglory); and reducing frequency and intensity of tillage. Rotating to summer cover crops and cool-season vegetables can disrupt their lifecycles and thereby reduce weed pressure.

Winter Annual Weeds such as chickweed, deadnettles, shepherdspurse, wild mustards and annual sowthistle, also reproduce through prolific seed production, and emerge in response to tillage or light stimulus. They are winter hardy, coming up in early fall or early spring, and setting seed in late spring before dying back in summer's heat. They are rarely troublesome for warm-season vegetables, though they can be a problem in garlic, salad greens and other cool season vegetables. Timely shallow cultivation, winter cover crops, and rotating to warm-season vegetables help keep winter annual weeds in check.

Simple Perennial Weeds such as dandelion, broadleaf dock, pokeweed and tall fescue, arise each year from winter hardy taproots, root crowns or coarse fibrous root masses. They reproduce mainly by seed, and while the new seedlings can be controlled by timely shallow cultivation, this strategy does not work for established weeds. Light or local infestations can be dug out. Repeated close mowing can slowly weaken rootstocks, and vigorous tillage alternating with heavy smothering cover crops can reduce more widespread infestations.

Biennial Weeds such as burdock, prickly lettuce and wild carrot share characteristics of both winter annual and simple perennial weeds. They come up during spring through late summer, overwinter as a rootstock, then emerge, bolt and flower the next spring. Timely mowing or digging just before flowering can interrupt propagation.

Invasive or "Wandering" Perennial Weeds, such as quackgrass, bermudagrass (=wiregrass), Johnsongrass, nutsedges, kudzu and bindweeds, are generally the most serious. They form extensive underground perennial structures – roots, rhizomes and/or tubers – from which they propagate and spread, often over a wide area. Many of these weeds can regenerate from a one-inch fragment of rhizome buried several inches deep in the soil – thus a single rotary tillage that chops up the rhizomes will propagate the weed. However, *repeated* tillage can weaken even these stubborn weeds, and growing smothering cover crops such as buckwheat, sorghum-sudangrass or winter rye after each tillage will counteract the damaging effects of the soil disturbance and help suppress weed regrowth. Mowing every 4 weeks to a short stubble height can slowly weaken invasive perennials, and may be the best option in pastures or other situations in which tillage is not desired.

Some farmers do a "blind cultivation" after crop planting but before emergence. Large seeded crops that are planted an inch or more deep, like soybeans and corn, can be rotary hoed several times before, during and just after emergence to wipe out weeds that were stimulated to germinate by seedbed preparation and planting operations.

Slow-sprouting, small-seeded crops like carrot, parsnip, spinach, or onion can be especially tricky, but they can be *flame weeded* just before emergence. Some farmers gauge timing by placing part of a row under a pane of glass or a soil-warming row cover so the crop emerges a day or two earlier. When seedlings first appear in the test plot, the rest of the field is immediately flame weeded. For carrots, simply planting a test row of beets without glass or row cover works fine, as beets normally emerge about one day ahead of carrots. When done correctly, flame weeding does not heat the soil or damage unemerged, germinated seedlings. The flame weeder should move over the ground at a speed and height that *briefly scalds* emerged weeds rather than charring them (they take a few hours to show signs of damage, then die overnight).

Keep the vegetable crop weed-free through its "minimum weed-free period" – usually the first one-third to one-half of the crop's growing season. Weed-free periods for vigorous summer crops like tomato, corn or summer squash might be 4-6 weeks, and perhaps 10 weeks for slower-starting crops like eggplant, carrot or onion. Weeds that are allowed to grow during this time are likely to reduce yields significantly – by 10 to 100 percent. Later-emerging weeds usually have little direct impact on crop yield. After this point, some weed growth may even help by protecting soil and providing beneficial insect habitat. However, certain weeds harbor diseases or pests of related crops, and should be eliminated.

Remove weeds before they multiply. Mow or pull flowering weeds to prevent seed set. Invasive perennial weeds like bermudagrass, nutsedges and Canada thistle can propagate underground anytime they are allowed to grow continuously for more than four weeks, or grow to a foot or more in height. Timely mowing, pulling or chopping must be done throughout the cropping cycle.

One way to get better weed control with less soil disturbance is to use mulch. Once the crop is established, a good strategy for smaller-scale market gardens is to hoe shallowly early on a clear, hot day, let the hoed weeds die in the sun, then spread hay or straw mulch that evening or the next day to conserve moisture and discourage additional weed emergence. This gives the crop a long jump on the weeds.

