Summer Squash and Zucchini: Organic Production in Virginia

By Mark Schonbeck, Editor, Virginia Biological Farmer

Introduction

Summer squash and zucchini are varieties of the genus *Cucurbita* (squash, pumpkins, and gourds) whose fruit are harvested and eaten at an immature stage. They come in many shapes and colors, are usually eaten as a fresh vegetable lightly steamed, stir-fried, or raw. Well-known types include zucchini (a general term for elongated, cylindrical, usually green summer squash), yellow crookneck, yellow straightneck, and patty-pan or scallop squash (which may be white, green, or yellow). Summer squash are harvested well before they reach their mature size, typically when fruit are 3 to 8 inches in their longest dimension, depending on markets and buyer preference. Overmature summer squash are tougher and less flavorful, though large zucchinis can be baked, used in soup, or for zucchini bread.

Zucchini and other summer squash are widely used and appreciated in our region, and in many different traditional cuisines. They are popular vegetables at farmers' markets, in community supported agriculture (CSA) programs, with restaurant chefs, and other market venues. With careful market analysis and planning, summer squash and zucchini can yield good economic returns.

Throughout this information sheet, the term "summer squash" will be used to cover zucchini as well as yellow, patty pan, and other types, colors, and shapes of summer squash.

Nearly all summer squash varieties are in the species *Cucurbita pepo,* which also includes some pumpkins and winter squash such as acorn, delicata, and spaghetti. Most summer squash have an upright bushy habit of growth, rather than the long vines characteristic of melons, cucumbers, and most winter squash and pumpkins. One notable exception is 'Tromboncino,' a variety of *C. moschata* (butternut squash) that forms long vines and bears light green, long-necked fruit that make excellent summer squash if harvested at 8 to 12 inches.

Summer squash is a frost-tender, warm season crop, but its short life cycle (40 to 60 days from germination to first harvest) allows production throughout the US and into southern Canada. In Virginia, our longer growing season allows multiple plantings for an extended harvest from early summer until fall.

Summer squash is *monoecious*, which means that the male (stamens, shedding pollen) and female (pistil and ovary, forming the fruit) organs are borne in separate flowers on the same plant. Thus, most varieties of summer squash depend on bees or other pollinators to deliver pollen to the pistils of female flowers, thereby initiating fruit development. A few varieties are *parthenocarpic*, which means that the female can form a marketable fruit without pollination. One recent release is 'Partenon,' and some dark green zucchini varieties, such as 'Black Beauty' and 'Black Magic' can also set fruit without pollination (Dawling, 2013).

Summer squash is fairly easy to grow, as it is a moderate feeder equipped with an extensive root system that efficiently forages for moisture and nutrients, and vigorous top growth that helps the crop keep ahead of the weeds. However, several insect pests and crop diseases can make this crop challenging to grow organically. Otherwise, the greatest hurdle for inexperienced squash growers may be dealing with the tremendous productivity of summer squash, especially zucchini (the butt of more than one Garrison Keeler joke), which can lead to market gluts. See the Crop Planning sections for more on this challenge.

VABF Summer Squash Field Trials in Virginia

In 2010, the Virginia Association for Biological Farming (VABF) was awarded a USDA Specialty Crop Block Grant (SCBG), administered through the Virginia Department of Agriculture and Consumer Services, for a two-year project entitled *Organic Management of Pest Predation in Commercial Production of Summer Squash.* The project was designed to help Virginia's organic growers address three major squash pests in our region – cucumber beetles *(Diabrotica* spp. and

Acalymma spp.), squash bug (*Anasa tristis*), and squash vine borer *(Melittia satyriniformis)*. A fourth pest, the invasive exotic brown marmorated stink bug (BMSB) *(Halymorpha halys)* was also monitored.

Six producers conducted field trials in 2011 and 2012:

- Mitch Wapner of Paradox Farm, Lexington (Shenandoah Valley)
- Hans Burkholder of Glen Eco Farm, Linville (Shenandoah Valley)
- Lee Bristow, farmworker at Charlie and Miriam Maloney's Dayspring Farm, Cologne (Tidewater)
- John Wilson of New Earth Farm, Virginia Beach (Tidewater)
- Andy Hankins, Virginia State's Randolph Farm, Petersburg (2011), and St. Paul's Baptist Church, Richmond (2012)
- Earrett Parson. Elberon, VA (Southside)

Each farm planted four F-1 hybrid varieties of summer squash: 'Raven' zucchini, 'Zephyr' bicolor (yellow and light green) straightneck, 'Sunburst' patty pan, and 'Magda,' a light green Middle-Eastern specialty variety (Figure 1). Each farm planted a total of ¼ acre of summer squash, and kept records of their harvest size criteria, yields, pest pressures, and pest control measures.

Pests were managed through a combination of beneficial habitat plantings (strips of buckwheat and sunflower along the edges and down the middle of the planting), regular monitoring and, as needed, spray applications of a formulation of pyrethrin botanical pesticide allowed by the USDA National Organic Standards. In addition, three of the farms planted a perimeter trap crop of 'Blue Hubbard' winter squash, known to be highly attractive to cucumber beetle, squash vine borer, and squash bug. On these farms, *only* the trap crop was sprayed when pest levels merited action; the production crop was never sprayed. The three farms that used the trap crop in 2011 acted as controls in 2012, and vice versa.

Row covers were not used in these trials. Row covers supported on hoops can exclude pests and provide a warm microclimate to accelerate crop emergence and establishment; however their installation and subsequent removal at flowering (to allow pollinator access) is too costly and labor-intensive to be practical in squash plantings of 1 acre or more. The project aimed to demonstrate effective organic pest management strategies that are workable for both small and larger scale enterprises.

Participating farmers gathered and shared data on marketability and profitability of the four different varieties.

Field events featuring the squash trials open to the public were held at each of the participating farms over the two year project. A total of at least 300 farmers and gardeners attended.

