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Bee Pollination of Georgia Crop Plants

Keith S. Delaplane, Extension Entomologist
Paul A. Thomas, Extension Horticulturist
Wayne J. McLaurin, Retired Extension Horticulturists

Background

Pollination is the transfer of pollen from the male part of a flower to the female part of a flower. *Cross-pollination* is the transfer of pollen among different plants or varieties of the same species. If the pollen is compatible, fertilization of the ovule and seed formation occur. Generally, more seeds develop when large numbers of pollen grains are transferred. Seeds, in turn, stimulate surrounding ovary tissue to develop so that, for example, an apple with many seeds will be larger than one with fewer seeds. In this way, good pollination improves both fruit yield and size.

The Flower and the Fruit: Male parts of a flower are called the *stamens*, each made up of a slender *filament* holding an *anther* at the tip. At the right time, the anther releases *pollen grains,* which are equivalent to animal male sperm.

Female parts of a flower are called the *pistil*, each made up of an *ovary* with *ovules* and a stalk-like *style* with a sticky *stigma* on top.

A flower with both stamens and a pistil is called a *perfect* flower. However, many plants have flowers that are *imperfec;* that is, only male or only female. Sometimes both types of imperfect flowers occur on the same plant. It is easy to identify imperfect female flowers in cucurbit crops (cantaloupe, cucumber, squash, watermelon) because of the large ovary at the flower's base that later develops into a mature fruit.

Monoecious plants have both male and female flowers on the same plant. *Dioecious* plants have only one sex of flower per plant. Both monoecious and dioecious plants generally require cross-pollination.

When a pollen grain lands on a receptive stigma, it forms a *pollen tube* down the style to the ovary. Male genetic material passes down the pollen tube and fertilizes an ovule. Ovules become seeds and the surrounding ovary develops into the fruit.

Bees and Pollination: Many insects visit flowers to collect pollen and nectar as food. As they forage, these insects spread pollen grains among flowers, accomplishing pollination. Many flowers offer sugary liquid nectar as an added enticement for these pollinating insects. Among insect pollinators, bees are especially efficient because they eat pollen and nectar exclusively, visit many flowers of the same species during a single trip, and have hairy bodies that easily pick up pollen grains.

There are more than 3,000 species of bees in North America. Most of these are *solitary* bees, but a well-known minority are *social*; that is, they live together in colonies and cooperate in colony tasks. Both solitary and social species are important in crop pollination, but the social species - namely honey bees and bumble bees - are more easily managed.

Compared to honey bees, some wild bees pollinate certain crops more efficiently because of unique and desirable behaviors. For example, Southeastern blueberry bees *buzz-pollinate* blossoms by shaking pollen from the flower with high frequency muscle vibrations; for blueberry, this greatly improves pollination efficiency.

In many parts of the country, fruit and vegetable growers are concerned about declining numbers of wild bees. Human activities destroy bee habitat and forage. In short, growers are receiving less "free" pollination from wild bees and increasingly they must make up for this by renting managed honey bee hives during bloom periods.

Managing Honey Bees for Pollination

If you need honey bees for pollination, you may want to keep your own bees. However, maintaining large numbers of robust hives year-round is hard work and most growers prefer to rent hives. For detailed information on managing bee hives, ask your Georgia county Extension agent for Bulletin 1045, *Honey Bees and Beekeeping*. The section on **"Bees and Beekeeping Reference Books"** in this publication lists important beekeeping reference books.

Never expect a beekeeper to loan you colonies "in return for the honey they'll make." Moving bees is hard work, and almost no crop plants in Georgia yield surplus honey. Pollination is a valuable service that warrants fair compensation. See your county Extension agent for help in locating pollination services.

A Good Pollinating Hive: A bee hive is made up of stacked boxes called *supers*. As colonies grow during a season, beekeepers add supers to accommodate the growing bee populations and honey stores. A very tall hive is probably strong, but unscrupulous beekeepers may stack empty supers on weak hives to make them look strong. Don't rely on external appearances.

When the lid is removed, bees should immediately "boil over" and blanket the tops of six to eight combs. In colonies with small populations, bees do not well up so dramatically. There should be at least five combs with brood. When brood is young, you can see glistening white larvae in their cells, but older brood are covered with cardboard-looking wax cappings. Bees are best motivated to collect pollen when they have young, uncapped brood. Strong colonies with large populations and plenty of brood are superior pollinators, and the beekeeper should get a higher rental fee.

Moving Hives: Bee hives are almost always moved at night when bees are not flying and temperatures are cooler. Smaller beekeepers may screen hive entrances individually and manually load hives on and off a pickup truck. Larger beekeepers group hives, usually four to a pallet, and load them with a forklift onto a trailer or flatbed truck; in these cases, the beekeeper may net the entire truckload to contain flying bees. In either case, be prepared for nighttime arrival and arrange details in advance with the beekeeper about field access and hive placement.

Timing: Move hives into the crop after some flowering has already begun. If you move them in before the crop blooms, you give bees a chance to forage on another non-target plant such as Dutch clover. Once bees are trained to such competing flowers, they often ignore the crop when it blooms. Eliminate competing weeds with herbicides or mowing.

Number of Hives: The number of recommended hives per acre depends on the attractiveness of the crop to bees, number of wild bees, number of competing weeds, strength and location of bee hives, weather and the grower's experience. Generally, anything that reduces pollination efficiency (unattractive crop, few wild bees, many competing weeds, poor weather, etc.) calls for more bee hives per acre to compensate. As a starting point, consider one hive per acre, and move up or down according to the advice of experienced growers, beekeepers or your county Extension agent. The section on **"Crop Pollination Requirements"** gives more specific recommendations.

Hive Placement: Although honey bees can fly several miles, they prefer to work within 300 feet of their hive. For this reason, by putting groups of hives at 500-foot intervals (about 0.1 mile) within a field, you can place the whole field within ordinary bee foraging range. If the interior of a field is inaccessible, you can group hives around the edges. In these cases, the center of the field is less likely to be visited by bees, but you can remedy this by putting more colonies in the center-most groups along the field edge; this increases competition and forces bees to forage deeper into the field.

Place hives in ample sunlight and do not place them in low areas that accumulate cool, damp air. Chilly, shaded bees are poor pollinators. As much as possible, keep hives away from farm workers, pedestrians and livestock.

Chemical Attractants: Growers are sometimes interested in chemical attractants to increase the number of bees visiting their crops. The best of these products contain synthetic queen pheromone or components of *Nasanov* pheronome - a chemical bees use to orient to nest sites.

In general, attractants are helpful only under marginal pollination conditions. For example, it may be impossible for a beekeeper to unload hives in the center of a very large and muddy field. In this case, the grower may apply attractant to the center of the field to increase bee visitation. Remember, bee attractants encourage bee *visitation*, not necessarily bee pollination. If the flowers are not appealing to bees, no chemical attractant will make them work the blossoms. Likewise, if there are no bees in the area, an attractant will not draw them in from great distances. A grower's first priority must be the bees themselves.

Bees and Pesticides: Most bee poisonings occur when bees visit flowers that were treated with insecticide. This kind of exposure is more hazardous than a direct spray on a hive. With fast-acting toxins, foraging bees are killed in the field. However, slower-acting toxins are even more hazardous to a colony because foraging bees survive long enough to return to the hive with contaminated pollen, which enters the food supply and kills young bees for weeks. Such hives either die outright or become worthlessly weakened for the rest of the season.