5. Put the Weeds Out of Work – Grow Cover Crops!

Cover crops – domesticated plant species that grow vigorously with relatively little care – perform many of the same ecosystem functions as weeds. They fill open niches in crop rotations, protect and feed the soil, recycle nutrients, enhance biodiversity, harbor beneficial insects, and outcompete the weeds themselves. Some cover crops, including cereal grains, sorghum-sudangrass, radish, subclover and buckwheat further inhibit weeds through allelopathy.

Whereas the long, hot growing seasons of the South make weeds grow like mad, they also expand opportunities for cover cropping. Warm-season crops like forage soybean, sorghum-sudangrass, and several millets can grow rapidly, choke out weeds, and produce tremendous biomass within 50-70 days. Buckwheat and cowpea form especially dark and fast-closing canopies and are thus excellent weed fighters during short summer fallow periods.

During cooler seasons oats, rye, wheat or barley can be grown in combination with a variety of cool-season legumes – vetches, field peas, annual clovers or bell beans. Bicultures generally give better weed suppression and soil building than either grain or legume alone. Rye, wheat, hairy vetch, crimson clover or Austrian peas, can be grown over winter throughout the South, and the other species grow vigorously in the milder winters of the Deep South. Daikon and forage radishes are especially weed-suppressive and are frost hardy to about 15 F.

For more on cover crops, see the information sheets *Cover Cropping: On-Farm, Solar-Powered Soil Building; Cover Crops for All Seasons;* and *Using Manually-Operated Seeders for Precision Cover Crop Plantings on the Small Farm,* available on the Virginia Association for Biological Farming web site, *www.vabf.org*.

Many annual cover crops can be killed by mowing or rolling after full bloom to create mulch in place. This eliminates soil disturbance and open niches between the cover crop and the next cash crop. Whereas these "organic no-till systems" can be challenging to manage, an increasing number of farmers have adopted them, especially for summer vegetables after winter cover crops. For more on this topic, see the information sheet *Reduced Tillage and Cover Cropping Systems for Organic Vegetable Production*, by Mark Schonbeck & Ron Morse, available at *www.vabf.org*.

Beating the Weeds with Innovative Cover Cropping and Cultivation

David Stern, an organic grower in the Finger Lakes region of New York, has developed an innovative, integrated weed management strategy for his 40-acre vegetable farm. In addition to winter cover crops of rye + vetch and oat + peas, he intercrops vegetables with other widely-available, low-cost cover crops. Red clover is overseeded into winter squash. This hardy, shade-tolerant clover gets established under the squash foliage, rapidly covers the ground after harvest, and is allowed to grow through the following season to reduce annual weeds and rebuild the soil. David sows buckwheat between plastic-mulched rows of sweet potatoes. Just before the sweet potatoes vine out, he mows the buckwheat to produce mulch in place and suppress weeds. He overseeds proso millet (birdseed – low cost!) into spring shell and snap peas; and oats into fall brassicas. Late Irish potatoes are planted in alternate beds with sorghum sudangrass, which is mowed periodically to generate mulch for the potatoes.

When it is time to roll out the steel, David strives to combine the efficiency of mechanization with the fine precision of the human eye and hand. He has designed tractor drawn platforms from which workers can comfortably hand weed or operate tractor-mounted wiggle hoes while the tractor moves slowly down the row. He also has a range of tractor drawn implements, from Buddingh basket weeders for tiny weeds to more aggressive Lilliston rolling cultivators and Regi weeders for larger weeds in established crops.

6. Manage the Soil Weed Seed Bank.

The reason so MANY weeds come up soon after tillage is that most soils have a large *weed seed bank* – millions of viable, dormant weed seeds per acre, waiting for the right stimulus (often a light flash associated with tillage) or conditions to germinate and emerge. Every year, weed seed germination, and some degree of seed decay or seed consumption by soil organisms, draws down the weed seed bank. Then, when the current season's weeds shed their seeds, they make a deposit into the weed seed bank.

Managing the weed seed bank entails *encouraging "withdrawals"* and *minimizing "deposits."* Seed inputs can be reduced by cutting or pulling weeds before they set seed, and by mowing or tilling fields as soon as crop harvest is complete. "Walking the field" to remove large weeds from established crops before the former set seed is a good way to reduce seed bank deposits. Some growers find that the added labor is a good investment even on multi-acre fields.

One way to draw down the seed bank is to prepare a *stale seedbed.* Till the soil several inches deep several weeks before crop planting, watch closely, and till again each time more weeds appear. Till again *immediately* before planting the crop, this time going *very shallowly* (0.5-1 inch) to avoid stimulating more weed to sprout while the crop is coming up.

Another way to draw down the weed seed bank is to encourage weed seed decay and predation. Ground beetles and some other beneficial insects eat weed seeds as well as insect pests. Birds, some species of field mice and even slugs glean newly-shed weed seed from the ground. By all means *mow* fields promptly after harvest to stop weed seed formation, but consider delaying *tillage* to give the "cleanup crew" time to eat some of the weed seeds already formed.