Development of this information sheet was supported through the Specialty Crop Block Grant, and was based in part on the outcomes of the SCBG-funded project, hereafter referred to as the "VABF summer squash trials."

Crop Planning, Variety Selection, and Market Considerations

Begin planning your summer squash production with market research. What do your market customers, CSA sharers, restaurant chefs, or other buyers want? Find out their favorite varieties or colors, how much they want, when they want it, and what size or stage of maturity they prefer. The last is important, as younger squash tend to have more flavor, and some buyers will reject a load of squash or zucchini if they exceed a certain length or diameter. Some chefs use squash flowers – either the male flowers, or female flowers with the "baby" fruit attached – for specialty dishes. At the other extreme, some CSA sharers or market customers might appreciate a few large zucchinis for stuffing and baking, or to make zucchini bread.

When selecting what varieties to grow, consider local adaptation, disease and pest resistance, your own past experience, and most importantly market needs and preferences. Catalogue descriptions (yield, maturity date, tolerance to pests and other stresses, and fruit flavor, texture, and harvest sizes) can be helpful, but both crop performance and culinary quality may be different in your particular soil and microclimate. By all means try new varieties that seem interesting for one reason or another – on a small scale until the varieties prove themselves in the field and at market.

You may need to do some consumer education when you bring a new variety to market. For example, your customers may be familiar with zucchini varieties such as 'Cocozelle' or 'Black Beauty' harvested at 6 inches, and if you decide to try 'Costata Romanesca' for its superior flavor, folks may not realize that the larger (12 inches) fruit are sweet and tender, and pass them by. 'Yellow Crookneck' is an old favorite in our region; if you switch to straightneck for its smoother skin or higher yield, you might sacrifice some flavor and disappoint customers used to crookneck.

Pam Dawling, author of Sustainable Market Farming (2013), recommends hybrid varieties for their higher and more reliable yield. Examples include 'Zephyr' which is a bicolor (yellow / light green) straightneck that has become quite popular; and 'Raven' zucchini.

Conventional seed suppliers now carry several GMO varieties of summer squash, engineered for resistance to certain viruses. If you are USDA certified organic or you choose not to use GMO crop varieties for ethical or ecological reasons, check catalogue descriptions and seed packets carefully.

The trick to making a profit with summer squash is to match your yields with your market demand. Marketable yields of summer squash may vary from 4 to 8 tons/acre (100 to 200 lb per 100 feet of row), and sometimes as high as 15 tons/acre, depending on growing conditions, production methods, variety, and harvest size. Remember that younger, smaller fruit may fetch considerably higher per-pound prices than large fruit; thus, maximum yield may not mean the highest net profit. Also consider growing early and late crops, for which market opportunities and prices may be much better than midseason crops – everyone has zucchini and yellow squash in July and August!

Succession planting and season extension

Unless you have a guaranteed wholesale market that is expecting your product at a certain time of the year, don't plant all your summer squash at once! Succession planting helps avoid gluts and allows you to market quality squash to customers or buyers over an extended period.

A planting of summer squash typically yields over a three to six week period beginning 45 to 55 days after sowing. Make additional plantings every three or four weeks to extend your harvest season. Estimate your weekly market demand to determine how much to plant at one time, then adjust up or down based on actual yields and experience with your markets. For example, if you expect to sell 200 lb per week, and to harvest a *total* of 200 lb per 100 feet of row, you might start with a 400-ft planting. If you regularly sell out, plant more next time; if you end up with boxes of unsold squash, plant less.

Use season extension to capture lucrative early and late markets. With care and skill, summer squash can be transplanted (more below). Start seeds in a heated greenhouse in early to mid spring, and transplant to a high tunnel up to a month before the spring frost date. Transplant the next succession outdoors under row covers at or shortly before the frost date. These early plantings can provide squash harvests during the weeks before the first field planting kicks in. Similarly, you can extend the fall harvest season a few weeks beyond the first light frost by using row cover or high tunnel.

Remove row covers and open end or side walls of the high tunnel when the crop flowers to allow pollinators access; or introduce pollinators into the enclosed space (most feasible in the high tunnel); or plant parthenocarpic varieties that do not require pollination.

See Dawling, (2013)) for more on crop planning, succession planting, and season extension.

Figure 1. Squash varieties in VABF trials (from left to right): 'Sunburst' patty pan, 'Magda', 'Raven' zucchini, & 'Zephyr.'

Figure 2. Drip irrigation of summer squash on raised beds.

Field Performance and Market Appeal of four Varieties in the VABF Summer Squash Trials

In the VABF summer squash trials, yields were recorded in 10 of the 12 trials, and averaged 5.3 tons/ac with a range of 3.6 to 8.4 tons/ac. Extreme rainfall cause a crop failure in one trial, and yields were not recorded for one trial. Zephyr gave the highest average yield of 7.3 tons/ac, while yields of the other three varieties were similar: 5.0 tons/ac for Raven, 4.8 tons/ac for Sunburst, and 4.4 tons/ac for Magda. Zephyr gave the highest yield in six out of nine trials. One farmer harvested Zephyr at a very early stage (full bloom), and other varieties at later stages, yet his Zephyr yields were only 15-20% less than the top yielder in both years.

Several project participants reported that Zephyr was most popular with their customers, followed by Raven. Sunburst and Magda were sometimes more difficult to market. One farmer reported that customers appreciated having multiple and distinctive varieties to choose from, and a couple others noted that different varieties fit different markets. Several restaurant chefs liked the Sunburst and Magda that farmers' market shoppers passed by.

Customer education played a significant role. One producer "carved a niche" for Zephyr harvested at full bloom, and found an eager ethnic market for Magda in a nearby Kurdish community. Three other farmers remarked on the excellent flavor of Magda; and although some customers "liked it when they tried it," the variety was still difficult to sell. Apparently, shoppers were deterred by its unfamiliar appearance.

Between its high yield and market appeal, Zephyr had the greatest overall income-generating potential in these trials.