As a rule, never spray a plant that is flowering. However, many crop plants bloom in cycles, which makes it difficult to use insecticides without risk to bees. Fortunately, there are still ways to reduce bee kill. First, not all insecticides are equally hazardous to bees. Some pesticides are listed according to their relative bee hazard. Look for a product labeled for the target pest, with low bee toxicity (that is, a high LD_{50}), and with a short residual time. Secondly, granules and solutions are safer than wettable powders and dusts. Finally, many insecticides are deadly to bees when they are first applied but degrade within hours to a safer level.

Since bees only forage in daylight, apply bee-hazardous pesticides in early evening. By morning, the insecticide has controlled the target pests, but the residues are reduced and risk to bees is minimized.

Obviously, pesticide applications must be clearly worked out between the grower and the beekeeper. Most contracts require the grower to give the beekeeper a 24- to 48-hour notice of a pesticide application (see **Sample beekeeper/grower contract**).

Other Pollinating Bees and Ways to Increase Their Numbers

In general, bees need nest sites and enough food (from blooming plants) to produce offspring. These facts are the foundation of any bee conservation program.

Bumble Bees: These large, hairy bees are common in the southern United States. These social bees are especially good pollinators of blueberry, tomato, eggplant, and pepper. Bumble bees visit flowers during rainy, cool or windy weather when other bees stay in the nest, and they are especially good in greenhouse pollination because they do not fly against windows like other bees. In some parts of the world, bumble bees are cultured in artificial nests and used for commercial pollination, but the rearing methods are often proprietary and unpublished.

Rather than culturing bumble bees, Plowright and Laverty (1987) advocate enhancing their natural habitat to support crop pollination. In nature, bumble bee queens start colonies in abandoned rodent nests or similar dry, well-ventilated cavities. In early spring, one can see these bees flying slowly near the ground in search of nest sites. Growers can provide nest sites by leaving undisturbed strips of grass along fence rows, field margins and other dry, unflooded areas.

From a bumble bee's point of view, the entire season's activities - nest founding, worker production and food collection - are all aimed at producing next year's queens in late summer. A colony's success at queen production depends largely on its nutrition; that is, the abundance of flowers in its habitat (Bowers 1986). A prolonged shortage of flowers - common during mid-summer in the South - severely reduces queen production. Farmers can benefit from growing a succession of flowering plants throughout summer. This attention to season-long bumble bee nutrition pays dividends with increased queen production and, ultimately, a large, recurring local population of bumble bees. (See **"Establishing Bee Pasture"**)

Soil-Nesting Bees: Most solitary bees nest in soil, and some of these bees are very good pollinators. In the Southeast, the most important soil-nesting bees are Southeastern blueberry bees and bees in the genus *Peponapis*. These solitary bees dig tunnels in soil in which they provision cells with pollen, nectar and eggs.

Southeastern blueberry bees look like small bumble bee workers, but they occur earlier in the year than worker bumble bees. They are sometimes abundant in blueberry orchards throughout the Southeast (Cane & Payne, 1993). These bees are excellent pollinators of blueberry because they emerge from winter hibernation in time for early blueberry bloom, specialize on blueberry, buzz-pollinate the blossoms and work very fast. On a per-bee basis, they are more efficient than honey bees or bumble bee queens (Cane & Payne, 1990).

Bees in the genus *Peponapis* are about the same size as honey bees, and they are called squash or cucurbit bees because they only visit squash, gourd or pumpkin. As such, they are extremely effective pollinators of these crops. These bees make tunnels in high, well-drained bare soil and often under leaves, rocks or other objects. Their tunnels have small mounds at the entrance. Large nest aggregations can recur in the same patch year after year if it is left undisturbed and surrounding fields are repeatedly planted in cucurbits.

The keys to large numbers of soil-nesting bees are long-term undisturbed nest sites and dependable food sources. In Rhode Island, a large recurring population of *Peponapis* was decimated when its nest site was plowed (Mathewson, 1968). Crop growers should seek out nesting areas of these bees and leave them as undisturbed bee sanctuaries. A dependable diet is also important. This is usually not a problem with more-or-less permanent blueberry orchards and their attendant populations of Southeastern blueberry bees.

However, it can be a problem with *Peponapis*, which depend on annual plantings of cucurbits. Although other agronomic considerations apply, continuous plantings of cucurbits may be advisable to build up large recurring populations of *Peponapis*.

Wood-Nesting Bees: Certain bees in the genus *Osmia* are important pollinators of apples and other orchard fruits. They provision their cells like other solitary bees, but they nest in hollow reeds or holes in wood such as abandoned beetle burrows or nail holes. They use mud to partition individual cells and to seal their tunnels. One important member of this genus, the blue orchard or horn-faced bee, is native to the Southeast. It is blue-green colored and has two small projections on its face.

Blue orchard bees are very good pollinators of apple because they land directly on the anthers and stigma, thus maximizing the chance of successful pollination (Torchio, 1985).

Populations of *Osmia* are limited by the availability of nest sites, flowering plants, mud for nest construction, fungal diseases and fire ant predation. Research in Utah and Idaho showed that these bees readily accept artificial nests made by drilling many holes, each 5/16-inch in diameter, into blocks of wood (Torchio, in preparation). Although the idea is untested in the Southeast, growers may encourage local populations of *Osmia* by placing similar artificial nests near the orchard. Do this in early spring just before crop bloom so that sites are available when the bees emerge from diapause, forage and provision new nests.

The goal is large numbers of female bees nesting in the artificial holes. Don't make holes smaller than 5/16-inch in diameter; smaller holes increase production of male bees which, compared to females, are inferior pollinators.

Carpenter Bees: Carpenter bees are large bees that closely resemble bumble bees. Unlike bumble bees, their abdomens are shiny, not hairy. These solitary bees emerge in early spring, excavate tunnels in solid wood, mate and provision nests.

The value of carpenter bees in crop pollination is doubtful. They are effective pollinators of passionfruit. In Georgia, they visit blackberry, canola, corn, pepper and pole bean, but their value on these crops is uncertain. Carpenter bees are notorious for "robbing" flowers by cutting slits in the side of the flower to reach nectar without even touching the pollinating parts.

With blueberry, robbing by carpenter bees can be a serious problem because the robbery holes attract other bee species that would otherwise legitimately visit the flower. When possible, blueberry growers should control carpenter bee populations. For infested wood in structures, inject an approved insecticide in individual tunnels, plug the holes and paint the wood surface. See your county Extension agent for help in selecting a suitable insecticide.

Establishing Bee Pasture

Types of Bee Pasture: Because wild bees are valuable crop pollinators, growers should always encourage their numbers. One way is to improve bee nutrition (ultimately, increasing their populations) by planting or encouraging more-or-less permanent bee pasture near the crop of interest. Especially for bumble bees, it is best if the planting provides an unbroken succession of bloom.

First, decide your objectives and the length of time you expect to need the pasture. This will help determine the level of inputs (labor, materials, etc.) and the type bee pasture you need.

For our purposes, there are three types of forage areas.

Single-year productive bee pastures are made of annual clovers, wildflowers and ornamentals that collectively bloom for most of one forage season. They require reseeding every year, usually in late November. These forage areas can be set up easily with inexpensive seed, a simple plowing schedule and little extra maintenance. On the negative side, they require considerable acreage to provide full-season bloom coverage, and, in Georgia, they are easily stressed by mid-summer heat that can cause up to 10 weeks of forage dearth.