A vigorous and diverse soil microbiota shortens the "half life" of weed seeds in the soil by promoting decay. Keeping the soil covered by organic mulch and/or live vegetation provides ground beetle habitat, and good organic soil management with ample organic inputs encourages the microorganisms that consume weed seeds through decay.

7. Keep the Weeds Guessing – Diversify Cropping System.

If the soil is tilled on a regular, predictable schedule year after year, certain weeds will likely proliferate and eventually become a major problem, even if the crop rotation appears quite diverse. Continuous corn or a simple corn/soy rotation, in which fields are moldboard-plowed every spring before planting, is known to promote velvetleaf, cocklebur and other aggressive, large-seeded summer annual weeds that can emerge from several inches depth. A four-year vegetable rotation of sweet corn – snap beans – squash – tomato family with winter cover crops, though more diverse, can still result in heavy populations of pigweeds, foxtails, morningglories, and other summer annual weeds that emerge in response to tillage and seedbed preparation every May. Adding some cool season vegetables and summer cover crops to shift the dates of tillage year to year will make it harder for certain weed species to adapt to the more unpredictable pattern of soil disturbance.

Vary not only the dates of tillage, crop planting and harvest, but also the depth and method of tillage (chisel plow, rototiller, rotary spader, harrows, etc.). Include some strip tillage, reduced or no tillage at some points in the rotation.

8. Keep Observing the Weeds and Adapt Practices.

Nothing in this handout can tell you as accurately how to manage the weeds on your farm, as your own observation! Keep watching the weeds through the season and year after year. What tactics seem to work best? What crops seem to suppress – or encourage – certain weeds? What rotation sequences or other strategies seem to reduce weed control labor or crop losses to weeds?

Some weeds may indicate certain soil conditions – nutrient imbalances, or physical conditions (compaction, poor aeration, etc) – that may hinder the crop. There is a lot of traditional lore on this subject – some of it well substantiated and some less so. Several books have been written on this topic, but again your own observations are often the best guide.

In general, increasing problems with *annual* weeds may result from frequent tillage – so reduce intensity and frequency of tillage, consider no-till vegetable planting into mowed or rolled cover crops, and consider rotating weedy fields into perennial crops or pasture/hay for a few years. Consider no-till cover crop management or overseeding cover crops into vegetable or row crops. If *summer annual weeds* get bad in warm season vegetables, rotate to cool season vegetables and competitive summer cover crops. If *winter annual weeds* become a problem in cool season vegetables, rotate to summer vegetables and vigorous winter cover crops.

Increasing problems with *invasive perennial* weeds may indicate a need for increased tillage for a period of time to bring these problem weeds under control. If an asparagus bed, berry patch or pasture has become infested with these weeds, consider tilling it up thoroughly and (after the weeds are somewhat under control) rotating the area into annual crop production. Be sure to follow each tillage with a vigorous, weed-smothering cover crop to minimize soil damage and to enhance weed suppression.

Experimental Practices and Cutting Edge Research

Nighttime Cultivation

Because tillage exposes weed seeds to a light flash, cultivation to remove existing weeds is often followed by a new flush of weeds. This can result in a soil-exhausting "cultivation treadmill" if the soil's weed seed bank is large. Some growers and researchers have experimented with cultivating at night or with an opaque cover over the tillage implement. This eliminates the light stimulus, and can significantly reduce subsequent weed emergence.

Soil Solarization

Covering the soil surface with clear plastic mulch during hot sunny weather can raise the temperatures of the top few inches of soil to kill vegetative propagules (e.g. rhizomes of Johnsongrass) and some weed seeds. A few growers use this method on a small scale to prepare beds for high value specialty crops. Soil solarization is not so effective on dormant or "hard" weed seeds, on purple nutsedge tubers (which are incredibly heat tolerant), or any seeds or propagules buried at a depth of six inches or more.

Biological Weed Controls and Organic Herbicides

Several organic (OMRI approved) herbicides based on common allelochemicals (natural weed-suppressive substances released by certain crops) are commercially available. They are fairly expensive and are practical for spot applications such as clearing weeds from around a farmstand or dealing with a localized infestation of a noxious weed.

Researchers have also attempted to develop bioherbicides, based on specific plant pathogens. Two products – DeVine against stranglervine in citrus, and Collego against northern jointvetch in rice and soybeans, achieved commercial success in the 1980s. These products are now off the market because the target weeds were largely eliminated, and demand for the products dried up. A new product against amaranths (pigweeds) will soon become commercially available.