Figure 3. These pigweed emerged late enough not to compete seriously with the squash, but should be removed before they interfere with air circulation or set seed.

Figure 4. In this trial at Virginia Tech, summer squash was planted no-till into roll-crimped rye + vetch yielded 15 tons/ac. Buckwheat at left harbored predators of squash pests.

Figure 5. Squash bug nymphs on butternut squash foliage. The leaf at left has withered as a result of squash bug feeding.

Figure 6. Pennsylvania leatherwing, whose larve prey on cucumber beetle, is attracted by this flowering yarrow.

Crop Growth Requirements and Cultural Practices

Season, temperature, moisture

Summer squash is a frost-tender, warm season crop that thrives in warm, moist, well-drained soil; and moderate summer weather with daily highs of 75-85°F and nights around 65°F. It is fairly tolerant to heat and drought, but will give better yields and quality when provided with sufficient moisture.

Summer squash can be planted outdoors anytime from late spring through late summer. The last field planting should be sown at least 8 weeks before the fall frost date to allow time for maturation and harvest.

The minimum soil temperature for seed germination is 60°F, but the crop germinates best and most rapidly (in about 5 days) at 85°F. Seeds will rot if planted in cool, wet soil, so avoid overwatering newly-seeded squash, especially if soil temperatures are near the lower end of the range.

Because summer squash roots extend fairly deep into the soil profile, it is rarely necessary to irrigate daily, and overwatering can contribute to disease problems or lower fruit quality. During dry spells, irrigate thoroughly once per week. Very sandy, low-moisture-capacity soils may require two irrigations per week. Drip irrigation (Figure 2) is recommended for more efficient water use, and for disease and weed management. In-row drip waters the crop, not between-row weeds; it also help prevent foliar fungal diseases by delivering water without wetting the leaves.

During hot, sunny afternoons, it is normal for the large succulent leaves to wilt slightly, even in an adequately-watered crop. Wilting that persists into the evening or overnight indicates either yield-limiting soil moisture deficit, or pest or disease problems.

Soil fertility, soil quality, and nutrient requirements

Summer squash thrives in loamy to sandy soils that are biologically active, rich in organic matter, and slightly acid to neutral (pH 6.0 to 7.5). It requires moderate levels of available soil nitrogen (N) and phosphorus (P), and fairly high levels of potassium (K), for optimum yield and quality. Standard fertilizer recommendations (from Peet, 1996) are 75-100 lb N/ac in a split application, plus the following rates of phosphate and potash based on soil test rating:

Soil nutrient level		L	M	H	VH
Phosphate (P_2O_5)		150	100	50	25
Potash (K_2O)	200	150	100	50	

As with any crop, it is important to identify and remedy any soil nutrient deficiencies or imbalances before planting summer squash. Obtain a complete soil test from a reputable university, Extension, or private soil testing laboratory, and pay attention to micronutrient levels as well as P, K, and pH (acidity). The "H" (high) rating for nutrients is considered optimal. Use organic or natural mineral amendments to supplement any nutrients marked "VL" (very low) or "L" (low). Correct acid pH (below 6.0) with high-calcium limestone if magnesium (Mg) is high or very high; otherwise use dolomitic limestone. Use the above guidelines to estimate how much N, P, and K to provide through compost and organic fertilizers, taking legume cover crop N into account.

It is fairly easy to provide for crop nutrition through organic means because:

- Summer squash is not an especially heavy feeder.
- The crop is grown during the warm season, when soil life is actively mineralizing (releasing) nutrients from the organic matter.
- The crop's extensive root system absorbs nutrients efficiently.

On high quality, well-managed soils, nutrient release by the soil life can often meet the crop's nutritional needs, and you may not need supplemental fertilizer. Your main goals are (1) to replenish organic matter consumed by soil life, removed in harvest, and oxidized by tillage; and (2) to replace nutrients removed in harvest. Assuming crop residues are returned to the soil, harvesting 10 tons/ac summer squash removes only 20 to 30 lb N, 8 lb phosphate (P_2O_5), and 30 to 40 lb potash (K_2O) per acre. Two tons per acre of a good quality compost, applied in the crop row at planting, will provide this much NPK, as well as adding some organic matter and helping to maintain an active and diverse soil food web. Immediately after squash harvest is complete, growing a high biomass cover crop with a legume component will replenish soil organic matter, feed soil life, and provide some N for the following crop.

On lower-fertility soils with less organic matter, limited biological activity, and low to moderate P levels, use generous amounts of compost (10 tons/ac) to restore overall fertility. Provide some available N by incorporating a legume cover crop prior to the squash, or by applying 300 to 500 lb/ac feather meal (13% N, medium release) or blood meal (12% N, fast release) at planting. A good compost should provide 10 to 20 lb available K per ton. If soil test K is low, supplement with potassium sulfate (51% K_2O), or use clean hay mulch brought in from another field (a 3-inch hay mulch can provide 200 lb/ac K_2O).

If soil P is at or above optimum ("H"), limit compost use to deliver the amounts of phosphate shown above. Obtain a compost nutrient analysis so that you know how much NPK it contains; and calibrate compost rates and supplements accordingly.

If you are unable to obtain compost in sufficient quantities, use a concentrated organic fertilizer such as Harmony (5-4-3) or NatureSafe (8-5-5) at rates to provide the desired amount of P, and use other materials as needed for N, K, and micronutrients.

Soil Test Recommendations and Nutrient Management for the VABF Summer Squash Trials

With the exception of one trial in 2012, VABF squash project consultant Mark Schonbeck visited each participating farm in early spring, took a soil sample from the experimental plot, and walked the field with the farmer to get a sense of soil conditions (texture, tilth, presence/absence of a subsoil hardpan), recent field history including amendments, and performance of recent crops. Soil samples were tested by A&L Eastern Laboratories in Richmond. Test reports were evaluated in light of direct field observations and information from farmers to develop customized amendment recommendations for organic production of summer squash at each site. For one site, recommendations were developed based on an Extension soil test and e-mail communication with the farmer.