Multi-year productive bee pastures have perennial blooming flowers and some woody vines and bushes. Some of these plants bloom lightly all season, lightly for a brief time or lavishly for a brief time. These pastures require more work and advance planning, but they give the grower optimum control of successional bloom.

Because perennials have diverse flowering dates and are easily replaced, the multi-year pasture is versatile. You can add or remove plants to fill in bloom gaps on your calendar. Material and installation costs are greater than for single-year pastures, but a planting should be good for at least five years. Its greatest advantage is that the entire bee forage season can be covered with a diverse selection of plants in small, otherwise unproductive areas such as fence rows. On the negative side, most herbaceous perennials are planted as grown seedlings, which cost more and require eventual weeding and dividing.

Permanent productive bee pastures have permanent trees, bushes and a few woody perennials. Plantings can last more than 30 years, making plant selection a critical task. In the long run, these woody plants and trees provide the most dependable source of pollens and nectars, but productivity varies year by year.

Initially, permanent production pastures are expensive to set up, considering the investment in bushes and small trees. But, in the long run, they are economical because they need little or no plowing, weeding or fertilizing. This type of forage area is best for fruit and vegetable growers who want permanent, large, wild bee populations. As with many things, you get what you pay for, and if permanent, large bee populations is an important goal, this pasture is best.

Installing Bee Pasture: See your county Extension agent for detailed information on plant selection and planting. Flowering plants that are good sources of pollen and nectar in the Southeast are listed elsewhere. Reference books and other sources of information about annuals, wildflowers, perennials, bushes, trees and vines are also listed.

Crop Pollination Requirements

Apple: Most apple cultivars are self-sterile and require cross-pollination with another compatible cultivar. For this reason, orchardists must interplant main varieties with compatible pollenizer varieties. Generally, different strains of the same variety do not cross-pollinate each other as well as two different varieties. It is equally important that the bloom periods of the main and pollenizer varieties overlap. To optimize pollination, plant both early- and late-blooming pollenizers so that the main variety blooms in between. That way, ample pollen will be available for the early-blooming king bloom on the main variety - the flower that produces the choicest fruit.

Some apple varieties have sterile pollen. These varieties willingly receive pollen from other varieties and produce fruit, but they cannot be used as pollenizers. The table below lists cultivars, their pollen viability and relative bloom intervals.

Growers can use flowering crab apples as pollenizers instead of another commercial variety. This would be warranted if other candidate pollenizers produce inferior fruit, take up too much orchard space, have conflicting pesticide requirements or produce fruit that pickers cannot distinguish from the main variety.

Crab apples can be planted in existing space between main variety trees or grafted onto them. Cut bouquets of flowering crab apples can be placed in barrels of water between rows during bloom. Make sure that the flower color of your crab varieties matches the color of the main variety since bees do not readily switch to a different colored blossom during a foraging trip. Crab apples are more susceptible to virus diseases, but whole-tree crab apple plantings, rather than grafts, reduce incidence of virus diseases.

Bees prefer to work up and down rows rather than across rows. This is especially so in dense plantings and during even the lightest wind. Growers must consider this as they plan the arrangement of main and pollenizer varieties in their orchards. With plan 1, every other tree is a pollenizer (Figure 1); this maximizes the number of pollenizers, but it is practical only if there is a market for the pollenizer. All other plans compromise some degree of pollination efficiency in favor of convenience at harvest.

With plan 2, every third tree in every third row is a pollenizer (Figure 2). This ensures that every tree of the main variety is next to, diagonal to or across from a pollenizer on one side. Plan 3 calls for a solid planting of the pollenizer every fourth row (Figure 3). This leaves one row of main variety by itself and is only practical if the pollenizer has market value. Plan 4 calls for two pollenizer rows next to four rows of the main variety (Figure 4). This is the least efficient design. If main and pollenizer varieties cannot withstand the same chemical regimen, do not interplant them in the same row as in plans 1 and 2. Instead, plant pollenizers in their own rows so they can be treated separately, as in plans 3 and 4. Crab apple pollenizers can be pruned for tall growth to take up little or no extra space. In this manner, they can be planted as every sixth to ninth tree in every row.

Recommended Bee Populations for Apple	
No. of honey bee hives/acre	**Reference**
1	Ambrose, 1990
1	Crane & Walker, 1984
2	Mayer & others, 1986
0.25, 0.5, 1, 2	McGregor, 1976
1, 2	USDA, 1986
1.2	**Literature average**
No. of *Osmia* bees/acre	
250	Torchio, 1985

Apple Cultivars, Pollen Viability and Bloom Periods (from Horton & others, 1990)											
Cultivar	**Good pollenizer interplants**	**Pollen viability**	**Relative bloom period**								
Winter banana	yes	good	X	X	X	X	X	X	X		
Jersey Mac	yes	good	X	X	X	X	X	X			
Empire		good	X	X	X	X					
Pauland		good		X	X	X	X				
Stayman		not good		X	X	X	X				
Yates	yes	good		X	X	X	X	X			
Jonagold		not good			X	X	X	X			
Delicious		good			X	X	X	X			
Braeburn		good			X	X	X	X			
Mutsu		not good			X	X	X	X			
Jonathan		good				X	X	X	X		
Granny Smith		good				X	X	X	X	X	
Arkansas Black		good				X	X	X	X		
Gala		good				X	X	X	X		
Golden Delicious		good				X	X	X	X		
Fuji		good				X	X	X	X	X	
Rome Beauty		good					X	X	X	X	X

Blueberry: Most blueberries grown in the Southeast are one of three types: rabbiteye, southern highbush and northern highbush. Each type has numerous varieties or cultivars. Rabbiteye varieties are the most popular because they are productive, disease resistant and adaptable throughout the region. Northern highbush ripen earlier than rabbiteye, and they are well-suited to the Piedmont and the Appalachians. Southern highbush varieties also ripen earlier than rabbiteye, but they are best suited to the southern coastal plain where soils are well-drained and hard spring frosts are rare. Cross-pollination requirements vary among the three blueberry types.

Rabbiteye varieties are almost completely self-sterile and require cross-pollination with another rabbiteye variety. One exception is the cultivar 'Centurion', which