Several invasive exotic range weeds have been successfully controlled through *classical biological control*, in which insects that feed on the weeds in their countries of origin are imported to the US and released. Biocontrol insects can be ordered through Biological Control of Weeds, Inc., 1418 Maple Drive, Bozeman, MT 59715; tel. 406-586-5111; *www.bio-control.com/products.asp*.

Crop-Weed-Soil Microbe Interactions

Some fascinating research has been done into the role of soil and root-zone microorganisms in crop-weed interactions and the so-called "rotation effect." Microbes play a role in many specific crop-weed interactions, forming beneficial symbioses with some plants while inhibiting or parasitizing others. One example is the mycorrhizal fungi, which *benefit* legumes, grains, tomatoes, cotton and some other major crops; *hinder* both crops and weeds in the amaranth, buckwheat, chenopod (spinach, beet, lambsquarters) families and nutsedges, and are themselves inhibited by brassica root secretions. The potential implications of plant-mycorrhizal interactions for crop rotations merit further investigation.

Whereas some researchers are attempting to give crops an edge over weeds by adding certain microbes to the soil, the most likely practical outcome of this research is to fine-tune crop rotations and soil management practices toward this end.

Resources for Organic Weed Management

Weed Identification – Books, CD's and Web Sites

Georgia Cooperative Extension Service, Bulletin 761, 1995. *Weeds of the Southern United States.* 45 pp. Field guide to 120 major weeds of the South. Available for $3; to order, call Georgia Cooperative Extension at 706-542-8999 or -8575.

Jon M. Stuckey, Thomas J. Monaco & A.D. Worsham, 1994. *Identifying Seedling and Mature Weeds Common in the Southeastern United States.* North Carolina Agricultural Research Service & NC Cooperative Extension Service.

USDA, Agricultural Research Service, 1971. *Common Weeds of the United States.* Dover Publishing, Inc., New York, NY.

Richard H. Uva, Joseph C. Neal and Joseph M. DiTomaso, 1997. *Weeds of the Northeast.* Cornell University Press, Ithaca, NY. 297 pp. Covers 299 weeds, with excellent photos and descriptions, includes majority of Southern weeds.

Virginia Tech Weed Identification Guide, an on-line resource at *www.ppws.vt.edu/weedindex.htm*, covers 324 weeds of the southeastern United States.

Weed Science Society of America (WSSA), *1000 Weeds of North America*. Computer CD with an interactive key to 140 grasslike weeds and 860 broadleaf weeds throughout the continent. CD can be ordered for $55 plus shipping through WSSA (1-800-627-0629, ext. 297, *http://www.wssa.net/*)

Weed Science Society of America – Weed Photo Gallery, has photographs of many weeds, including close-ups of leaves and flowers that can aid in identification. No verbal descriptions at this site. *http://www.wssa.net/Weeds/ID/PhotoGallery.htm.*

Tools for Cultivation and Weed Control

Greg Bowman, ed., 1997. *Steel in the Field: a Farmer's Guide to Weed Management Tools*. Sustainable Agriculture Network, National Agricultural Laboratory, Beltsville, MD. 128 pp. Order at *www.sare.org*.

Earth Tools, Inc., Joel Dufour, manager, 1525 Kays Branch Road, Owenton, KY 40359, 502-484-3988, *www.earthtoolsbcs.com*. This company offers a wide range of excellent hand tools and walking (two-wheel) tractor implements for weed control at the market garden scale

Vendors of tractor-drawn cultivation implements: Bezzerides Brothers (559-528-3011, *www.bezzerides.com),* Buddingh Weeder Co. (616-698-8613). Brillion Farm Equipment (800-409-9749, *www.brillionfarmeq.com),* Bigham Brothers *(806-745-0384, www.bighambrothers.com/lilliston.htm).*

Ecological Weed Management Principles and Practices

Vern Grubinger, 1997. *10 Steps Toward Organic Weed Control.* American Vegetable Grower, Feb. 1997, pp 22-24.

National Sustainable Agriculture Information Service (aka ATTRA), *Principles of Sustainable Weed Management for Croplands*, available at *www.attra.org/pest.html#weed*. Excellent overview with extensive resource list.

Anne and Eric Nordell, *A Whole-Farm Approach to Weed Control.* A compilation of articles by the Nordells, published in the Small Farmers Journal, on their "weed the soil" system. Approximately 50 pp. Available for $10 by mail order, Eric and Anne Nordell, 3410 Rt. 184, Trout Run, PA 17771.

Cover Cropping and Reduced Tillage

Managing Cover Crops Profitably, 3rd Edition. Sustainable Agriculture Network, National Agricultural Library, Beltsville, MD. 2007. 244 pp. $19.

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