Each participant received two 50-lb bags of Harmony 5-4-3 (N-P_2O_5-K_2O) organic fertilizer (heat treated poultry litter) as part of project supplies. When applied in a band in crop rows of the quarter-acre of squash, this provided starter nutrients of about 20 lb N, 16 lb P_2O_5, and 12 lb K_2O per acre. Additional materials and practices were recommended to:

- Provide the amounts of N, P_2O_5, and K_2O recommended by Peet (1996) for squash based on soil test P and K levels.
- Remedy soil acidity (lime when pH below 6.0) or micronutrient deficiencies (boron at several sites, zinc at one site, and manganese at one site).
- Provide an inoculum of beneficial soil organisms (compost).
- Relieve any compaction problems (subsoiling in crop row) and prevent erosion (contour planting and grass buffer strips on sloping land at one site).

Because excessive soil P can suppress beneficial mycorrhizae, compost application rates were calibrated according to soil test P levels. Where P tested very high, Harmony was not used and compost rates were limited.

An estimate of available N was based on % soil organic matter and soil texture, amount of compost used (in which 25% of total N was assumed available), the 20 lb N in the Harmony starter where it was used, and whether a winter legume cover crop preceded the squash. Any anticipated N shortfalls were made up with feather meal (13-0-0). Potassium sulfate was used as needed to bring total K inputs up to the Peet (1996) recommendations.

Lime and boron were broadcast, and other fertilizers and compost were applied in a 12-18 inch wide band centered on the crop row, and worked into the top few inches.

With the exception of one trial washed out by extreme rainfall, yields were satisfactory, and several participants thought that the site-specific fertility recommendations were helpful in maintaining crop nutrition and yield.

Soil preparation, planting and plant spacing, direct-seeding and transplanting

Summer squash is usually planted in rows spaced 5 to 6 feet apart. Some growers plant squash on raised beds (Figure 2) to enhance soil warming, drainage, and aeration. This is especially helpful on heavier soils that are somewhat slow to drain and warm up, and in fields with a high water table.

Use a probe or penetrometer, or dig a couple of exploratory holes to determine whether the soil is compacted or has a subsurface hardpan within the top 12 to 16 inches. A hardpan can hurt crop nutrition and drought tolerance by preventing deep root penetration. To relieve compaction, run a single shank subsoiler or chisel down each crop row before planting, working just an inch or two deeper than the bottom of the hard layer.

Before planting (but after subsoiling if this is done), apply and lightly incorporate compost and any other organic fertilizers or amendments in a band about 1 to 2 feet wide centered on the crop row. *Exceptions:* if lime is needed, broadcast the recommended rate over the entire field anytime, preferably 6 months prior to planting to allow full activation in time for the crop. And always broadcast any recommended boron (B) supplements – *never band*, as too much near the roots can hurt most crops.

Sow seeds about 1 inch deep (1/2 inch if soil is cool), either in groups of 3 to 5 spaced 3 to 4 feet apart (hills), or singly every 6 to 12 inches. If the soil is dry, water once at planting, then wait until after emergence before applying more water. For planting in hot, dry weather, pre-irrigate the seed row with drip tape about 24 hours before sowing.

Do your first *unprotected* field planting when soil temperatures measured at seeding depth (about 1 inch) at midmorning are 65 to 70°F. This may not occur until several weeks after the spring frost date. For earlier plantings, use transplants, or plant under row covers or in a high tunnel to provide needed warmth.

When the crop is established (plants 6 to 12 inches tall), thin hills to the best two or three plants, or thin rows

to one strong plant every one to two feet of row. A plant spacing of one foot helps suppress within-row weeds, keeps the soil surface cooler by shading, and may thereby conserve moisture. If fungal disease pressure is heavy, a two-foot spacing can help by allowing plant surfaces to dry faster after rain or dew.

Transplanting summer squash requires care to avoid disturbing the roots, but can give excellent results. Start the seeds in a warm place (70 to 85°F) with ample sun or a good bank of grow lights; for cooler locations, use a germination mat to provide bottom heat until seedlings emerge. Use a light-textured, well-drained potting mix that includes some good compost. Including 10% worm castings (vermicompost) in the mix can enhance seedling vigor. Plant seeds singly in 2-inch cells or soil blocks.

When seedlings have one or two true leaves, transplant to the field or high tunnel. Take care not to disturb the roots when taking plugs out of cells or handling soil blocks. Set plants one to two feet apart in the row, covering stems up to just below the seed leaves, and water to settle field soil around the plug.

Dealing with Weeds, Pests, and Diseases

Weed management: crop competition, crop rotation, and cultivation

Summer squash is not especially susceptible to weed pressure, because the plants rapidly grow to a large size, and harvest begins as soon as 45 to 50 days after planting. However, good weed management, beginning with prevention, is important for successful squash production.

Develop a sound crop rotation that includes weed-smothering cover crops, and that varies the timing of field operations from year to year, to "keep the weeds guessing." Fewer summer weeds are likely to emerge in squash planted after a year or two of cool-season vegetables and summer cover crops, than in squash planted in a field that has grown other warm season crops over the past several seasons. In the latter scenario, tillage occurs on a predictable schedule (late spring for the vegetable, late summer or fall for winter cover crop), allowing certain weeds to proliferate over time.

During the seasons prior to squash planting, prevent weeds from propagating, especially tall, aggressive summer annuals like pigweeds and velvetleaf; vining weeds like morningglories; and invasive perennial weeds like nutsedges, Bermuda grass, or Canada thistle. Vegetable fields that have a large "weed seed bank" of summer annuals should be rotated to perennial grass-clover for two or three years to disrupt weed life cycles and rebuild soil organic matter. Fields that are heavily infested with perennial weeds should be planted to a series of competitive cover crops with strategically timed tillage for a year or more before attempting squash production.

One other weed to watch out for is horsenettle. Although this low-growing rhizomatous perennial competes little against squash, its fine, sharp, brittle spines can make harvest a most uncomfortable chore.