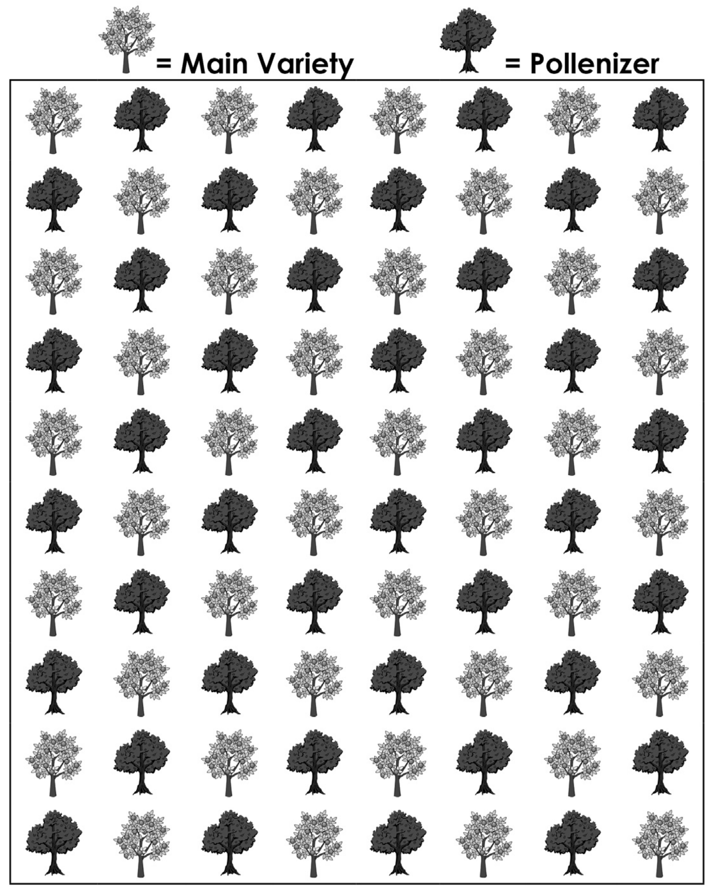

Figure 1. Plan 1 - Every other apple tree is a pollenizer.

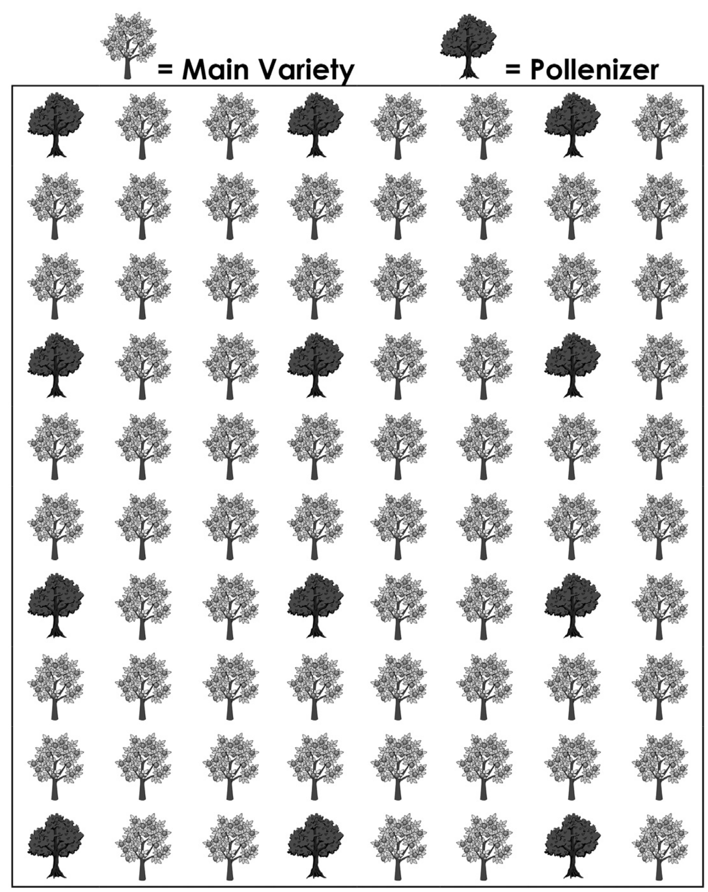

Figure 2. Plan 2 - Every third tree in every third row is a pollenizer.

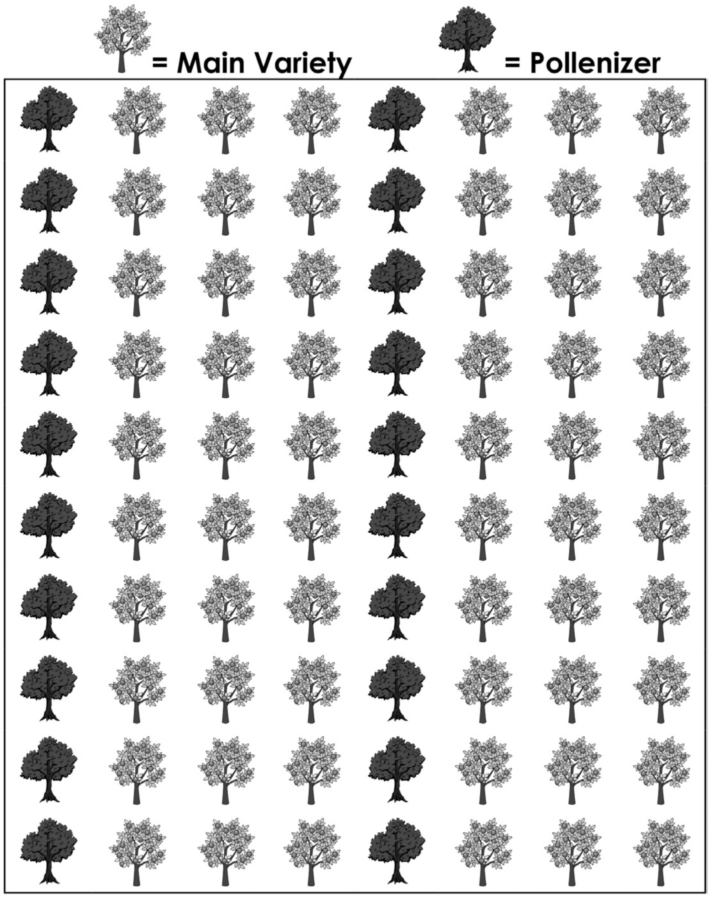

Figure 3. Plan 3 - Every fourth row is a pollenizer.

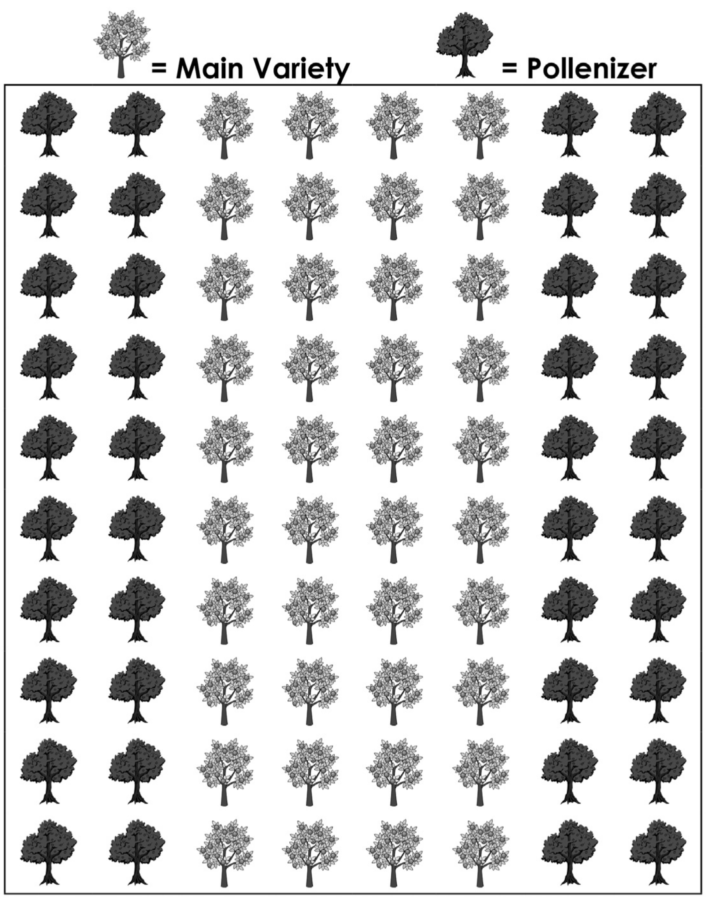

Figure 4. Plan 4 - Two pollenizer rows are next to four rows of the main variety.

is self-fertile, at least when grown in North Carolina (P. Lyrene, Univ. Florida, pers. comm.). Cross-pollination with other rabbiteye varieties improves fruit-set, size and earliness of ripening. On a per-bee basis, Southeastern blueberry bees are the best pollinators of rabbiteye, followed by bumble bees and honey bees (Cane & Payne, 1990). Carpenter bees do not pollinate rabbiteye blueberry and, in fact, reduce the effectiveness of bees that do (see the section on **Carpenter Bees**). By carefully selecting rabbiteye varieties for interplanting, you can prolong your harvest season and provide bloom overlap of compatible varieties for good cross-pollination. Choose varieties for interplanting with similar chill hour requirements (hours below 45 degrees F during winter) because these have the most bloom overlap. The table describes some rabbiteye varieties.

The table can help you choose rabbiteye varieties for interplanting. For example, an interplanting of 'Beckyblue,' 'Bonita' and 'Woodard,' having similar chill hours, promotes good bloom overlap and cross-pollination. By interplanting 'Climax,' 'Bluebelle' and 'Baldwin,' one can maximize both cross-pollination and length of harvest interval. Along with pollination, you must also consider fruit characteristics, flavor and harvesting characteristics of the different varieties, so consult your county Extension agent for help in determining the best varietal blend for you.

The planting arrangement of rabbiteye blueberries is important to good cross-pollination. You want to increase the chances of a bee visiting two or more varieties during the same foraging trip. If you want equal numbers of two varieties, plant them according to Figure 5. If you want two-thirds of variety A and one-third of variety B, plant them according to Figure 6. If you want three varieties, a pattern like Figure 7 encourages good bloom overlap.

Rabbiteye Blueberry Varieties (from Krewer & others 1986, 1993).

Variety	Chill-hour Requirement	Spring Freeze Resistant?
Early-Season Harvest		
Beckyblue	300	
Bonita	300	
Brightwell	350-400	yes
Climax	450-550	
Premier	550	
Woodard	350-400	
Mid-Season Harvest		
Bluebelle	450-500	
Briteblue	400-650	
Powderblue	550-650	yes
Tifblue	550-750	yes
Late-Season Harvest		
Baldwin	450-500	
Centurion	550-650	yes
Delite	500	

Northern and southern highbush varieties range from somewhat self-fertile to highly self-fertile, which means they can produce fruit with their own pollen. Most varieties do not need to be interplanted with different varieties to promote cross-pollination, and these solid block plantings are convenient for managing and harvesting. However, even with highbush varieties, cross-pollination between varieties improves fruit size, seed count and earliness of ripening, all of which are important economic considerations (Lang & Danka, 1991). In Florida, the southern highbush variety 'Sharpblue' has reduced fruit set and size if it is not cross-pollinated (P. Lyrene, pers. comm.). In one study, honey bee visitation to the 'Gulfcoast' variety shortened the time between pollination and harvest by five days and increased berry weight by 28 percent. These effects did not depend on the type of pollen the bees were carrying (selfing with same variety, crossing with different variety or crossing with rabbiteye variety), so this study confirms the value of honey bees as pollinators to southern highbush blueberries (Danka & others, 1993).

Gibberellic acid can artificially induce fruit-set and increase yield. However, it is expensive and may reduce fruit size and delay ripening (Krewer & others, 1991).

Two Varieties	A	A	B	B	A	A	B	B
	A	A	B	B	A	A	B	B
1/2 Variety - A **1/2 Variety - B**	A	A	B	B	A	A	B	B
	A	A	B	B	A	A	B	B
	A	A	B	B	A	A	B	B

Figure 5. Equal numbers of two rabbiteye blueberry varieties.

Two Varieties	A	B	A	A	B	A	A	B	A
	A	B	A	A	B	A	A	B	A
2/3 Variety - A **1/3 Variety - B**	A	B	A	A	B	A	A	B	A
	A	B	A	A	B	A	A	B	A
	A	B	A	A	B	A	A	B	A

Figure 6. Two-thirds of one rabbiteye blueberry variety and one-third of another.

Three Varieties	A	B	C	A	B	C	A	B	C
	A	B	C	A	B	C	A	B	C
1/3 Variety - A **1/3 Variety - B** **1/3 Variety - C**	A	B	C	A	B	C	A	B	C
	A	B	C	A	B	C	A	B	C
	A	B	C	A	B	C	A	B	C

Figure 7. Equal numbers of three rabbiteye blueberry varieties.

Recommended Bee Populations for Blueberry	
No. of honey bee hives/acre	**Reference**
1	Krewer & others, 1986
1, 5, 10	McGregor, 1976
3, 4	USDA, 1986
4	**Literature average**
Bumble bees and Southeastern blueberry bees	
1 to 4 bees per bush	Cane, 1993

Cantaloupe: Cantaloupe plants have perfect flowers and imperfect, male flowers. The perfect flowers cannot self-pollinate, and the pollen is too heavy to blow in the wind, so insect pollination is necessary. Bees visit cantaloupe blossoms for both pollen and nectar, but nectar yield is low. The flowers open shortly after sunrise and close in the afternoon of the same day. The stigma is receptive to pollen for only a few hours in the morning, but in hot weather the stigma may be receptive for only a few minutes. Good bee visitation in early morning is important to fruit-set.

Increasing the density of honey bee hives improves yield, weight and sweetness of 'Primo' variety cantaloupe.

Recommended Bee Populations for Cantaloupe	
No. of honey bee hives/acre	**Reference**
2, 3	Atkins & others, 1979
3	Crane & Walker, 1984
1.3, 3	Eischen, Underwood, 1991
0.5, 1, 2, 3, 4, 5	McGregor, 1976
1, 2	USDA
2.4	**Literature average**
Rate	
1 honey bee per 10 perfect flowers	McGregor, 1976

Cucumber: Cucumber plants ordinarily have both male and female flowers, and some agent is required to transfer pollen between flowers of the same or different plant; the only exception is some seedless varieties that produce fruit without pollination. As with other cucurbits, cucumber pollen is large and sticky, so pollination relies heavily on bees. In monoecious varieties (both male and female flowers on one plant), male flowers open about 10 days before female flowers and outnumber female flowers. These varieties are planted at a rate of 5,000-15,000 plants per acre, and harvesting the fruit stimulates the plant to produce new flowers and fruit; in this manner, several hand-harvests are possible. *Gynoecious* (only female flowers) varieties were developed in the interest of maximizing fruit production with one destructive, machine harvest. They are grown in dense plantings of about 50,000 to 150,000 plants per acre. Gynoecious varieties require a source of male flowers for pollen. Commercially-prepared seed is pre-mixed with around 15 percent monoecious seed to provide this pollination. With plantings of gynoecious varieties, large bee populations are doubly important to pollinate the high density of female flowers.