Utilize crop competition to deal with weeds. Select locally adapted, vigorous squash varieties, and be sure that soil temperature, moisture, and fertility are optimal for rapid crop emergence and growth. Summer squash planted in cool, wet soil, or in soils low in organic matter and biological activity will grow slowly and may become overwhelmed by weeds.

Keep the crop weed-free during the first four to six weeks after sowing or transplanting (the "minimum weed-free period"). Later-emerging weeds (Figure 3) will have little *direct* impact on yield. However, letting these later weeds grow large can interfere with harvest, promote diseases by restricting air circulation, and set seed, leading to heavier weed pressure the next season.

Control weeds during the minimum weed-free period through timely, shallow cultivation or hoeing, mulching, and/or manual pulling if necessary. The upright growth habit of most summer squash can facilitate cultivation later into the crop's growth cycle than is feasible for vining cucurbits such as cucumber and winter squash. However, *be especially careful to minimize damage to crop roots.* Summer squash forms a widespread network of shallow feeder roots, which can extend several feet beyond the canopy spread of a mature crop. If the hoe or cultivator unearths more than a few white, hairy, succulent roots, you are going too deep or too close to the plants, and are compromising the crops' capacity to take up moisture and nutrients.

Weed management: mulching options

Three alternatives to cultivation or manual weeding around large plants are: straw or other organic mulch spread immediately after the first or second cultivation when the crop is about a foot tall; no-till or strip-till seeding or transplanting into residues of a winter cover crop; and plastic film mulch or landscape fabric laid just prior to planting.

An organic mulch, such as straw or hay (3 to 4 inches, loosely packed) conserves moisture, protects the crop's feeder roots, provides some nutrients (especially K), and feeds the soil life. Be sure that mulch hay is *clean* – free of weed seeds and persistent herbicide residues. Organic mulch keeps the soil cooler, which is beneficial in the heat of summer, but can slow crop growth if applied too early in spring.

A winter cover crop (cereal grain + winter annual legume) that is roll-crimped or flail-mowed shortly before planting can suppress most weeds for 4 to 6 weeks. This "organic no-till" technique can be very successful with squash and other cucurbit crops (Figure 4). However, the *in-situ* mulch present at planting can result in cool, wet soil conditions, or harbor slugs and other pests – so try

this out on a small scale first to see if it works on your farm.

Note: any organic mulch can provide habitat for squash bug, and may not be a good option in locations with moderate to high populations of this pest.

Opaque plastic film mulches and landscape fabric will block most weeds. However, emerging nutsedges can penetrate the plastic, and morning glories will grow toward planting holes, emerge, and climb plants. Black plastic accelerates soil warming, which speeds establishment and harvest maturity in early plantings. During the heat of summer, use a white-on-black opaque mulch, or spread a layer of straw on black plastic to prevent overheating of the soil. After preparing and amending beds, lay the plastic, and make holes about 3 to 4 inches in diameter, spaced 12 to 24 inches apart (for single plants) or 3 to 4 feet apart (for hills) down the center of the row. Be sure to lay drip irrigation under plastic film mulches, which exclude rainfall and overhead irrigation.

Many growers find the plasticulture system highly economical because of higher or earlier yields and less weeding. Disadvantages include the labor and costs of end-of-year removal and disposal, and the fact that the plastic does not feed the soil and complicates organic amendment application while it is in place.

Insect pests and organic pest management

The three major insect pests of summer squash are the squash bug (Figure 5), cucumber beetles, and squash vine borer. Additional pests include aphids, squash beetle, and stink bugs.

Squash bug (*Anasa tristis*) is a large (5/8 inch long), dark brown, hard-shelled bug, closely related to stinkbugs. Nymphs (immature stage) are lighter gray in color. Squash bug nymphs and adults damage young and mature squash plants by piercing and sucking foliage and fruit. Heavy feeding by this pest often causes foliage to wither and dry up, and often makes fruit unmarketable

Squash bug adults overwinter in plant debris and emerge in late spring to feed on early cucurbit plantings, and begin to mate. Females lay yellow-orange eggs in clusters of a dozen or more, firmly glued to the undersides of young leaves. Eggs darken to bronze, may become separated from one another in an even pattern as the leaf expands, and hatch in 10 to 14 days. The soft-bodied, light-gray nymphs pass through five instars (molts) over four to six weeks, then reach maturity. There are one to two generations per year, but overwintering adults continue to mate and lay eggs well into the summer, so that all stages of the pest occur together on the plant.

Striped cucumber beetle *(Acalymma vittatum)* and spotted cucumber beetle *(Diabrotica undecimpunctata)* are small, fast-moving, yellow-and-black beetles that damage squash and cucumbers by direct feeding (chewing), and by transmitting bacterial wilt (caused by the bacterium *Erwinia tracheiphila)*. Feeding damage can severely injure or kill seedlings or young plants. Mature plants can tolerate moderate numbers of cucumber beetles unless the beetles transmit bacterial wilt.

The adult striped cucumber beetle is about 1/5 inch long, with a black head, yellow thorax, and three longitudinal black stripes on the wing covers. Spotted cucumber beetle is somewhat larger (1/3 inch), yellow or yellow-green with 11 black spots on the wing covers.

Cucumber beetles overwinter as adults in plant debris or perennial vegetation, emerge in spring, and can feed on a variety of plant species. After mating, the female lays hundreds of eggs at the base of plants. Eggs hatch and larvae burrow into the soil, feed on plant roots for several weeks, pupate, and emerge above ground as adults. Two or three generations occur annually in the South. All life stages of the striped cucumber beetle strongly prefer cucumber, squash, and other members of the cucurbit family. Spotted cucumber beetles feed on a wide variety of plants, and their larvae (often called corn rootworm) typically feed on the roots of corn, peanut, or cereal grains.