Cucumber is not a rich source of pollen or nectar, but bees readily visit the plants if there are no more attractive plants nearby. Bees collect pollen on cucumber mostly in early morning and switch to nectar later in the morning. In Maryland, pollen foraging is highest before 10:00 a.m. and decreases dramatically in the afternoon (Tew & Caron, 1988). Not surprisingly, the stigma is most receptive to pollen in morning. Each stigma should receive several hundred grains of pollen for best fruit-set and quality.

In Georgia, cucumber vines screened to exclude pollinating insects produced no fruit, but open-pollinated vines set about 6.5 fruit per foot (Coleman, 1979).

Recommended Bee Populations for Cucumber	
No. of honey bee hives/acre	Reference
2, 3	Atkins & others, 1979
3 for gynoecious hybrids	Hughes & others, 1982
1, 2, 3; >3 for gynoecious hybrids	McGregor, 1976
1, 2	USDA, 1986
2.1	**Literature average**
Rate	
1 colony per 50,000 plants	Hughes & others, 1982
1 bee per 100 flowers	McGregor, 1976

Squash: Squash plants produce separate male and female flowers. Male flowers outnumber female ones by about 3.5 to one to 10 to one. This helps ensure pollination of the female flowers, which must be pollinated to set fruit. Bees are the most important pollinators, and seed number and fruit weight increase proportionally to the amount of pollen transferred to the stigma. In west Tennessee, each flower opens for only one day, usually between 5:15 and 11:00 a.m. (Skinner & Lovett, 1992). However, if it is hot, flowers close early. Consequently, as with other cucurbits, good bee visitation in the morning is important.

In west Tennessee (Skinner & Lovett, 1992), squash plants caged to exclude pollinators produced no fruit. By bagging flowers after one bee visit, the authors found that bumble bees were more efficient than honey bees in promoting good fruit-set. However, in normal conditions with adequate bee populations, each flower is visited many times, probably by more than one bee species, and fruit-set is very good.

Bees in the genus *Peponapis* are excellent pollinators of squash and pumpkin. Compared to honey bees, they make more contact with reproductive parts of a flower, work faster and work earlier in the morning. However, in spite of these desirable behaviors, *Peponapis* are no more efficient than honey bees at setting fruit (Tepedino, 1981). Nevertheless, growers should always encourage *Peponapis* populations. Where *Peponapis* occur in high numbers, supplemental colonies of honey bees are unnecessary.

Recommended Bee Populations for Squash	
No. of honey bee hives/acre	Reference
1	Hughes & others, 1982
0.04, 0.08, 0.5, 1, 3	McGregor, 1976
1, 2	USDA, 1986
1	**Literature average**
Rate of *Peponapis* bees	
1 Peponapis per 20 flowers	derived from Tepedino, 1981

Watermelon: Watermelon plants have separate male and female flowers. The pollen is sticky and not blown by wind, so insect pollination is necessary to transfer pollen to receptive female stigmas. In the absence of superior food sources, bees readily visit watermelon blossoms for nectar and pollen. However, the overall density of flowers is low enough that bees rarely collect a surplus. As with other cucurbits, watermelon flowers open early in the morning and close in the afternoon, so early morning (10:00 a.m. or earlier) bee activity is important. Not surprisingly, the stigma is most receptive in the morning. Each stigma needs about 1,000 grains of evenly-placed pollen to develop a well-shaped, large fruit. This corresponds to about eight bee visits per flower.

Seedless, triploid watermelon varieties also require pollination. Pollination triggers seed formation and fruit development, but seeds abort shortly thereafter.

Recommended Bee Populations for Watermelon	
No. of honey bee hives/acre	Reference
2, 3	Atkins & others, 1979
1	Hughes & others, 1982
0.2, 0.5, 1	McGregor, 1976
1, 2	USDA, 1986
1.3	**Literature average**
Rate	
1 bee per 100 flowers	McGregor, 1976

Other Crops: Many crops are visited by bees and sometimes benefit from the supplemental pollination they provide. Others set high quality fruit without bee pollination. This table summarizes some of these crops. Unless cited otherwise, factual statements in this section draw from McGregor (1976) and references therein.

Crop	Comment
Bean, lima	Lima bean self-pollinates, but cross-pollination also occurs. Plants openly visited by bees have higher seed weight and yield than plants experimentally caged to exclude insects.
Bean, snap, shelled dry	Self-pollination is common, but cross-pollination also occurs. Seed set is generally good with or without bees. Bean flowers are not especially attractive to bees.
Canola	In the greenhouse, canola (Swede rape varieties 'Erglu,' 'Gulle,' 'Janetskis,' 'Maris Haplona,' 'Midas,' 'Oro,' 'Turret' and 'Zephyr') is self-fertile and seed set is good whether the plant is self- or cross-pollinated. Varieties 'Erglu' and 'Turret' have slightly more seeds per pod when they are cross-pollinated (Williams, 1978). Although these varieties are self-fertile, they do not always self-pollinate. When the flowers are shaken, whether by wind or insects, the anthers release a cloud of pollen grains. This shaking is very important to canola pollination; plants grown in still, insect-free cages typically have poor seed set (Eisikowitch, 1981; Mesquida & others, 1988). Canola is extremely attractive to bees, and their foraging activity helps ensure pollination. Avoid insecticide applications during bloom.
Cotton	Flowers of many varieties are self-fertile and self-pollinating; however, some varieties respond well to cross-pollination. The pollen is not wind-borne, and insects are good pollinators. With some varieties, bee pollination increases seed set per boll ('Pima S-1'), cotton yield ('Ashmouni', 'Pima S-1') and earliness

Crop	Comment
Cotton *(continued)*	of seed set ('A-33', 'A-44'). In practice, few, if any, growers manage bees for pollinating cotton. The crop is attractive to bees, and if insecticide pressure is low honey bees may store surplus cotton honey. Limit insecticide applications to evening to reduce bee kill.
Grape	Unlike most Old World grape varieties, muscadines are generally self-sterile and benefit from bee-mediated cross-pollination. Other self- or partially self-sterile American grapes are 'America,' 'Barry,' 'Blue Lake,' 'Brighton,' 'Edna,' 'Gaertner,' 'Herbert,' 'Last Rose,' 'Lindlye,' 'Merrimac,' 'Munson' and 'Salem'.
Peach	Most peach varieties are self-fertile, but insects, and possibly wind, are needed to transfer pollen to receptive stigmas. Bees and flies are attracted to the blossoms and no doubt help pollination.
Pear	Bee-mediated cross-pollination improves fruit-set in many varieties ('Anjou,' 'Bartlett,' 'Kieffer'). However, in some parts of the country and under optimum orchard conditions, 'Bartlett' is self-fruitful. In British Columbia and Washington, fruit diameter in 'Anjou' and 'Bartlett' varieties increased when honey bee visitation was encouraged with synthetic queen pheromone attractant; this translated to an increase in return of $427 per acre (Currie & others, 1992). Pear nectar has low sugar content, and bees readily move to other, richer sources. This could cause a problem with fruit-set in some years.
Pepper, green, bell	Cross-pollinating increases fruit-set in many varieties. Insect pollinators help ensure pollination of receptive stigmas. Flower is not especially attractive to bees.
Plum	Although varieties range from self-sterile to self-fertile, nearly all varieties need bees to transfer pollen to receptive stigmas. Some varieties are cross-incompatible.
Pumpkin	See **Squash.**
Soybean	Honey bee pollination increases yield in 'Corsoy' and 'Hark' varieties, but not in 'Chippewa 64' (Erickson, 1975).
Strawberry	All pistils must be evenly pollinated to make a well-shaped fruit. Wind and bees help ensure good pollen distribution. Fruit shape is best when a diversity of bee species visit the blossoms (Chagnon & others, 1993). With the variety 'Veestar,' at least four honey bee visits per flower are necessary for adequate pollination (Chagnon & others, 1989); with the variety 'Houkou-wase' in greenhouses, 11 visits are necessary (Kakutani & others, 1993).
Tomato	Stigmas are pollinated when the flower is shaken, whether by wind or insects. Bumble bees are good pollinators of tomato.

Bees and Beekeeping Reference Books and Supplies

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The A.I. Root Co., 1990. *ABC & XYZ of bee culture*, 40th Edition. Medina, Ohio.

Dadant & Sons, Inc., 1992. *The hive and the honey bee.* Hamilton, Illinois.

Delaplane, K.S., 1993. *Honey bees & beekeeping: A year in the life of an apiary*. The Georgia Center for Continuing Education, Athens, Georgia.

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O'Toole, C. & A. Raw, 1991. *Bees of the world.* Blandford, London.

Seeley, T.D., 1985. *Honeybee ecology*. Princeton University Press, Princeton, New Jersey.

Winston, M.L., 1987. *The biology of the honey bee.* Harvard University Press, Cambridge, Massachusetts.

Bee Supplies

Brushy Mountain Bee Farm, Inc., 610 Bethany Church Rd., Moravian Falls, NC 28654, (800) 233-7929 www.brushymountainbeefarm.com

Dadant & Sons, Inc. www.dadant.com

Rossman Apiaries, Inc., P.O. Box 909, Moultrie, GA 31776, (800) 333-7677 www.gabees.com

The Walter T. Kelley Co., P.O. Box 240, Clarkson, KY 42726, (800) 233-2899 www.kelleybees.com

Horticulture Reference Books

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Insecticides and Miticides: Consult the current edition of the Georgia Pest Management Handbook for a list of common insecticides and miticides and their relative risk to honey bees. Never spray during bloom periods unless it is absolutely necessary. If treatment is unavoidable, choose a product with a high LD_{50} and short residual. If a more toxic chemical is required, choose a residual under eight hours and spray at night.

Sample Beekeeper/Grower Contract
Draft Pollination Agreement
(For Consideration of Legal Counsel)

This agreement is made ______________________ between ____,
(date) (grower's name)

afterwards called grower, and ____, afterwards called
(beekeeper's name)

beekeeper.

1. **TERM OF AGREEMENT:** This agreement involves the 20____ growing season.

2. **RESPONSIBILITIES OF BEEKEEPER**

- Beekeeper will supply grower with ____________ bee hives delivered to ____________________________________ (name or orchard or field) for pollination during the applicable growing season as follows: (Fill in appropriate lines and cross out those that do not apply.)

  Approximate date: ____________________________________
  _______________ days after written notice from the grower.

  Time in relation of amount of crop bloom:____
  ____

  Description of hive placement in field:____
  ____
  ____

- Beekeeper will provide hives of the following minimum standards:

  A laying queen and:
  __________ frames with brood and bees to cover
  __________ pounds of honey stores or other food
  __________ story hives

  Grower may inspect hives after giving reasonable notice to beekeeper of his intent.

- Beekeeper will maintain hives in proper pollinating condition by inspecting, feeding, medicating, or treating for mites as needed.

- Beekeeper will leave bees on the crop until: (Fill in appropriate lines and cross out those that do not apply.)

  Approximate date: ____________________________________
  _______________ days after written notice from the grower.
  Time in relation of amount of crop bloom:____
  ____
  Other: ____
  Beekeeper will, absent any other notice, remove hives no later than midnight on _________________ (date).

- Beekeeper is not responsible and, as a condition of this agreement, will be held harmless for inherent risk of bee stings to people, animals or livestock.

3. **RESPONSIBILITIES OF GROWER**

- Grower will provide a suitable place to locate hives. The site must be accessible to beekeeper's vehicles. Grower will allow beekeeper entry whenever necessary to service the bees, and grower assumes full responsibility for all loss and damage to his fields or crops resulting from the use of vehicles over agreed routes in servicing bees.

- Grower will not apply **highly toxic** pesticides to the crop while the bees are being used as pollinators nor immediately before their arrival if residues will endanger the hives. The following agricultural chemicals and methods of application are mutually agreeable while bees are on the crop: ________________________________
____

  Grower will notify beekeeper 24 to 48 hours in advance if hazardous materials not listed above will be used. Grower will pay for the cost of moving bees away from and back to the crop to prevent damage from highly toxic materials on the crop being serviced or on adjacent crops.

- Grower will compensate beekeeper in full for hives destroyed or severely weakened by pesticides or other action by the grower at a rate per hive to be determined by arbitration (see section 5), or, if loss is undisputed, beekeeper will be compensated by grower at the rate of $______________ per hive.

- Grower will pay for pollination services of __________ hives of bees at $ __________ per hive. Payment will be made to the beekeeper as follows: $ __________ per hive on delivery and the balance on or before ____________________ (date). Additional moves will cost grower $ __________ per hive per move.

- Grower will provide adequate sources of water for the bees if none is within one-half mile of each hive.

- As a condition of this agreement, grower agrees to hold beekeeper harmless from any and all claims of injury or damage to person or property which might arise from beekeeper's performance of this agreement between beekeeper's placement and removal of hives from grower's fields or orchards.

4. **PERFORMANCE:** Either party will be excused from obligations of this contract if, before delivery of hives, performance is prevented by events beyond their control. Notification will be given to the other party as soon as reasonably possible.

5. **ARBITRATION:** If any controversy arises between parties, it will be settled by arbitration. Each party, within 10 days, will appoint one arbitrator, and the two arbitrators will select a third, and the decision of any two arbitrators will be binding on the parties. Cost of arbitration will be divided equally between the two parties.

6. **ASSIGNMENT OR TRANSFER:** This agreement is not assignable or transferable by either party, except that the terms will be binding on a successor by operation of law.

IN WITNESS WHEREOF, the undersigned parties have made this agreement,

Grower

____

____

By

____

____

Address

____

____

Beekeeper

____

____

By

____

____

Address

____

____

Plants for Year-Round Bee Forage

This is an incomplete list of both wild and commercially-available plants that are important sources of pollen and nectar for bees in the South. It is important for bees, especially bumble bees, to have an unbroken succession of bloom all summer to build up their local populations. If you want to encourage bee populations, grow or encourage plants from this list so that bloom is more-or-less continuous on your property.