Squash vine borer *(Melittia satyriniformis)* overwinters in the soil as a larva or pupa, and emerges in late spring as a clear-wing moth, with striking orange and metallic black or green-black body, and translucent wings. It is a fast and strong flyer, often mistaken for a wasp. The female lays reddish-brown eggs singly on stems near the base of squash plants, and one female can lay 150 to 250 eggs. Larvae hatch out and burrow into the stem, where they feed for four to six weeks, eventually causing the entire plant or branch to wilt and die. The larva is whitish and wrinkled with a light brown head, and reaches about 1 inch in length before pupating in the soil. The appearance of frass (insect poop) that looks like wet sawdust coming out of the original bore-hole in the stem is a sure sign of borers inside. Two generations per year of squash vine borer may occur in the South.

Preventive measures for these and other pests of squash include sanitation and crop rotation. Remove and destroy (burn or hot-compost) badly infested plants if practical. As soon as harvest is finished, destroy pests and overwintering habitat by disking or tilling crop residues and organic mulch into the top few inches of soil. Follow promptly with a vigorous cover crop or another production crop to minimize the adverse effects of tillage and soil exposure. On a small scale, it may be practical to gather up and compost the organic materials. Make sure all parts of the compost pile heat to 130°F or more for several days to kill pests and pathogens

Although crop rotation cannot eliminate pests with highly mobile adult phases such as cucumber beetles and squash vine borer, it is still valuable in delaying the buildup of pest and pathogen populations. For multiple plantings within a single season, sow later plantings at a distance from earlier plantings, or use row covers to delay pest migration onto the new planting. If practical, destroy

badly infested squash before removing row cover from younger plantings.

Additional cultural controls include beneficial habitat plantings (also known as farmscaping) in proximity to summer squash plantings, and trap crops. Plant strips of flowering plants known to provide accessible nectar and pollen for natural enemies of squash pests (Figure 4). These include buckwheat; dill, cilantro, and other members of the umbel (carrot) plant family; and sunflower, yarrow, and other members of the composite (aster) family. Aim to provide flowering plants throughout the summer squash cropping cycle, from emergence of the first planting until harvest is over for the year. Consider establishing a diverse perennial field border, hedgerow, and/or mid-field buffer strip with early, midseason, and late flowering species. If you rely on annuals, include some that quickly reach the bloom stage so that beneficial habitat is available early in the season. Examples include buckwheat, cilantro, dill, and mustards. Succession plantings of buckwheat will provide a longer period of availability of this excellent habitat plant.

One predator to note is Pennsylvania leatherwing (*Chauliognathus pensylvanicus*) (Figure 6), whose larvae consume a number of insect pests and pest eggs, including cucumber beetle. This beetle is commonly found on flowers of buckwheat, dill and other umbels, and yarrow. In Floyd and Montgomery Counties (Appalachian region of Virginia), abundance of Pennsylvania leatherwing seemed to increase from about 1995 through 2005, with a corresponding decrease in cucumber beetle pest problems (personal observation). In addition, several tachinid flies and other parasitoids are known to attack squash bug, stink bug, and cucumber beetle.

A trap crop is a crop variety or other plant that is highly attractive to the target pest, so much so that it can be used to divert pests away from the cash crop to be protected. 'Cocozelle,' 'Seneca,' and 'Dark Green' zucchini may act as trap crops for cucumber beetle (Dawling, 2013), and Blue Hubbard has been suggested as a trap crop for all three major squash pests. Plant the trap crop before the cash crop to provide protection when the latter emerges, and position crops strategically to maximize pest concentration on the trap. Monitor regularly; when the trap crop becomes infested, destroy pests by spraying with pyrethrin or other natural pesticide allowed for organic production, or by flaming the trap crop (will kill pests and damage the crop, but it may grow back). If you want to avoid the use of pesticides altogether, you can till-in a heavily infested trap crop – but you will need a succession planting of trap crop or other means to maintain continued protection.

One effective way to protect young squash plants from pests is row cover, which consists of a fine, lightweight, woven or spun-bonded fabric that excludes pests while allowing air circulation, rainfall penetration, and about 90% light transmission. Place row cover over crop rows immediately after sowing or transplanting. Although lightweight "floating" row covers can be laid directly on plants, the use of hoops (9-or 10-gauge metal) to create a "low tunnel" of row cover is recommended to avoid abrasion or overheating of foliage. Anchor the edges of the row cover so that they fit tightly to the soil surface, thereby excluding crawling pests

Row cover must be used in conjunction with a sound crop rotation. If a cucurbit crop was grown in the same bed or an adjacent bed in the past two or three years, pests may emerge inside the row cover and wreak havoc on your squash. Locate row-covered squash at least 50 feet away from last year's cucurbit crops, if practical. Remove row covers at flowering to allow pollination.

Excluding cucumber beetles, flea beetles, squash and stink bugs, and squash vine borers until first flower can give your crop a huge head start on these pests. Even if pest pressure in your area is relatively high, you should be able to get a few weeks' production before pests seriously damage the large plants. On the other hand, the cost of materials for installing row covers is about $1200 per acre; and the practice may be too labor intensive for larger scale plantings. Row covers can be awkward if weed pressure necessitates cultivation during crop establishment.

Whatever preventive practices you implement, be sure to scout your squash weekly (or more often) for pests, and be prepared to use pyrethrin, pyrethrin-soap formulations, spinosad, or other natural pest controls if needed. During emergence and establishment, even a few squash bugs or cucumber beetles can do serious damage, and prompt treatment may be warranted. Hand picking may be feasible for squash bug on small plantings. Drop bugs in a bucket of soapy water – don't crush them, as the odor can attract more squash bugs (Dawling, 2013). On larger plants, action thresholds are one or more squash bug egg masses per plant, or more than five cucumber beetles per plant. For squash bug, wait until eggs are *just* hatching, as the young nymphs are the most susceptible to insecticidal soap or botanicals.

The most effective treatment for squash vine borer is to spray Bt on the basal 1-2 feet of stem of each plant at weekly intervals, beginning just *before* the first larvae have burrowed into the stems, so that hatchlings are exposed and soon die. The trick is knowing when the vine borer is present – you may or may not be fortunate enough to spot the fast-moving female moth when she first arrives in your field. Use a pheromone trap for squash vine borer, or obtain information from your local Extension office about the first arrival of this pest in your county. Normally, vine borer adults begin flying in our region in late June or early July.

Efficacy of Organic Pest Management Practices in the VABF Summer Squash Trials

Beneficial habitat plantings, trap crops, weekly scouting, and pyrethrin sprays on an as-needed basis all helped with pest management. None of these *alone* provided sufficient control, but together they allowed satisfactory marketable summer squash yields in 11 trials (the 12th crop was lost to extreme rainfall, not insect pests). Trial participants applied pyrethrin only when pests reached action thresholds suggested in National Sustainable Agriculture Information Service (ATTRA) bulletins and other sources. During the first 30 days after planting (DAP), action thresholds were 5 cucumber beetles per 10 ft. row, or one or more squash bugs present and causing damage. After 30 DAP, action thresholds were 5 cucumber beetles or one squash bug egg mass per plant. Because squash vine borer spends its damaging larval stage inside crop stems, it is not susceptible to pyrethrin sprays; their presence/absence was noted but no action thresholds or treatments were implemented.

Pest pressures varied widely among trial sites. Two participants did not need any pyrethrin sprays in either year, while others made three or more applications. Squash bugs were most ubiquitous (seen in all trials), followed by cucumber beetle (7 out of 10 trials), and squash vine borer (4 out of 10). Brown marmorated stink bug occurred at one site in 2012. Pyrethrin sprays appeared effective against squash bugs, especially the nymph stage; and somewhat less effective on cucumber beetle.

In trials that included a perimeter trap crop of Blue Hubbard winter squash, both cucumber beetle and squash bug went preferentially to the trap crop early in the season. Later on, squash bug and (in one trial) brown marmorated stink bug migrated into the cash crop. Overall, however, marketable yields and pest damage levels were similar for the trap crop trials (in which only the trap crop received pyrethrin sprays) and for the control trials (in which the cash crop was sprayed). Thus, trap cropping reduced the amount of pesticide needed and afforded a larger pesticide-free refuge for pest predators and parasitoids, pollinators, and other desirable organisms.

The beneficial habitat plantings ("farmscape") of buckwheat and sunflower attracted an abundance of predatory and parasitic insects including lady beetles, syrphid flies, predatory wasps, lacewings, and assassin bugs. Some of these insects migrated into the summer squash or the trap crop. One farmer observed "lethargic" or "immobilized" squash bugs both years, and found a parasitic larva inside one squash bug. Most participants felt that farmscaping helped keep pest levels down, though the benefits were hard to discern when pest pressure was high.

In 2011, one participant lost two summer squash plantings to heavy populations of squash bugs, cucumber beetles (which transmitted bacterial wilt), and flea beetles. The squash had been planted into black plastic mulch laid for another crop in 2010 and left in place over winter. When the farmer observed numerous squash bugs sheltering under the plastic, he removed it from the field before the third planting, which yielded well, though the high pest pressure necessitated pyrethrin applications every 2 to 5 days (total 17 sprays). In 2012, pest pressure remained fairly high, but 13 spray applications applied only to the trap crop adequately protected the cash crop. In addition, this farmer noted that his high tunnel provided an excellent early season trap crop for cucumber beetle; spraying the high tunnel just prior to planting the field trial took out "hundreds" of cucumber beetles, and likely reduced field populations.

Discussions after the 2011 season revealed some challenges related to timing. In addition to the problem of marketing harvests from a quarter acre of summer squash all at once, participants noted difficulties in coordinating the most pest-attractive stages of the trap crop (from the first through the sixth true leaf), and the most beneficial-attractive stages of the habitat plantings (flowering) with pest control needs for summer squash production, which extend from seedling emergence through harvest. Participants preferred the buckwheat over the sunflower because the former flowered much sooner after planting, and more consistently attracted diverse natural enemies of pests. Several suggested succession plantings of buckwheat to extend the flowering period. One farmer expressed concern about exposure of beneficial insects to the pesticide, and suggested separating the trap crop from the habitat plantings.

Protocols for 2012 were modified in several ways to address these challenges. The ¼ acre of summer squash was divided into three succession plantings at two week intervals. Half of the trap crop was started in the greenhouse and transplanted to the field at the time of the first cash crop planting, so that young Blue Hubbard plants in their most pest-attractive stage were present when summer squash emerged. The rest of the trap crop was planted at the same time as the second summer squash succession. Sunflower and *half* of the buckwheat were planted a week before the first summer squash to provide early season food (nectar) for beneficials, and the rest of the buckwheat was planted with the third cash crop planting to provide late season nectar.

All participants considered the buckwheat plantings an effective pest management practice in 2012, but sunflower again flowered too late to provide pest control benefits to the fast-maturing summer squash. At all three farms that used the trap crop, staggered plantings of Blue Hubbard squash clearly attracted cucumber beetle and squash bug and likely slowed their invasion of the cash crop. Efficacy of trap cropping on squash vine borer was not clearly demonstrated.

Differences in pest pressure on the four summer squash varieties were not dramatic. Zephyr tended to sustain the least damage and Raven zucchini the most. In a few trials, Zephyr seemed less attractive to pests, and in one instance it hosted high pest populations yet survived longer than Raven or Magda.

Several farms experienced damage from powdery mildew or downy mildew, and bacterial wilt was a contributing factor in the loss of one planting as noted above. Two participants had some success controlling the mildews with copper applications (tank-mixed with pyrethrin), when sprays were initiated early enough, before the disease became entrenched.