Bloom Season	Common Name	Type	Scientific Name	Availability	Reference
Feb	Red Maple	tree	*Acer rubrum*	Feral	Delaplane, 1991; Goltz, 1987c; H. York, Jesup, Georgia, pers. obs.
Feb-Mar	Redbud	tree	*Cercis canadensis*	Feral	Goltz, 1987c; Cane, 1993
	Titi	shrub	*Cyrilla racemiflora*	Feral, coastal plain	Delaplane, 1991; Goltz, 1987b; H. York, pers. obs.
Mar	Native Blueberry	shrub	*Vaccinium elliottii*	Feral	Mitchell, 1962; Cane, 1993
Mar-Apr	Canola	ann.	*Brassica napus*	Commercial oilseed	K.S. Delaplane, pers. obs.
	Henbit	per. herb	*Lamium amplexicaule*	Feral	Cane, 1993
	Jessamine	shrub	*Gelsemium sempervirens*	Feral	Cane, 1993
Apr	Tupelo	tree	*Nyssa sylvatica*	Feral, coastal plain river bottoms	Delaplane, 1991
Apr-May	Apple	tree	*Malus* spp.	Commercial, feral	Mitchell, 1962; K.S. Delaplane, pers. obs.
	Black Locust	tree	*Robinia pseudoacacia*	Feral, piedmont and upper south	Mitchell, 1962; Delaplane, 1991; Goltz, 1987a
	Black-berry	shrub	*Rubus argutus*	Feral, esp. in piedmont	Mitchell, 1962; Goltz, 1987b; B. Engle, The Rock, Georgia & K.S. Delaplane, pers. obs.
	Common Ajuga	per. herb	*Ajuga reptans*	Commercial ornamental	P.A. Thomas, pers. obs.
	Crimson Clover	ann.	*Trifolium incarnatum*	Commercial forage	Mitchell, 1962; K.S. Delaplane, pers. obs.
	Dutch Clover	per.	*Trifolium repens*	Commercial, feral	Mitchell, 1962; K.S. Delaplane, pers. obs.
	Red Clover	per.	*Trifolium pratense*	Commercial forage	Mitchell, 1962; K.S. Delaplane, pers. obs.
	Skip Laurel	shrub	*Prunus lauro-cerasus*, var. 'Schip-kaensis'	Commercial ornamental	K.S. Delaplane, pers. obs.
	Tulip Poplar	tree	*Liriodendron tulipifera*	Feral	Delaplane, 1991; Goltz, 1987c
May	Gallberry	shrub	*Ilex glabra*	Feral, coastal plain	Delaplane, 1991; Goltz, 1987b; H. York, pers. obs.
	Honeysuckle	shrub	*Lonicera fragrantissima*	Feral	P.A. Thomas, pers. obs.
	Privet	shrub	*Ligustrum sinense*	Feral, esp. in piedmont	B. Engle & K.S. Delaplane, pers. obs.
	Rhododendron	shrub/ tree	*Rhododendron catawbiense*	Feral, esp. in mountains, commercial ornamental	Mitchell 1962; K.S. Delaplane, pers. obs.
May-Jun	Cabbage Palmetto	per.	*Sabal palmetto*	Feral, coastal plain	Delaplane, 1991; Goltz, 1987c
	Persimmon	shrub/ tree	*Diospyros virginiana*	Feral	B. Engle & K.S. Delaplane, pers. obs.
	Tallow Tree	tree	*Sapium sebifrum*	Commercial ornamental	Goltz, 1987c
Jun	Heavenly Bamboo	shrub	*Nandina domestica*	Commercial ornamental	G.W. Krewer, Univ. Georgia, pers. obs.
Jun-Jul	Bee Balm	per.	*Monarda didyma*	Commercial ornamental, feral	Mitchell, 1962; Goltz, 1987d; P.A. Thomas, pers. obs.

Bloom Season	Common Name	Type	Scientific Name	Availability	Reference
Jun-Jul *(continued)*	Chaste Tree	shrub/ tree	*Vitex agnus-castus*	Commercial ornamental	G.W. Krewer & P.A. Thomas, pers. obs.
	Sourwood	tree	*Oxydendrum arboreum*	Feral, esp. in mountains	Delaplane, 1991; Goltz, 1987c
	Sumac	shrub/ tree	*Rhus copallina*	Feral, piedmont and upper south	Goltz, 1987b; K.S. Delaplane, pers. obs.
	Sunflower	ann. or per.	*Helianthus* spp.	Commercial ornamental and oilseed	Mitchell, 1962; W.J. McLaurin, pers. obs.
Jun-Aug	Brazilian Verbena	ann. or per.	*Verbena bonariensis*	Commercial ornamental	Mitchell, 1962; S. Scarborough, Baxley, Georgia, & P.A. Thomas, pers. obs.
	Butterfly Bush	shrub	*Buddleia davidii*	Commercial ornamental	P.A. Thomas, pers. obs.
	Crape myrtle	shrub/ tree	*Lagerstroemia indica*, var. 'Natchez'	Commercial ornamental	G.W. Krewer, pers. obs.
	Glossy Abelia	shrub	*Abelia grandiflora*	Commercial ornamental	Mitchell, 1962; S. Scarborough & P.A. Thomas, pers. obs.
	Mountain Mint	per. herb	*Pycnanthemum incanum*	Commercial ornamental	P.A. Thomas, pers. obs.
	Purple Coneflower	per. herb	*Echinacea purpurea*	Commercial ornamental	P.A. Thomas, pers. obs.
	Summer Phlox	per. herb	*Phlox paniculata*	Commercial ornamental	P.A. Thomas, pers. obs.
	Wood Mint	per. herb	*Blephilia* spp.	Feral	Mitchell, 1962
Jun-Sept	Sweet Pepperbush	shrub	*Clethra alnifolia*	Feral, coastal plain	D. Wade, Alma, Georgia & G.W. Krewer, pers. obs.
Jul	Button-bush	shrub/ tree	*Cephalanthus occidentalis*	Feral	Mitchell, 1962; Goltz, 1987b
Jul-Sept	American Germander	per. herb	*Teucrium canadense*	Feral	Mitchell, 1962
	Cup Rosinweed	per. herb	*Silphium perfoliatum*	Feral	Mitchell, 1962
	Milkweed	per. herb	*Asclepias* spp.	Feral	Mitchell, 1962; Goltz, 1986a
	Partridge Pea	ann. herb	*Cassia fasciculata*	Feral	Mitchell, 1962; Cane, 1993
	Redroot	per. herb	*Lachnanthes caroliana*	Feral, wetlands	G.W. Krewer, pers. obs.
Aug	Meadow Beauty	per. herb	*Rhexia* spp.	Feral	D. Wade, pers. obs.
Aug-Sept	Bush Clovers	shrub	*Lespedeza bicolor* and *L. thunbergii*	Commercial ornamental and forage	Cane, 1993
Aug-Oct	Brazilian Pepper	shrub	*Schinus terebinth-ifolius*	Feral	Goltz, 1987b
	Mexican Sage	per. herb	*Salvia leucantha*	Commercial ornamental	C. Reed, Douglas, Georgia & P.A. Thomas, pers. obs.
	Mexican Sunflower	ann.	*Tithonia rotundifolia*	Commercial ornamental	P.A. Thomas, pers. obs.
	Pineapple Sage	ann. or per.	*Salvia elegans*	Commercial ornamental	P.A. Thomas, pers. obs.
	Thoroughwort	per. herb	*Eupatorium hyssopifolium*	Feral	Mitchell, 1962
Aug-Nov	Asters	per. herb	*Aster* spp.	Feral	Mitchell, 1962; Goltz, 1986c; B. Engle & P.A. Thomas, pers. obs.
	Colorado River Hemp	shrub	*Sesbania exaltata*	Commercial, feral	G.W. Krewer, pers. obs.
Sept-Oct	Goldenrod	per. herb	*Solidago* spp.	Feral	Mitchell, 1962; Delaplane, 1991; Goltz, 1986b
	Kenaf	ann.	*Hibiscus cannabinus*	Commercial fiber	B. Baldwin, Miss. State Univ., pers. obs.

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