Disease management

Summer squash can suffer from any of several plant diseases. One of the most common fungal diseases in our region is powdery mildew, caused by the fungi *Erysiphe cichoracearum* or *Sphaerotheca fuliginea*, which have multiple plant hosts and whose spores spread by wind. Powdery mildew begins as small, white spots on older leaves. These expand to form a fine, powdery growth (looks like frost) over the leaf surface, and the leaf may wither and drop off. The disease spreads up the plant, and reduces fruit yield and quality by limiting the plant's photosynthetic capacity. Unlike most fungal diseases, powdery mildew is favored by hot, dry weather. It can be prevented or minimized with sprays of baking soda, copper, sulfur, or the biofungicides Sonata™ (*Bacillus pumilis*) and Serenade™ (*B. subtilis*). Apply these materials when conditions favor powdery mildew, or at the *first* sign of the disease. If the disease becomes established, use neem oil, jojoba oil, or horticultural oils (some of which are permitted by USDA Certified Organic). Never spray oil within two weeks of a sulfur application or in very hot weather, as this can damage plant tissue.

Several powdery mildew-tolerant varieties of summer squash are available, including 'Partenon' F1, 'Success PM Straightneck,' and 'Yellow Scallopini' F1.

Downy mildew, caused by the water-mold *Pseudoperonospora cubensis,* is promoted by warm, moist weather, and can be checked by a hot, dry spell. This pathogen is an obligate parasite of the cucurbit plant family. It overwinters in greenhouse crops or winter cucurbit plantings in low latitudes, and spreads northward each season by wind. The disease begins on older leaves with small, yellow, angular spots, which quickly enlarge, spread, and turn brown. When viewed from the leaf underside on a dewy morning, early spots appear water-soaked, and older lesions may show black or purple spore masses. If favorable conditions continue, the disease spreads rapidly toward the growing point, and can cause severe losses. Preventive sprays labeled for this disease include Sonata, Serenade, and copper.

Bacterial wilt (*Erwinia tracheiphila)* is transmitted by cucumber beetle, and its progress is little affected by weather. Symptoms include wilting of individual leaves, whole branches, and ultimately the entire plant. The disease is most virulent in cucumber and cantaloupe, but can occur in summer squash as well. Cut an affected leaf stalk or stem, lightly press the cut ends together for a few seconds, then pull slowly apart. If a whitish, sticky string of mucus appears, bacterial wilt is likely present. If not, the plants may be wilting from vine borer, drought, or other causes. Bacterial wilt is managed by controlling cucumber beetle, for which action thresholds are much lower (one beetle per plant) when this disease is present.

Angular leaf spot, caused by the bacterium *Pseudomonas lachrymans,* appears as small, angular, water soaked spots on foliage and sometimes fruit. Leaf spots later dry out to tan or gray, and may drop out, leaving ragged holes. The pathogen overwinters on crop residue, may also be seedborne, and can be spread from plant to plant by workers or equipment, especially when foliage is wet and temperatures are 70 to 80°F. Copper sprays can help control angular leaf spot.

Mosaic viruses, including cucumber mosaic virus (CMV) and squash mosaic virus (SqMV), cause stunted growth and mottled yellow/green leaves. Mosaic viruses are spread primarily by aphids, and sometimes by cucumber beetles, by workers in the field, or by infected seed.

When young squash fruits shrivel up and fall off, the most common cause is lack of pollination. Rarely, there is a temporary lack of male flowers at the beginning of the crop's flowering season; more often the problem is lack of pollinators, an increasing problem in recent years. Remedies include: place one strong hive of honey bees per acre of squash; create, protect, and enhance native pollinator habitat (a long term solution, with which USDA Natural Resources Conservation Service can provide assistance); or plant parthenocarpic varieties of squash.

If fruit shrivel and are also covered at the blossom end with a mold growth that looks like a mass of tiny black pins or hairs, the fungus *Choanephora cucurbitarum* has infected the female flower, leading to the fruit decay. High moisture conditions promote this disease.

Because most of the pathogens discussed above are wind- or insect-borne, crop rotation will not completely prevent squash diseases. However, a sound rotation can delay onset and reduce severity. Conversely, growing cucurbit crops in the same or adjacent fields year after year can allow pathogens to carry over on crop residues and build up to overwhelming levels. Allow at least three and preferably four to six years between successive cucurbit crops in a given field, and plant this year's squash and other cucurbits as far as practical from last year's plantings. If you are part of a multi-farm CSA, food hub, or marketing cooperative, consider rotating summer squash and other cucurbit production among growers so that individual farms grow this plant family every other year.

Practices that minimize wetness of crop foliage, fruit, and stems; and keep fruit from contacting the soil can reduce fungal diseases. Use drip irrigation rather than overhead; plant in raised beds to promote drainage away from plant crowns; use a clean, fast-draining organic mulch (e.g., grain straw) or plastic mulch to keep fruit clean; and remove weeds to enhance air circulation through the crop. If disease pressure is heavy, use wider row and within-row plant spacings.

In addition to the specific anti-fungal sprays noted above, a plant-based extract that stimulates plants' natural defenses against fungal and bacterial diseases is now available under the trade name Regalia™ (see Seven Springs Farm). Use this material before disease symptoms appear, so that plants' defenses are "up" when pathogens arrive.

Harvest and Post-harvest Handling

Summer squash fruit grow and develop quickly, so the crop should be harvested at least every two days. Many farmers harvest daily in order to gather squash at the size desired by customers or buyers. If you are harvesting squash flowers or very young squash with the flower still attached, daily harvest is a must.

Avoid scratching the soft, tender skin of summer squash during harvest. Scratches reduce market appeal and can shorten shelf life. Wear light gloves to prevent fingernail gouges, and be aware that the small spines on squash leaves and stems (or on weeds like horsenettle or spiny amaranth) can also mar squash skin.

Summer squash is moderately perishable, and will keep 2 to 3 weeks at 45°F and 80% humidity. Avoid storage temperatures below 45°F, which can cause chilling injury and shorten shelf life.

Flowers and young squash with flowers attached are much more perishable (shelf life two days), and should be picked and cooled as close to the time of delivery as practical. Flowers can be held with the stems in water.

Resources

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